In cooperation with Northern Arizona University and the National Park Service

Using Packrat Middens to Assess How Grazing Influences Vegetation Change in Glen Canyon National Recreation Area, Utah

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Dirk Kempthorne, Secretary

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)

Area		
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
Mass		
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Vertical Datum of 1988 (NAVD 88).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1983 (NAD 83).”

Using Packrat Middens to Assess How Grazing Influences Vegetation Change in Glen Canyon National Recreation Area, Utah

By Jessica F. Fisher, Kenneth L. Cole, and R. Scott Anderson

Abstract

The fossil and sub-fossil plant macrofossils and pollen grains found in packrat middens can serve as important proxies for climate and vegetation change in the arid Southwestern United States. A new application for packrat midden research is in understanding post-settlement vegetation changes caused by the grazing of domesticated animals. This work examines a series of 27 middens from Glen Canyon National Recreation Area (GLCA), spanning from 995 yr BP to the present, which detail vegetation during the periods just prior to, and following, the introduction of domesticated grazers. By comparing middens deposited before and after the start of grazing by domesticated sheep and cattle, the effect on the native plant communities through time can be determined. This analysis of change through time is augmented by measurements of change through space by contrasting contemporaneous middens from nearby similar grazed and ungrazed sites. These comparisons are only made possible by the presence of inaccessible ungrazed areas surrounded by steep cliffs.

Multivariate ordinations of the plant assemblages from packrat middens demonstrated that even though all middens were selected from similar geologic substrates, soils, and vegetation type, their primary variability was site-to-site. This suggests that selecting comparable grazed versus ungrazed study treatments would be difficult, and that two similar sites several kilometers apart should not be assumed to have been the same prior to grazing without pre-grazing data. But, the changes through time on grazed areas, as well as the differences between grazed and ungrazed areas in the diversity of certain taxonomic groups, both suggest that grazing by domesticated ungulates has had a noticeable effect on the vegetation. The changes seen through time suggested that grazing lowered the number of taxa recorded and lessened the pre-existing differences within sites, homogenizing the resultant plant associations.

Late Holocene pre-settlement middens, and modern middens from ungrazed areas, contained more native grasses, skunkbush sumac (*Rhus trilobata*), blackbrush (*Coleogyne ramosissima*), winterfat (*Krascheninnikovia lanata*), Utah serviceberry (*Amelanchier utahensis*), and roundleaf buffaloberry (*Shepherdia rotundifolia*) than modern middens from grazed areas. Pollen data supported the macrofossil data, recording decreases in pollen of the goosefoot family (Chenopodiaceae), grass family (Poaceae), and globemallow (*Sphaeralcea* spp.) from pre- to post-settlement.

Introduction

Climate change is the dominant driving factor influencing plant community change on the geologic timescale (R.S. Anderson et al., 2000). However, after the dynamic power of natural events, human influences have the second most profound effects on the fragile landscapes of the Southwest. This work focuses on grazing to understand how it has affected the plant communities of Glen Canyon National Recreation Area, Utah. Most packrat midden studies have examined solely how climate change has affected plant communities through time (Betancourt et al., 1990). This study applies a novel approach by comparing plant community change in grazed versus ungrazed areas through the same time period. With the exception of one preliminary study on grazing effects (Cole et al., 1997; Cole and Murray, 1999), this is a new application for packrat midden studies.

Identifying truly ungrazed sites in the Southwest is very difficult. The effects from sheep and goat grazing by the Diné (Navajo) in the area may have become apparent as early as 1829 AD (Savage & Swetnam 1990). Cattle became abundant this region by the 1870's (National Park Service [NPS], 1999). Existing historical records are not reliable in determining the extent of this Nineteenth Century grazing, but what records do exist suggest that grazing was extensive and severe in almost all areas that could be effectively grazed. Because semi-arid vegetation is notoriously slow in its recovery from disturbance (Lovich and Bainbridge, 1999), it is likely that areas with no record of late Twentieth Century grazing are nevertheless still recovering from earlier impacts. Fortunately, Glen Canyon NRA has several isolated mesas that have never been affected by cattle, sheep, or goats, due to their inaccessible cliffs and/or lack of available water (Tuhy and MacMahan, 1988).

In this study, we assessed grazing effects on vegetation in two ways: temporally and spatially. Temporally, series of middens were examined in several areas from prior to grazing until after grazing. Spatially, middens from grazed areas were compared to middens from nearby ungrazed areas. In this way, we were able to compare changes due to grazing using two independent approaches, one of which controlled for spatial variability and the other for temporal variability. This study will serve as an important tool for land managers to use when implementing decisions on the management of Southwestern public landscapes (Fisher, 2006).

Plant Community Change

Evidence for plant community change is found in long-term studies on modern communities (Brown et al., 2001; Mack, 1981) as well as in studies of micro- and macrofossils found in the paleoecological record (Davis and Turner, 1986; Earle, 2003; Lavoie and Filion, 2001). By looking at past plant communities and assessing the factors that have caused them to change, the characteristics of future communities might be predicted, and undesirable human-caused modifications can potentially be prevented or mitigated.

Arid environments, such as the cold deserts of the Colorado Plateau and Great Basin of the Western United States, are particularly susceptible to plant community alterations. Human-caused impacts, such as the introduction of domesticated sheep and cattle, the spread of exotic species, and land-use changes all have effects on the plant communities of these dry, highly sensitive environments (Lovich & Bainbridge 1999).

The human-influenced changes observed in desert ecosystems of the West range from those affecting a single species to those having broad and sweeping community-wide alterations. Native (Cole et al., 1997) and exotic (Bashkin et al., 2003; Knapp, 1996) species richness, sex-distribution (Cibils et al., 2000), plant cover (de Soyza et al., 2000), plant composition (Menke and Bradford, 1992), and above-ground (Barrow, 1997) and below-ground (Abbott et al., 1991; Wan et al., 2002) architecture of the plants have all been modified, especially in the past two centuries. Certain exotic species invasions, such as by the annual cheat and red brome (*Bromus tectorum* and *B. rubens*) grasses and by the riparian invasive tree saltcedar (*Tamarix* spp.), are so pervasive they may have permanently altered the landscape (Mack, 1981; Salo, 2004; Vandersande et al., 2001).

Grazing History and Conservation

Horses, sheep, goats, and cattle were introduced into the Southwest by Spanish colonists in the Sixteenth Century (Underhill, 1971) and they were quickly adopted for use by Native Americans. They eventually spread to the indigenous tribes of the Colorado Plateau and Great Basin and were widespread by the late 1800's (Cole et al., 1997; Knapp, 1996). Many documentary sources exist for cattle grazing by Mormons in southeastern Utah in the late 1800's (Topping, 1997). Grazing was especially intense on the open range between 1870 and 1890 AD. It continued throughout the Twentieth Century, at what was likely a more controlled rate in the study area through grazing leases administered through Glen Canyon National Recreation Area (GLCA). Grazing ceased on this allotment soon after the completion of this study.

Unlike U.S. National Parks, land uses such as mining and grazing are allowed in many National Recreation Areas, including GLCA, as mandated by their enabling legislations. However, almost all of the potentially public or private grazable land in the Southwest is either grazed now, or has been grazed in the past. Because of this, it is often hard to find suitable ungrazed comparative sites (Stohlgren, 1999). Since the natural rates of vegetation recovery are so slow on arid landscapes, it is likely that these areas still reflect changes brought about by the most intense, but poorly understood, grazing of the late 1800's. Areas that have simply gone ungrazed during the late 1900's may not serve as suitable representatives for the condition of "ungrazed" lands (Guenther et al., 2004). Fortunately for this study, many mesas within GLCA are surrounded by cliffs rendering them inaccessible to grazing animals (Tuhy and McMahan, 1988).

Grazing affects all aspects of the ecosystem. Studies of biodiversity of plants (Cole et al., 1997, Fleischner, 1994; Jones, 2000; Stohlgren, 1999), birds (Bock et al., 1993; Saab et al., 1995), fish (Stuber, 1985), mammals (Longland, 1994), reptiles (Jones, 1981), biological crusts (Hiernaux et al., 1999) and insects (Rambo and Faeth, 1999) have shown that grazing has a negative effect on biota. Flather et al. (1994) found that livestock grazing in the United States was the second most important cause of endangerment to plant species and fourth most important cause for all species.

Packrats and Middens

Midden Formation

Packrat, or woodrat, is the common name for species in the genus *Neotoma,* family Muridae, the largest mammalian family. They are native to the New World, although other small nesting rodents also create middens with identifiable plant fossils elsewhere, such as the dassie rat (Petromuridae) in Africa (Scott, 1990), hyrax (Procaviidae) in Africa and the Middle East (Fall et al., 1990; Scott, 1990), the stick-nest rat (Muridae) in Australia (Nelson et al., 1990), and various rodent species (Chinchillidae, Abrocomidae, and Cricetidae) from South America (Holmgren et al., 2001).

Packrats are mainly nocturnal animals (Warren, 1910). They are browsers, and have specially designed digestive and circulatory systems allowing them to acquire all of their fluid needs from plants. This is an important adaptation for survival in arid climates where the occurrence of standing water is uncertain throughout the year. To obtain enough moisture in the southwestern deserts, they depend on succulent plants with at least 50% water by weight, making plants such as prickly pear cactus (*Opuntia* spp.), juniper, and ephedra mainstays of their diets (Vaughan, 1990).

In the desert Southwest, packrats find shelter and create homes in caves, rock cliffs, or under spiny plants if there are no rocky outcroppings available. Next to their home they will create a midden out of collected objects. Packrats collect not only their food plants but also any plant parts in the vicinity of their home base. Usually the packrat collects plants within a radius of 30-50 m from home (Vaughan, 1990), but have been known to occasionally collect from up to 100 m (Cole, 1990; King and Van Devender, 1977). They will collect any part of the plant, including fruits, seeds, flowers, cones, and twigs, as well as other objects lying about such as insects, bones, or rocks. Packrats then urinate and defecate on the midden, and over time the urine crystallizes into a hard, indurated midden, which creates a protective barrier around the packrat's nest. In the dry desert Southwest, middens that are protected from the elements can survive for well beyond 50,000 years (Betancourt et al., 1990). Up to 22 other species have been found to inhabit middens, including lizards, snakes, and mice, particularly *Peromyscus* sp. (Vaughan, 1990).

The reason for the collecting behavior and midden formation is not exactly known. It is likely that the midden aids in providing protection from predators (Vaughan, 1990; Warren, 1910). Other possible reasons including buffering extreme temperatures and for food storage (Vaughan, 1990). Research has shown that the packrat's preference for food can sometimes skew the representation of plants collected (Dial and Czaplewski, 1990; Van Devender and King, 1971). Plant remains commonly are brought in by the packrat, while some plant pieces can also blow in with the wind.

Modern middens typically are unconsolidated, being essentially debris piles of loose twigs, pellets, and finer plant material. The youngest middens can often be distinguished by green or yellowish plant parts. Determining the time represented in a fossil midden is complicated by the statistical uncertainty in radiocarbon dating, often 100 years or more.

Four species of *Neotoma* have been collected from GLCA. These include the white-throated woodrat (*Neotoma albigula*), the bushy-tailed woodrat (*N. cinerea*), the desert woodrat (*N. lepida*), and the Mexican woodrat (*N. mexicana*) (GLCA, 2004a). One other species, Stephen's woodrat (*N. stephensi*), is listed as 'rare' in Canyonlands National Park (Utah Division of Wildlife Resources, 2004) but is not listed as typically found in Glen Canyon. It is known from around the Navajo Mountain area (Durrant and Dean, 1959).

It is difficult to determine which packrat species forms a particular midden. Although only one packrat lives at a midden site at one time, it is possible that individuals of two different species might have inhabited and contributed to the same midden over time as climate and temperature changed (Betancourt et al., 1990).

Pollen in Middens

Although macrofossils are the most commonly analyzed fossil remains in middens, pollen is also well-preserved in middens, and has become an important proxy for reconstruction of past environments. The method of pollen deposition in middens must be accounted for, however, because different sources of pollen can have different relevancies to the paleobotanical record. Davis and Anderson (1987) summarized the four ways, listed in order of presumed importance, in which pollen can be deposited in middens: by adhering to plants; by airborne and saltation means; from fecal pellets; and by adhering to the packrat. Each of these mechanisms is discussed below.

Pollen probably enters a midden most frequently by adhering to the collected plant. Often, (as is logical) a plant will be coated with the pollen of its own species, depending largely on the season it was collected. The surface characteristics of a species might affect how much pollen it collects on its exterior (O'Rourke, 1991); plants covered with thousands of stellate hairs, like globemallow (*Sphaeralcea* spp.), will be more likely to collect pollen than plants which are sparsely pubescent with short, rigid hairs, like paloverde (*Cercidium* spp.). Pollen deposited in this method should be fairly commensurate with the midden macrofossils, since it is deposited in direct connection with them.

The second most common deposition method is from airborne pollen that either floats or tumbles in to the midden by saltation. Saltation was noticed by Thompson (1985) who identified the algae *Pediastrum* in a midden, presumably from dried sediment of a nearby lake. Airborne pollen can be deposited during humid conditions, as the already viscous packrat urine will re-hydrate and become even stickier, allowing grains to adhere to the midden. There are two important concerns with this type of pollen in the sample. First, it most likely represents a regional pollen signal, since pollen in air can travel long distances. Second, this pollen could be a contaminant from another time period, because it could blow in after the midden has been formed. Therefore, it might not necessarily agree with the signal that the macrofossils provide.

Some midden pollen comes from packrat fecal pellets. Because this pollen is linked to the packrats' diet, it provides less information than the macrofossils, which show both plants eaten and all of the plants collected.

Last, it is known that pollen can adhere to human clothing (O' Rourke and Lebowitz, 1984), so it is assumed that it adheres to packrat pelts as well. This pollen representation is probably very closely related to the macrofossils on which the packrats were foraging.

Pollen in Middens on the Colorado Plateau

The published accounts of midden pollen research from the southwestern U.S. are limited. Most of the pioneering work in this area was done using Sonoran Desert middens (Anderson and Van Devender, 1991; Anderson and Van Devender, 1995; Davis and Anderson, 1987). Other recent works include middens from California (Koehler and Anderson, 1995; Koehler et al., 2005), south-central New Mexico (Betancourt et al., 2001), and the Sonoran Desert (Holmgren et al., 2003). The only other work besides this study which examines both midden macrofossils and pollen from the Colorado Plateau, was conducted at Capitol Reef National Park, Utah (Cole et al., 1997; Cole and Murray, 1999).

Cole et al. (1997) found that their pollen assemblages were well-matched to their macrofossils, both of which supported the conclusions that there were noticeable and striking differences in the plant communities there pre- and post-settlement. Pine, sagebrush (*Artemisia* spp.), Cheno-Am, and Poaceae pollen all showed distinct decreases after the introduction of grazing. Juniper pollen, though, increased post-settlement, indicating this non-palatable tree increased over the last few hundred years. There were also incidences of prickly Russian thistle (*Salsola tragus*) pollen in the modern middens, and fungal spores (*Sporormiella* spp.), the later being commonly associated with cattle dung.

Pollen and Macrofossils as Paleoecological Indicators

Pollen and macrofossils each tell a different story about the paloebotanical record of an area. Pollen grains show a more regional picture of the past vegetation, with plant pollen being represented that can blow in from 100 or more km away. Macrofossils, which usually come into the midden by being carried in by the packrat, show a more local picture, of plants growing from a distance of less than 100 meters from the midden.

Although it is possible to identify most macrofossils to species, this is much harder with pollen grains. Often, pollen can only be identified to genus (i.e. *Quercus*), family (i.e. Poaceae or Asteraceae) or type (i.e. Cheno-Am, or pollen grains resembling grains from the Chenopodiaceae and Amaranthaceae). Differences in levels of taxonomic recognition make comparison between the two different proxies difficult. Three studies, though, found reasonable correspondence between the pollen and macrofossils found in middens (Cole et al., 1997; Davis and Anderson, 1987; Thompson, 1985).

The more types of evidence from the past that can be examined, the more complete a picture can be composed of what the vegetation was like. Fossil pollen and macrofossils make an excellent compliment to each other, by showing slightly different views of the same picture. In this study, as well, the two different paleoecological indicators help to make a more complete understanding of the grazing history of Glen Canyon National Recreation Area.

Description of Research Area

Physical History and Features of Glen Canyon

Glen Canyon National Recreation Area (GLCA) is located in southeastern Utah and northern Arizona along the Colorado River as it cuts across the Colorado Plateau, an uplifted plateau encompassing the Four Corners region of the Southwest. It is bound by Grand Staircase-Escalante National Monument and the Henry Mountains on the west; Canyonlands National Park on the east, and the Navajo Nation Reservation to the south. The land that makes up GLCA encompasses 500,541 ha, which includes Lake Powell, the center point of the recreation area (NPS, 1999). It lies within three counties in Utah: Kane, Garfield, and San Juan; and includes the northern part of Coconino County in Arizona. The elevation range is from 945- 2,312 m.

GLCA has many geological features, including canyons, mesas, and buttes. The canyons, like the ones in Grand Canyon National Park, were formed in the past 5 million years by down-cutting action from the Colorado and San Juan Rivers. The 2,500 m of bedrock exposed by this shows a geologic history of more than 300 million years (Anderson, 2000). Most of the geologic formations in GLCA are sedimentary rock, predominantly sandstone but also limestone, siltstone, shale and conglomerate (Tuhy and McMahon, 1988).

The climate in Glen Canyon changes dramatically with elevation. Average annual precipitation is approximately 16 cm (GLCA, 2004b). Most of the precipitation arrives as winter snow, infrequent spring rains, and from summer monsoon thunderstorms. Annual potential evaporation greatly exceeds available moisture (Spence, 2001). Mean air temperature highs and lows are 36°C and 21°C, respectively, in July and 6°C and -4°C in January (GLCA, 2004b).

Biological Features of Glen Canyon

GLCA has a rich assemblage of plant species (Flowers, 1959; Spence and Zimmerman, 1996). Over 800 species of plants have been recorded in GLCA, three of which are federally listed as endangered or threatened: Brady's pincushion cactus (*Pediocactus bradyi*), Jones' waxy dogbane (*Cycladenia humilis* **var.** *jonesii*), and the Navajo sedge (*Carex specuicola*). The Utah Heritage Program lists 18 species as 'rare' (NPS, 1999). None of the protected plants grow in areas currently affected by grazing. Characteristics of the vegetation depend on elevation, rainfall, and location in the landscape. Tuhy and MacMahon (1988) divided GLCA into several distinct vegetation communities. Dominant plants growing along the rivers at lowest elevations (~1,070 m) are desert (*Salix exigua*) and Goodding's willow (*S. gooddingii*), Emory's baccharis (*Baccharis emoryi*), saltcedar (*Tamarix chinensis*), and arrowweed (*Pluchea sericea*) (Flowers, 1959). At mid-elevations (ranging from ~1,220 to 1,680 m), blackbrush (*Coleogyne ramosissima*), grasses, shadscale (*Atriplex confertifolia*), and ephedra (*Ephedra* spp.) dominate. At higher elevations (<1,830 m) extensive Colorado pinyon (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), and sagebrush stands grow (Tuhy and MacMahon, 1988). A few relict Douglas fir (*Pseudotsuga menziesii*) stands occur in the highest north-facing alcoves. A number of "hanging gardens" are found where surface water flows out of rock bodies and supports unique vegetation (Tuhy and MacMahon, 1988). Representative plants of these gardens and the wet areas surrounding them are tufted rockmat (*Petrophyton caespitosum*), Texas redbud (*Cercis canadensis* var. *texensis*), longleaf brickellbush (*Brickellia longifolia*), netleaf hackberry (*Celtis laevigata* var. *reticulata*), stream orchid (*Epipactis gigantea*), and Mancos columbine (*Aquilegia micrantha*). Other common plants in GLCA include winterfat (*Krascheninnikovia lanata*), narrowleaf yucca (*Yucca angustissima*), prickly pear (*Opuntia* spp.) milkvetch (*Astragalus* spp.), Utah serviceberry (*Amelanchier utahensis*), buckwheat (*Eriogonum* spp.), and fourwing saltbush (*Atriplex canescens*) (Tuhy and MacMahon, 1988). A flora of the park was completed (Spence and Zimmerman, 1996), as well as an addition to the flora (Spence, 2005).

Sixty-four mammal species are found in GLCA, none of which are federally listed (GLCA, 2004a,b). Bats and rodents are the most common types found (Durrant and Dean, 1959). Four species of *Neotoma* exist in GLCA: *Neotoma albigua*, *N. mexicana*, *N. lepida*, and *N. cinera*. Native ungulate grazers in GLCA include mule deer (*Odocoileus hemionus)*, bison *(Bison bison),* pronghorn *(Antilocapra Americana),* desert bighorn sheep (*Ovis canadensis)* and Rocky Mountain elk *(Cervus elaphus).* Other grazers include black-tailed jack rabbit (*Lepus californicus*) and desert cottontail (*Sylvilagus audubonii*).

Biological crusts are widespread in GLCA. These composite organisms living on undisturbed desert soils are made of cyanobacteria, cyanolichens, mosses, microfungi, bacteria, and green algae (Harper and Belnap, 2001). They can take decades or even centuries to develop. Biological crusts are important in preventing soil and water erosion, and aid in plant nutrient uptake (Harper and Belnap, 2001).

Site Descriptions

Middens were collected from five locations within GLCA (Fig. 1; Appendix A). These included two grazed sites, Waterhole Flat and Cove Canyon; the latter was divided into three sub-sites: CC-cow shade, CC-cow tank (Fig. 2), and CC-500 m from tank. Gandolf's Staircase was an ungrazed site (Fig 3.), chosen for its inaccessibility by domestic cattle and its geographical proximity to the two grazed sites (Fig. 4). Middens were also collected from two relict ungrazed mesas, 5381 Mesa and Mazuki Point. Field work on the least accessible

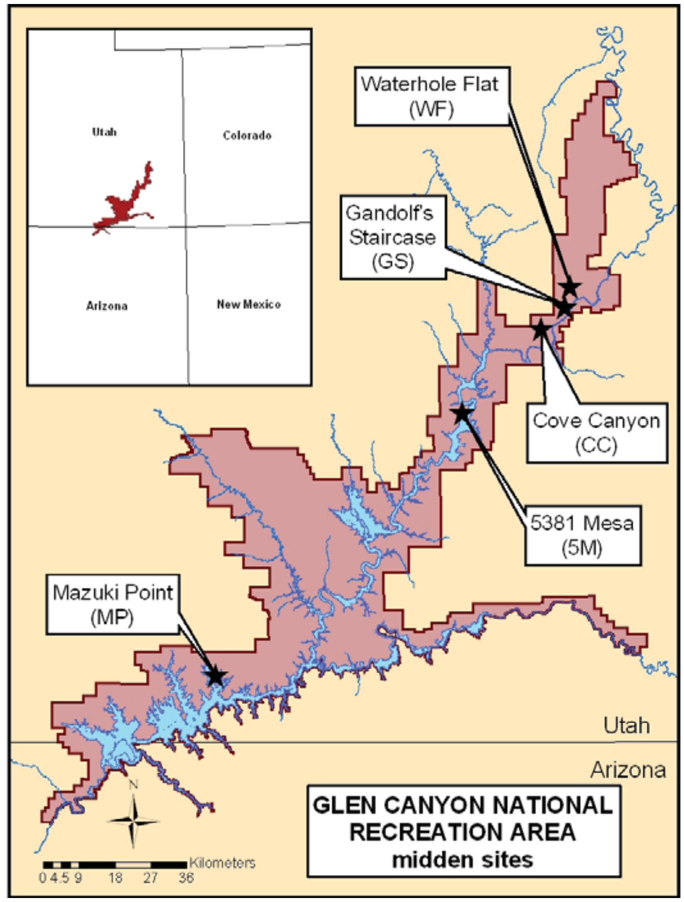

Figure 1. Map of midden collection sites, Glen Canyon National Recreation Area.

sites, 5381 Mesa and Mazuki Point, was conducted using helicopter support. Although these sites could be reached through difficult rock scrambling, as was the Gandolf's Staircase site, these areas could not be reached by domestic sheep or cattle and had well-developed soil crusts.

Materials and Methods

Fieldwork

Middens were collected using different methods. Modern middens (CC-3, CC-5, CC-11, CC-20, WF-1, WF-10, 5M-3, 5M-5, MP-1, MP-2, and MP-3) consisted of loose debris piles, sub-samples of which were scooped into a plastic bag using leather gloves, making sure to sample not only the larger twigs but also the finer plant material on the ground. The bags were then labeled and returned to the lab.

Older middens were encased in crystallized amberat and indurated. These were removed from rock crevasses by either breaking off small layers of the larger midden deposit by hand, or with a hammer and chisel. The target size was about 600 g

Figure 2. View from Cove Cave 5 in a grazed area near a cattle tank (photograph by K. Cole).

Figure 3. View from Gandolf's Staircase 1 and 2 in an ungrazed area (photograph by K. Cole).

Figure 4. View of the Gandolf's Staircase ungrazed site on a shelf within Cataract Canyon. The Cove canyon and Waterhole Flat grazed sites are located on the upper flat plateau (photograph by K. Cole).

of fossiliferous amberat. A tabular piece with clear horizontal stratigraphy measuring about 20 cm x 20 cm and 4-5 cm thick was preferred. All collected pieces were selected making sure they appeared to be one layer, and thus deposited by the packrat during the same time period. Seventeen middens older than 1000 yr BP were also collected and analyzed from GLCA, but are not included in this report, as they are too old to be directly related to this grazing study.

After collection, all consolidated middens were chiseled or dusted to remove potential contaminants. They were then placed in plastic bags and labeled. A UTM and elevation reading was taken at the site with a GPS unit. For most middens, the slope, aspect and angle were recorded using an inclinometer. Any other pertinent information about the midden was also recorded, such as an estimate of its age based upon hardness and visible plant contents.

Vegetation presently surrounding the midden site was recorded as an informal plant relevé. All recognizable trees, shrubs, herbs, and grasses within approximately 10 m of the midden were noted along with an estimate of the species' percent cover. Herbaceous plants with less than 1% cover were given values of frequent (f), common (c), infrequent (inf) or rare (r).

Lab Work

Lab work was performed at the USGS Southwest Biological Science Center's Colorado Plateau Research Station (CPRS) Macrobotanical Laboratory and the Quaternary Sciences Program Laboratory of Paleoecology (LOP), both located at Northern Arizona University (NAU). All unused middens, identified plants, picked middens, and midden records are also curated there as part of the collection.

Each midden was first unwrapped and analyzed by sight for fossils, potential age, color, smell, and any other distinguishing characteristics. Each midden was measured and sketched. The outer rind was again chiseled and dusted. Any visible rock was extracted and discarded, usually leaving a 400-500 gram sample. If more than one layer was apparent, one layer was labeled 'A' while the 'B' layer was stored.

The midden sample was weighed, placed in a plastic bucket with 2 L of distilled water, covered, and left to soak and disaggregate for several days to two weeks, depending on the degree of induration. The midden was stirred daily. Modern middens were also weighed and soaked for a day or two to remove dust and pollen.

After disaggregation, the plant material and slurry was sieved using a 500µm soil sieve (#35), separating plant macrofossils from the slurry containing midden pollen. An additional 2 L of water was used in this process. The 4 L of slurry was stored for later pollen analysis. The washed midden matrix was then labeled and left on a covered screen to dry. The midden matrix was then washed until clean. Once dry, the washed matrix was weighed, bagged and labeled. Any rocks were removed and weighed. Packrat (*Neotoma* sp.) pellets were also removed, weighed, and separated into full pellets and pellet pieces (Appendix B).

Macrofossil Identification

The plant macrofossil matrix was examined under a WILD Heerbrugg M5A boom microscope at 20x and plant macrofossils were separated into species categories. All identifiable plant pieces were placed in vials. The plant pieces were identified using the modern plant collections of Kenneth Cole, W. Geoffrey Spaulding, and the NAU Deaver Herbarium; several texts were also used as resources (Arnberger, 1982; Benson, 1982; Delorit, 1970; Dodge, 1985; Elmore, 1976; Epple, 1995; Flora of North America (FNA), 1993; Flowers, 1959; FNA, 2003; Harlow, 1946; Harris and Harris, 2001; Hickman, 1993; Hitchcock, 1971; Kearney and Peebles, 1969; McDougall, 1973; Parker, 1972; Ruyle and Young, 1997; Stubbendieck et al., 1997; U. S. Department of Agriculture (USDA), 1948; Welsh et al., 1993). Photos of some representative fossils were taken (see website: http://www.usgs.nau.edu/global_change/macrodigitallibrary.asp).

Vials were labeled using acid-free paper and pen, with the genus and species name if applicable, and the midden name and number. Any extraneous materials, such as insect parts, bones, feathers, or pellets were also labeled. The data are stored in an Access database in the Macrobotanical Lab at the USGS Colorado Plateau Research Station. Plant species nomenclature is from the Integrated Taxonomic Information System (http://www.itis.usda.gov/index.hyml). All 98 plants identified from the middens are found in Appendix C.

Radiocarbon Dating

The age of each midden was determined primarily through Accelerator Mass Spectrometer (AMS) dating of small organic samples and less frequently by bulk dating using conventional carbon 14 radiometric counting. For the conventional radiocarbon dating, approximately 10 g of pellets from the picked middens were removed, weighed, stored in a sterile plastic bag, and submitted to the University of Arizona Laboratory of Isotope Geochemistry. For extremely small or very old samples, specimens were submitted to the National Ocean Sciences Accelerator Mass Spectrometry Facility (NOSAMS) at the Woods Hole Oceanographic Institution and the University of Arizona/ National Science Foundation AMS laboratory. Radiocarbon ages were calibrated to calendar years using CALIB 4.2 (Stuvier and Reimer, 1993). These calendar year ages were then converted to the range from the earliest possible date to the last possible date (Appendix D).

Unconsolidated middens were not radiocarbon dated, and were assumed to be “modern”. These middens were only collected if they contained evidence of recent packrat activity, such as green or yellow plant debris.

Pollen Analysis

Twenty-three middens were analyzed for fossil pollen contents by R. Scott Anderson. These included Waterhole Flat 1 and 2A, and all Cove Canyon middens except for CC-14B. A 100 ml sub-sample of the 4 L slurry was poured into labeled beakers; 30 ml of which was poured into 50 ml test tubes. These were then centrifuged and decanted, noting the remaining volume of sediment. Two *Lycopodium* tablets were added as tracers. Subsequent steps included suspension in KOH, HCl, HF, and acetolysis solution (Faegri and Iverson, 1989). Pollen residues were dehydrated, stained with Safranin O, and mounted in silicon oil. Pollen assemblages were identified at 400x magnification using an Olympus microscope, with reference to known pollen specimens in the Laboratory of Paleoecology (LOP) pollen collection. Pollen found in the middens is listed in Appendix E.

Graphs

Results from the macrofossils and pollen are shown using Tilia graphs and Detrended Correspondence Analysis (DCA) ordinations. The Tilia graphs were made using the programs Adobe Illustrator, Tilia, and Tilia-Graph (http://www.ncdc.noaa.gov/paleo/tilia.html).

Ordination graphs are used to highlight patterns in the multivariate data. The differences inherent in the multiple variables are condensed into the two most significant axes in multivariate space so that they can be displayed in two dimensions. Items are arranged along axes such that items closer together are more similar than items further apart, and items that cluster together are more closely related than scattered items (McCune and Grace, 2002). In this case, middens are the item being graphed, and the assemblage of plants in the middens is the variable of concern, which determines how similar or distant the relationship between two middens is.

Ordinations are commonly used in community ecology to display patterns in species composition (McCune and Grace, 2002). DCA ordinations are usually applied in paleoecological studies because they are most suited to computing samples with high noise levels and their axes are quantified to represent species changes along environmental or temporal gradients. In addition the DCA ordination allows for simultaneous viewing of the item (midden) and variable (plant species), so it can be understood how the plant species are influencing the placement of the midden. The axes are scaled so that 100 units represents a turn-over of 50% of the species along the gradient (Gauch, 1982).

The computer program PCORD was used to generate the ordinations. Species occurring in fewer than three middens were not used in the ordinations to minimize noise levels, unless the species was rare but of special concern, such as the exotic prickly Russian thistle. Rare species were not down-weighted.

Results

Radiocarbon Dates

The 27 middens from this study range from the late-Holocene to modern periods (Appendix D). For purposes of discussion, middens are grouped into three time periods: late Holocene; transitional; and post-settlement. Post-settlement middens are then further divided spatially, into middens collected from grazed areas and middens from ungrazed areas.

The first category of middens is Late Holocene or “pre-settlement”: dating between 995 +/- 65 yr BP and 220 +/- 45 yr BP. Although climates have varied over this period, the extremes and averages were not too different from the ranges of the historic period for this area. These middens were deposited before the introduction of domestic grazing animals, and thus indicate what the native plant communities were comprised of before modern influences. The youngest two middens in this category, GS-2 and 5M-2, fall into a transitional time period, because their time ranges overlap the time periods before and after grazing was introduced, as early as the late 1700’s (Appendix D). However, as both of these middens are from ungrazed sites, the plants contained in them were not affected by grazing, so they are counted in the late Holocene category.

Another midden, CC-11, contained a pre-historic corncob. This was most likely planted and harvested during pre-settlement times, and picked up recently by a packrat from a nearby archeological site. However, because of the addition of this pre-settlement artifact, and the unique assemblage of plants in this midden that more resemble earlier middens, CC-11 is considered to be transitional in this analysis.

The last category of middens is post-settlement, or modern, from both ungrazed and grazed areas. These middens are either loosely consolidated or unconsolidated piles of sticks and smaller plant materials, usually containing green or yellowish plant debris that has not yet fossilized. With the exception of one midden, these were not radiocarbon-dated, and were most likely formed over the last 5 to 20 years. One midden, WF-3, was AMS dated, with the result being “post-bomb”, meaning carbon levels in it were so high that it hails from after the beginning of atmospheric testing of nuclear weapons, circa 1950 AD (Cole and Murray, 1999). Two samples of the exotic cheatgrass (*Bromus tectorum*) found in late Holocene middens GS-3 and 5M-1 were AMS dated and found to be modern contaminants.

Plant Macrofossils

A total of 98 different plant types, identified to their lowest possible taxonomic levels, were found in the middens analyzed for this study (Appendix C). Itemized lists of the plant contents of each midden are listed in Appendix F. Often more than one type of plant part (seed, leaf, twig, etc.) was found for a single plant type. Certain plants were chosen for discussion because they are directly affected by grazing or other effects related to large domestic herbivores. Results for these key grazing indicator trees, shrubs, herbs, grasses and pollen are shown in a series of Tilia graphs (Figs. 5-8).

Families well-represented with more than three different species include the sunflower (Asteraceae), borage (Boraginaceae), mustard (Brassicaceae), cactus (Cactaceae), goosefoot (Chenopodiaceae), pea (Fabaceae), hibiscus (Malvaceae), pine (Pinaceae), grass (Poaceae), and rose (Rosaceae) families. Several groups which occur extra-locally today but that are not present in the macrofossils include members of the evening primrose (Onagraceae), tomato (Solanaceae) and mint (Lamiaceae) families. No oak (Quercus spp.), sedge (Carex spp.) or rush (Juncus spp.) fossils were found.

Another noticeably absent species is ponderosa pine (*Pinus ponderosa*), which is present in higher elevation areas of GLCA today and which was found in other Holocene middens from southeastern Utah (Betancourt, 1984). Additional analyses included comparing how plant form (tree vs. shrub vs. herb vs. grass) has changed throughout time and space, as well as examining any noticeable trends in the presence/absence of C4 or C3 grasses. Neither of these investigations turned out to be significant or meaningful, and so they are not included in this work.

Late Holocene Plant Macrofossils

Fourteen middens fall into the pre-settlement time period, dating from 995 +/-65 yr BP to 220 +/- 45 yr BP. Middens from this time period come from all sites except Mazuki Point. These middens had diverse assortments of taxa, averaging 19.1 ± 5.4 genera/midden. Fremont’s barberry (*Mahonia fremontii*), Bigelow’s sagebrush (*Artemisia bigelovii*), Utah juniper, fourwing saltbush, pinyon pine, winterfat, broom snakeweed (*Gutierrezia sarothrae*), narrowleaf yucca, and prickly pear are all dominant members of the plant communities found in these middens. Native grasses are frequent in these middens, particularly Indian rice grass, needle and thread, galleta grass, and sixweeks fescue (*Vulpia octoflora*).

Shadscale is found only in five middens, all of which are near areas in Cove Canyon populated by shadscale. Rubber rabbitbrush (*Ericameria nauseosa*), skunkbush sumac, and roundleaf buffaloberry are all seen frequently in the younger half of the series. Cheatgrass, an introduced exotic, occurs in three middens in the later part of the series. This is unexpected, as there should be no records of exotics before the

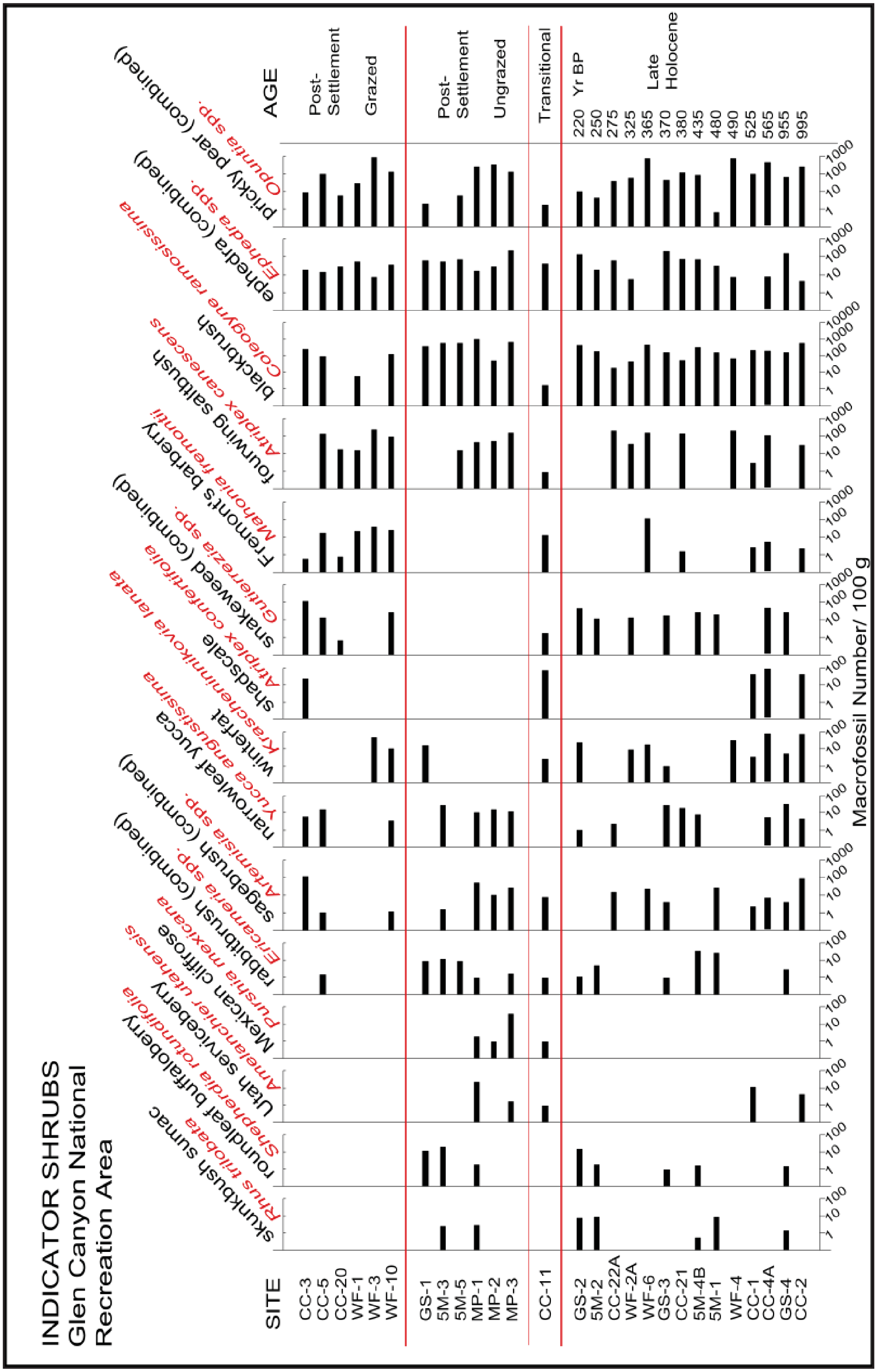

Figure 5. Tilia graph of indicator shrubs for the Glen Canyon Dam National Recreation Area midden series.

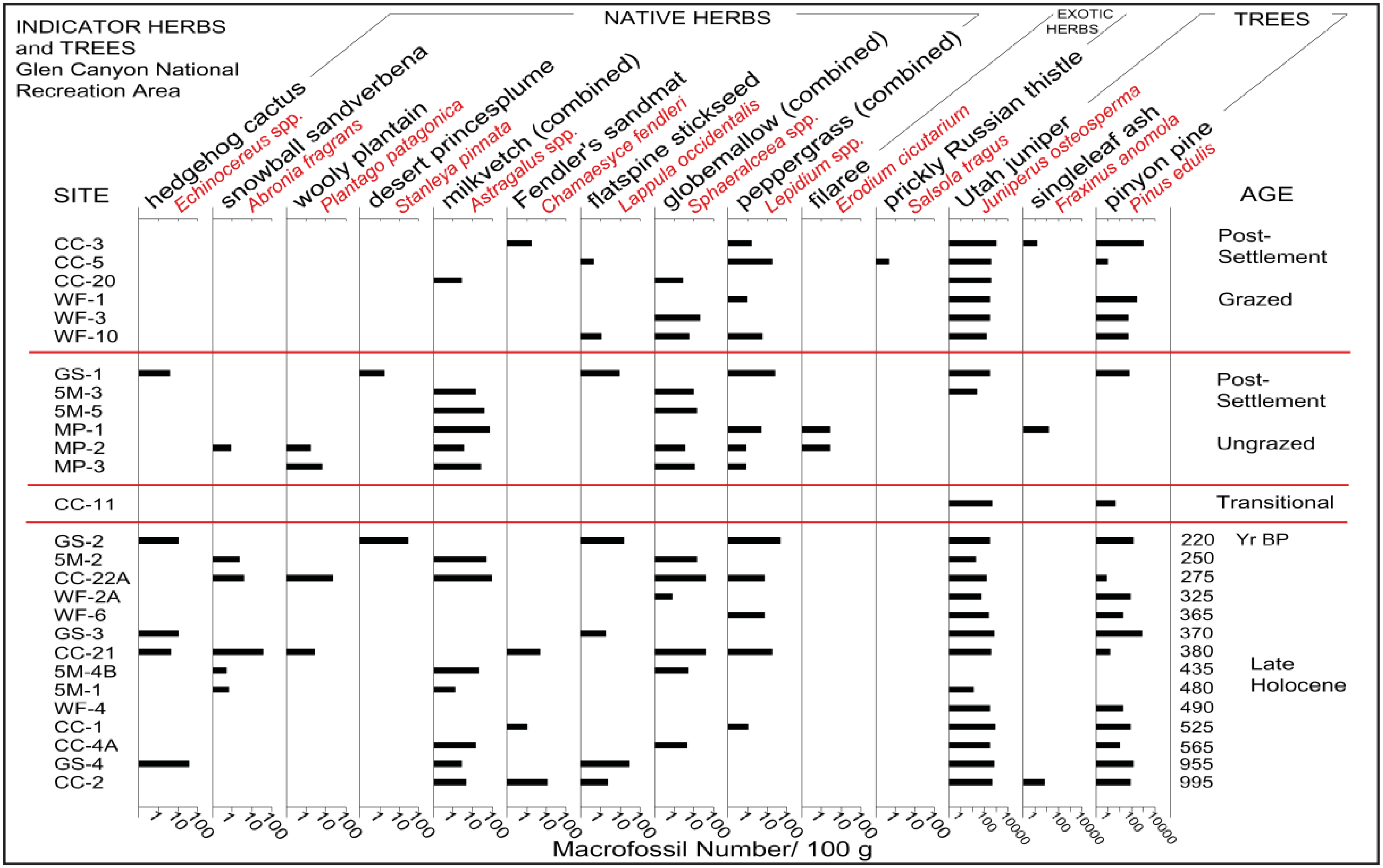

Figure 6. Tilia graph of indicator herbs and trees for the Glen Canyon Dam National Recreation Area midden series.

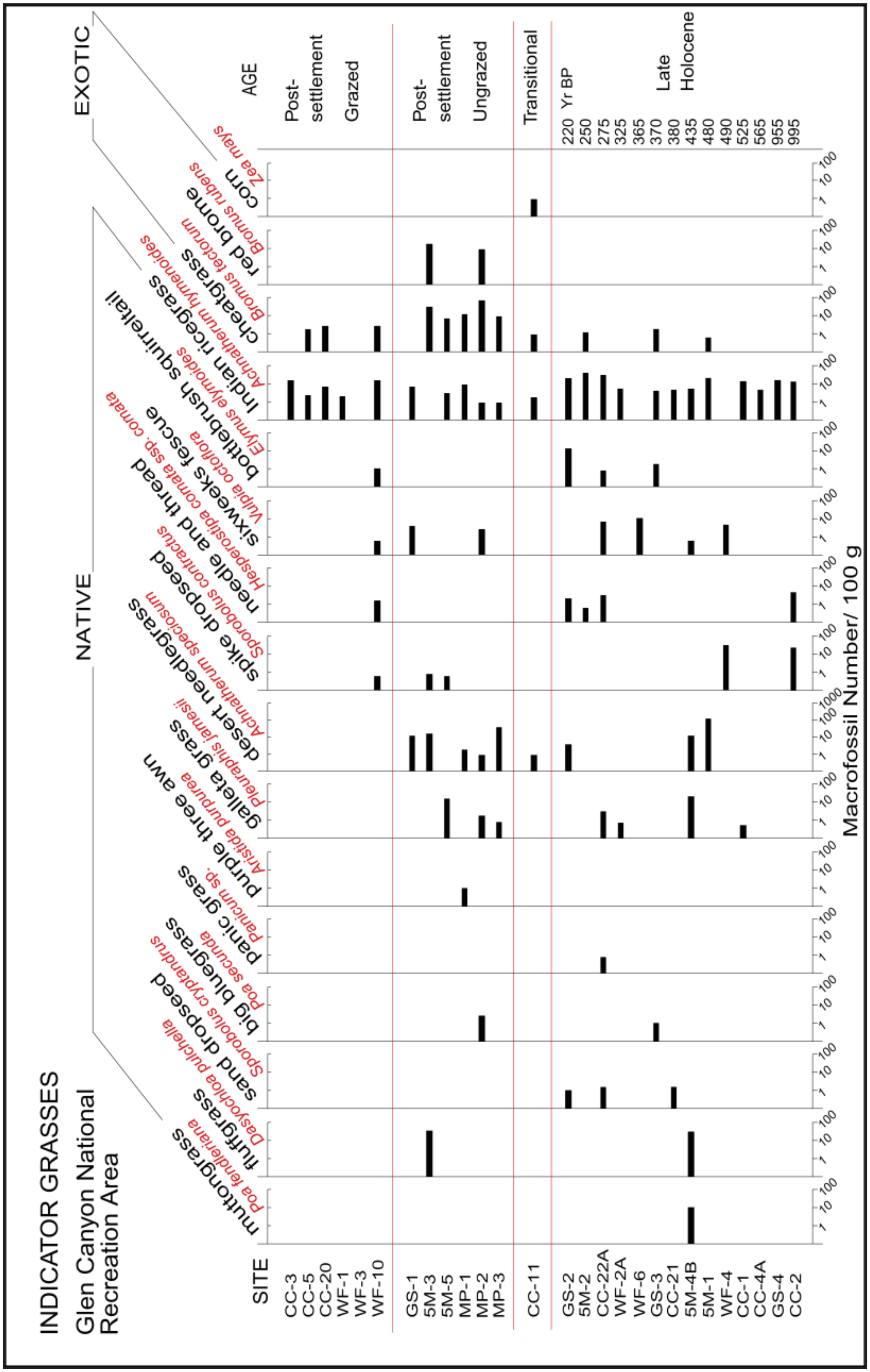

Figure 7. Tilia graph of indicator grasses for the Glen Canyon Dam National Recreation Area midden series.

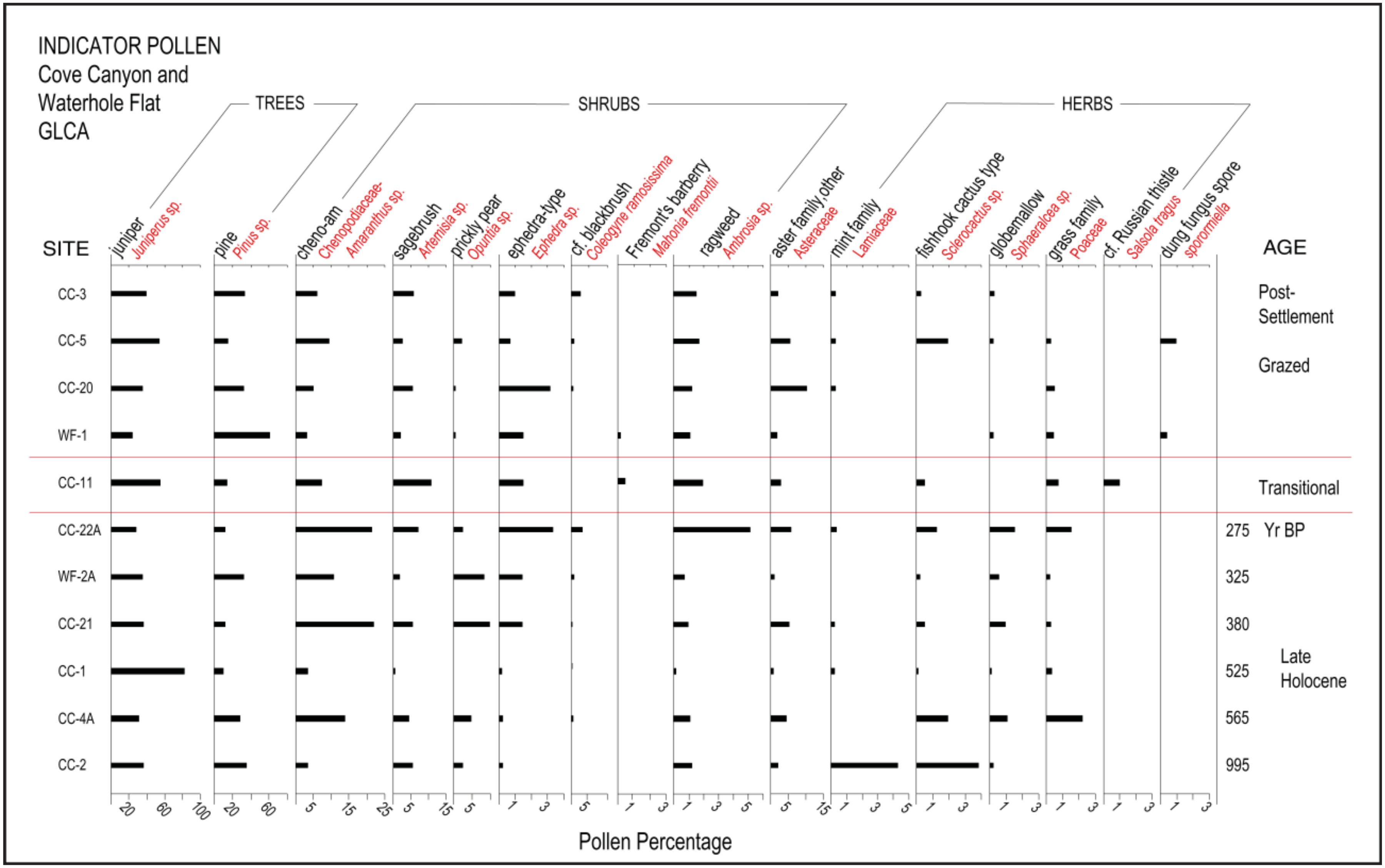

Figure 8. Tilia graph of indicator pollen for the Glen Canyon Dam National Recreation Area midden series.

settlement period. In each case, no more than two spikelets were recorded, which suggests that most likely these light plant parts are contaminants, incorporated into the midden after it was formed. AMS radiocarbon dating of two of these samples, from GS-3 and 5M-1, proved them to indeed be modern contaminants. These types of light macrofossils can blow into fissures within middens illustrating that the presence of small numbers of wind-transported macrofossils can be problematic.

Transitional Plant Sub-fossils

Only one midden in this work is considered transitional, CC-11. The uncertainty of the age is due to a pre-historic corncob found in the midden. There is evidence in the midden to suggest that it could be either pre- or post-settlement. The presence of Utah serviceberry, Mexican cliffrose, rubber rabbitbrush, and winterfat give the midden a plant composition more similar to the late Holocene, pre-settlement middens. However, it also contains two exotics—cheatgrass macrofossils and Russian thistle pollen. Because of the conflicting nature of the macrofossils, this midden is classified as transitional, of indeterminable time origin.

Post-settlement Plant Sub-fossils

Thirteen middens represent the post-settlement, or modern, era. These middens are not indurated but are merely loose piles of sticks, pellets, and fine plant material. Because of this, the plants found in these middens are called “sub-fossils” rather than macrofossils (Betancourt et al., 1990).

All five sites contain at least one modern midden, while all three middens from Mazuki Point are modern. The middens in this time category are differentiated spatially as well in order to distinguish the middens from ungrazed areas (Gandolf’s Staircase, 5381 Mesa, Mazuki Point) compared to the middens from grazed areas (Cove Canyon and Waterhole Flat).

Post-settlement Plant Sub-fossils: Ungrazed Areas

There are six modern middens from ungrazed sites in this study: one from Gandolf’s Staircase, two from 5381 Mesa, and three from Mazuki Point. Most of these middens have high species richness, averaging 21.2 ± 4.2 genera/midden. All of the middens share sub-fossils of Indian rice grass, blackbrush, and ephedra. Four or more middens share prickly pear, narrowleaf yucca, arid needlegrass, Bigelow’s sagebrush, rubber rabbitbrush, fourwing saltbush, and cheatgrass. Three middens contain roundleaf buffaloberry. Two middens from Mazuki Point have specimens of filaree, an invasive exotic, while two middens have plant parts of red brome, another invasive exotic along with cheatgrass. Only two middens have Utah juniper and only one contains pinyon pine. However, neither species grows today on Mazuki Point and only Utah juniper grows on 5381 Mesa. All of the ungrazed area middens have at least two native grass species.

Post-settlement Plant Sub-fossils: Grazed Areas

The only two areas with modern grazed middens are Cove Canyon and Waterhole Flat. Six grazed area middens are included here: CC-3, CC-5, CC-20, WF-1, WF-3, and WF-10. These middens had the lowest number of taxa, averaging only 14.5 ± 6.2 genera/midden. All middens contain Utah juniper, prickly pear, and Fremont’s barberry. Five out of the six contain Indian rice grass, pinyon pine, and fourwing saltbush. Four middens have a species of snakeweed, either *Gutierrezia sarothrae* or *G. microcephala*. Three middens contain a sample of cheatgrass. Plants of interest seen less frequently include shadscale, rubber rabbitbrush, winterfat, and yucca. One midden, CC-5, has the exotic plant prickly Russian thistle.

Pollen

Pollen was analyzed for 11 middens (Appendix E). The four post-settlement middens analyzed for pollen are all from grazed areas.

Of the arboreal pollen types, juniper was the most common, abundantly found in all middens throughout the time series. Pine grains, all grouped together, decrease in abundance from ancient to modern middens. Infrequent grains of oak (*Quercus* spp.), elm (*Ulmus* spp.), willow (*Salix* spp.), birch (*Betula* spp.), alder (*Alnus* spp.), and other trees are found scattered throughout all middens.

Some shrub pollen types decreased in counts from pre- to post-settlement eras, including Cheno-Am and prickly pear. Ephedra-type, mountain mahogany-type, blackbrush, and roundleaf buffaloberry increased during those time period transitions. Sagebrush and Torrey’s ephedra-type remained constant.

Several herbs also changed in abundance from the pre- to post-settlement periods. Fishhook cactus-type and grass family counts all decreased from pre- settlement to the modern, grazed era. Globemallow decreased, while ragweed (*Ambrosia* spp.) remained fairly constant. One transitional modern midden in the series, CC-11, contained grains of prickly Russian thistle. A different modern midden, CC-5, contained high counts of *Sporormiella,* a dung fungus spore that is often found in association with cattle dung.

Discussion

Regional Comparisons: Midden Studies

Midden studies designed to reveal the impact of grazing on plant species are uncommon (Cole et al., 1997). One study exists which uses a different paleoecological indicator, phytoliths, to examine a grazing history in Capitol Reef National Park (Fisher et al., 1995). There are also other complementary packrat midden studies and grazing studies from the Colorado Plateau region that examine modern vegetation change, often as it relates to anthropogenic factors.

Most of the packrat midden and pollen research on the Colorado Plateau is centered on the transition from the Pleistocene to the early Holocene, but a few studies focus mainly on late Holocene middens. Two relevant studies, looking at human impacts on the landscape, originate from the lower, drier southern Colorado Plateau. A series of Holocene middens were analyzed from Chaco Canyon National Park, in northwestern New Mexico (Betancourt and Van Devender, 1981). The purpose of that study was to assess the Native American impact on the plant communities of that area. A common plant community trend was seen here, with the progression from more cold-adapted plants in the early Holocene, such as limber pine (*Pinus flexilis*), Rocky Mountain juniper (*Juniperus scopulorum*), and Douglas Fir, to a pinyon-juniper/shrub/grassland in the late Holocene to present. Here, as with Wupatki National Monument and other drier areas, it was not Utah juniper, but one-seed juniper (*Juniperus monosperma*) - a more southerly species- that colonized the area. The youngest midden in the series, dated to 460 yr BP, lacks pinyon or juniper, and instead contains the dominant shrubs still existing in the area today, such as fourwing saltbush, Mexican cliffrose, and ephedra. The study from Chaco Canyon suggests that several herbaceous plants became locally extinct in the area in the late Holocene. One suggested cause for the extinctions is due to cattle and sheep grazing by the Diné (Navajo) in the last two centuries (Betancourt and Van Devender, 1981).

A second study examined prehistoric and historic impacts on the plant community at Cedar Canyon, Wupatki National Monument, Arizona (Cinnamon, 1988). Plants found in prehistoric middens but absent in the historic (last 200 years) middens include netleaf hackberry, pinyon pine, winterfat, sacred datura (*Datura wrightii*), and three species of native grasses. Plants more abundant in the historic middens than in older ones include one-seed juniper, green ephedra, fourwing saltbush, flatspine stickseed, snakeweed, paperflower (*Psilostrophe* sp.), milkvetch, the exotic Russian thistle, and five native grasses. Cattle and sheep grazing, by both Diné and Anglo ranchers, have a long history in this area. This practice has altered the plant communities, as evidenced by the strong species turnovers in these middens from Wupatki. These trends are similar to those for the GLCA midden series.

Cowboy Cave in Canyonlands National Park, approximately 50 km north of Cove Canyon, also contains prehistoric and historic middens (McVickar, 1991). A series of 20 middens found from this and other nearby caves spans from 7,760 years B.P. to 110 years B.P. This last midden is the only post-settlement midden. No modern debris piles were examined. Many species are found throughout the time series, yet are lacking in 110 yr BP midden: Gambel's oak (*Quercus gambelii*), sagebrush, winterfat, littleleaf mountain mahogany (*Cercocarpus intricatus*), rabbitbrush, Fremont's barberry, milkvetch, snakeweed, prickly pear, and skunkbush sumac. No exotic plant species were identified from any of these middens. Fewer fossils of roundleaf buffaloberry were found in this midden than the others from this series. Corn (*Zea mays*) was found in one midden dating to 1,170 yr BP. Grazing is conducted on these BLM lands.

Other packrat midden studies from the Colorado Plateau which focus more on Pleistocene and early Holocene middens include works from Canyon de Chelly (Betancourt and Davis, 1984; Schmutz et al., 1976), southeastern Utah (Betancourt, 1984), the Rainbow Plateau, Navajo Mountain (Koehler, P.A., unpublished manuscript), and Cowboy Cave, southeastern Utah (Spaulding and Peterson, 1980).

Regional Comparisons: Grazing Studies

Grazing studies in the West are generally conducted by comparing plant transects from within fenced cattle exclosures to nearby grazed sites (Cibils et al., 2000; LeCain et al., 2002; Stohlgren et al., 1999; Valone and Sauter, 2005). Two grazing studies from the Colorado Plateau include an ungrazed relict mesa (Willey, 1994) and a mesa not grazed for many years in their site comparisons (Guenther et al., 2004). Guenther et al. (2004) contrasted a site that had never been grazed by cattle, and had not been grazed by sheep or goats for the last 75 years, with a nearby grazed site in Grand Staircase-Escalante National Monument, Utah. Modified-Whittaker survey plots were employed to compare species frequency, cover, richness, cryptobiotic crust, and bare ground. This study found greater shrub vegetation cover at the grazed site, but fewer shrub species. The grazed site also had less cover of cryptobiotic crust and more bare ground, suggesting that cattle trampling affected the structure of the plant community. Four exotics were found at the grazed site: crested wheatgrass (*Agropyron cristatum*), cheatgrass, flixweed (*Descuriania sophia*) and lambsquarters (*Chenopodium album*). No exotic species were present in the near-relict mesa plots, although cheatgrass was observed to be growing in the area.

A second modern grazing study using a mesa site for comparison focused on how grazing impacted grassland birds in Capitol Reef National Park, Utah (Willey, 1994). Twenty vegetation measurements, including cover, patchiness and vegetation height were measured along transects. The relict mesa had greater overall grass and shrub coverage, with Indian rice grass, galleta grass, and needle and thread being dominants.

The grazed size had more bare ground, Russian thistle, and higher occurrences of snakeweed. The dominant grasses here were Alkali sacaton (*Sporobolus airoides*), sand dropseed, and blue grama grass (*Bouteloua gracilis*). The horizontal arrangement of herbs and shrubs was similar at both sites; vertically, though, the grazed site plants were shorter, being browsed by the cattle. The ungrazed mesa had more layering, higher canopy coverage, higher total cover, and greater variation in individual plant size.

Regional Comparisons: Grazing Studies Using Paleoecological Indicators

Two studies apply paleoecological data to examine changes over time that are probably related to grazing. One study examined plant phytoliths in the soil (Fisher et al., 1995). Phytoliths are created by the deposition of silica in certain terrestrial plants (Pearsall, 1989) and are resistant to oxidation and weather about as slowly as quartz (Fisher et al., 1995). Once a silica-rich plant dies and starts the process of decomposition, the organic material of the plant dissolves, while the phytoliths remain intact and resistant to microbial attack, and can be extracted in soil samples of different depths. Diverse plant species, genera, families, and other groupings have been found to create different shaped and sized phytoliths, making paleoenvironmental reconstructions possible (Pearsall, 1989). The grass family in particular is high in phytolith content, making grassland comparison studies an important aspect of phytolith research. This method has great potential to supplement data from plant macrofossils and pollen because it emphasizes different plant groups. But the identification and separation of phytoliths is complex and needs far more research.

Fisher et al. (1995) looked at phytoliths in Capitol Reef National Park, a place with a grazing history similar to GLCA. Modern grass percent biomass and percent of phytoliths in soil extractions were highly correlated, indicating the effectiveness of this indicator. Four sites were examined to compare changes in the plant communities due to grazing impacts from domesticated ungulates. The results showed more forbs, shrubs and cool-season grasses in the past (3000-5300 yr BP) compared to today, where warm-season grasses and invaders like cheatgrass are more prevalent. It is inconclusive whether the change in plant community is consistent with a grazing hypothesis versus through natural climate change, especially due to the poorly stratified and dated soil sections analyzed. Grazing could account for the decrease in cool-season grasses, since livestock are grazed here more during the cool season, and moved to higher elevations during the summer.

An original study relating packrat middens and grazing was set at Capitol Reef National Park (Cole et al., 1997; Cole and Murray, 1999). This work compared a series of middens dating from the middle Holocene (5,450 yr BP) to the present. Every midden in the series contained current dominants living there today, such as Utah juniper, Mexican cliffrose, prickly pear, and saltbush (*Atriplex* spp.). Plants occurring in the pre-settlement middens but not in the modern midden included pinyon pine, winterfat, roundleaf buffaloberry, Indian rice grass, globemallow, dropseed (*Sporobolus* sp.), and grama grass (*Bouteloua* sp.). Plants in the youngest two middens that were not found in the pre-settlement middens, include rabbitbrush (*Ericameria* sp.), broom snakeweed, Russian thistle, and greasewood (*Sarcobatus vermiculatus*).

Pollen from the middens supported the macrofossil findings. Pinyon pine pollen was lowest in the two modern middens, as were sagebrush and Grass family. Prickly pear, Aster family, and Cheno-am pollen did not show any significant changes between the modern middens and the older middens. Juniper pollen was at its highest levels in the modern middens, which also had the only occurrences of Russian thistle and dung fungus spores, *Sporormiella*. The cluster analysis on the pollen showed that the two modern middens deposited after the introduction of grazing were more similar to each other than to any of the pre-settlement middens.

A cluster analysis of the plant macrofossils from the middens shows that the youngest, modern midden was significantly different from all the other middens. This disparity between modern and pre-settlement middens, in both the macrofossils and the pollen, led the authors to suggest that the magnitude of change in vegetation during the last 200 year was far greater than during the previous 5000 yr (Cole et al., 1997). This large and rapid turnover of plants at the time of the introduction of grazing suggested that it was was the dominant factor changing plant associations.

The results of this study were criticized on the grounds that only changes through time were analyzed using too few middens. Although the vegetation changes observed seemed to correlate with the timing and likely effects of grazing, there were no control samples on untreated (ungrazed) areas. Thus one could argue that unique climate changes of the settlement period could have been responsible for the vegetation changes rather than grazing. The current study, incorporating both time series as well as ungrazed control sites, was designed to overcome this difficulty.

Analysis of the GLCA Midden Series

The data from our Glen Canyon midden series compliments these earlier midden and grazing studies. This midden series from five remote sites in Glen Canyon NRA exhibits the complex plant dynamics that have occurred during the late Quaternary. This series documents not only the natural vegetation change but also demonstrates that human-induced management practices can have a noticeable influence on the structure of plant communities.

In the first DCA ordination of all of the middens (Fig. 9), the middens cluster most closely by site location, not by age or treatment (grazed or ungrazed). The tightest groupings are the clusters of middens at the three ungrazed sites- Gandolf’s Staircase (GS), Mazuki Point (MP), and 5381 Mesa (5M). The

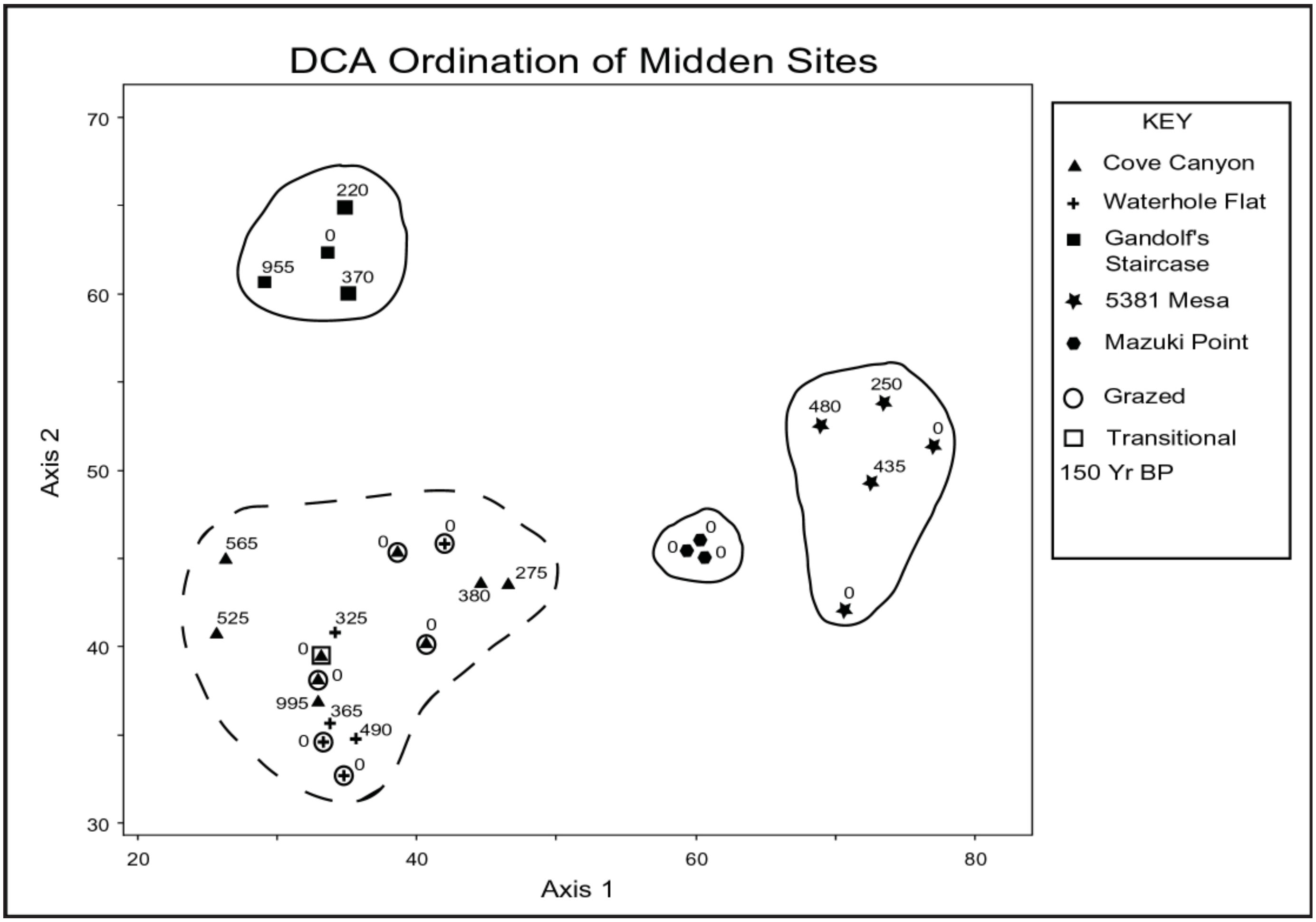

Figure 9. Detrended Correspondence Analysis (DCA) ordination of all five Glen Canyon National Recreation Area midden sites.

two sites that contain grazed middens, Cove Canyon (CC) and Waterhole Flat (WF), form one overlapping cluster, making the two sites nearly indistinguishable. WF has less variability along Axis 1 than Axis 2. Within CC and WF, there is no apparent separation of the middens of grazed areas from the ungrazed, pre-settlement middens. The GS site is more comparable to the CC and WF sites on Axis 1, while MP and 5M are more comparable to CC and WF on Axis 2.

This ordination shows that the main differences in the midden assemblages are a function of site-to-site differences. This most likely reflects variability in microclimate, geology, soils, and hydrology of the sites, which in turn have strong influences on the plants growing at each site. In this regard, it is logical that CC and WF group together, being close in physical proximity on the same stratigraphic level of the Cedar Mesa Sandstone. This ordination indicates that grazing is not the most important variable influencing plant assemblages in GLCA, but that other factors may be more important in influencing which plants are present. These results emphasize the extent to which plant communities naturally vary over the several similar geologic substrates.

This finding also highlights one of the fundamental problems with comparative grazing studies: finding adequate site comparisons (Guenther et al., 2004). All of the sites were selected from sandstone geologic units with similar sandy soils that had been mapped as the same grassland plant association. Gandolf's Staircase is in close proximity to CC and WF, the two grazed sites, sitting geographically between them (Fig. 1; 3). However, it is at a lower stratigraphic level within the Cedar Mesa Sandstone, and lies within a canyon with steep rock walls on two sides. Apparently, a combination of minor substrate differences, isolation, or the protection from direct insolation and/or wind is sufficient to modify local conditions, causing a plant community different from the flatlands above. Mazuki Point and 5381 Mesa are both on isolated mesa tops, on different sandstone geologic formations, and likely have high wind exposures near the tops of the mesas. Mazuki Point is a drier site than nearby areas, being at least 150 m lower in elevation and around 80 km southwest of the other sites (J.R. Spence, personal communication). Pinyon pine and Utah juniper cannot be sustained here, and are absent from the local flora (Tuhy and MacMahon, 1988).

Although these ungrazed sites do not make perfect comparisons, it is extremely difficult to verify that any site in the arid Southwest has avoided grazing for the last 200 years. Sites that could not have been grazed due to surrounding cliffs are usually quite different than the flatter landscapes nearby. GLCA is unique in having some flat expanses of grassland surrounded by steep cliffs that are similar to nearby grazed areas.

The ordination also demonstrates that the age of the midden has no bearing on the clustering. Modern middens are very similar to middens from up to 995 yr BP. This shows that it is acceptable to compare the middens from less than 1,000 yr BP to modern middens, and that climatic conditions have not changed drastically enough to create large changes in the plant communities at these locations.

A second ordination eliminates most of the site-to-site variability and graphs only the pre- and post-settlement middens from the most similar sites, CC and WF (Fig. 10). This graph also shows that there is no difference in middens due to age. This ordination further divides the CC middens into sub-sites, CC-cow shade, CC-cow tank, and CC-500 m from tank. WF, CC-cow shade, and CC-cow tank are all intensively grazed in the winter and spring months while CC-500 m from tank is further from the tank and only moderately grazed.

In this ordination, pre- and post- introduction middens do become separated. Because there is only one moderately impacted site, CC-3 from CC-500 m from tank, it is not possible to tell whether intensively and moderately grazed sites cluster separately. That midden, though, does fall to the periphery and is not central in the cluster. CC-11, the transitional midden, also is on the periphery of the cluster.

Fig. 11 shows movement through time of the middens through multivariate space. At this enlarged scale, there is a differentiation by age. The middens tend to move up Axis 2, and towards the middle of Axis 1. Although the CC-cow shade middens differ dramatically on Axis 1 from the CC-cow tank and CC-500 m from tank middens, the grazing treatment draws all middens to the middle. The moderately grazed site, CC-500 m from tank, shows less movement through ordination space, indicating the affect of grazing is not as strong here as with the more intensely grazed sites.

These changes, with the grazed assemblages tending toward the center of the ordination space, suggest a homogenization of the plant associations. With grazing, the frequency of the less common species was reduced, while the most common species were unaffected. The number of genera identified in each midden type further supports this conclusion. The 14 pre-settlement middens and 6 post-settlement, ungrazed

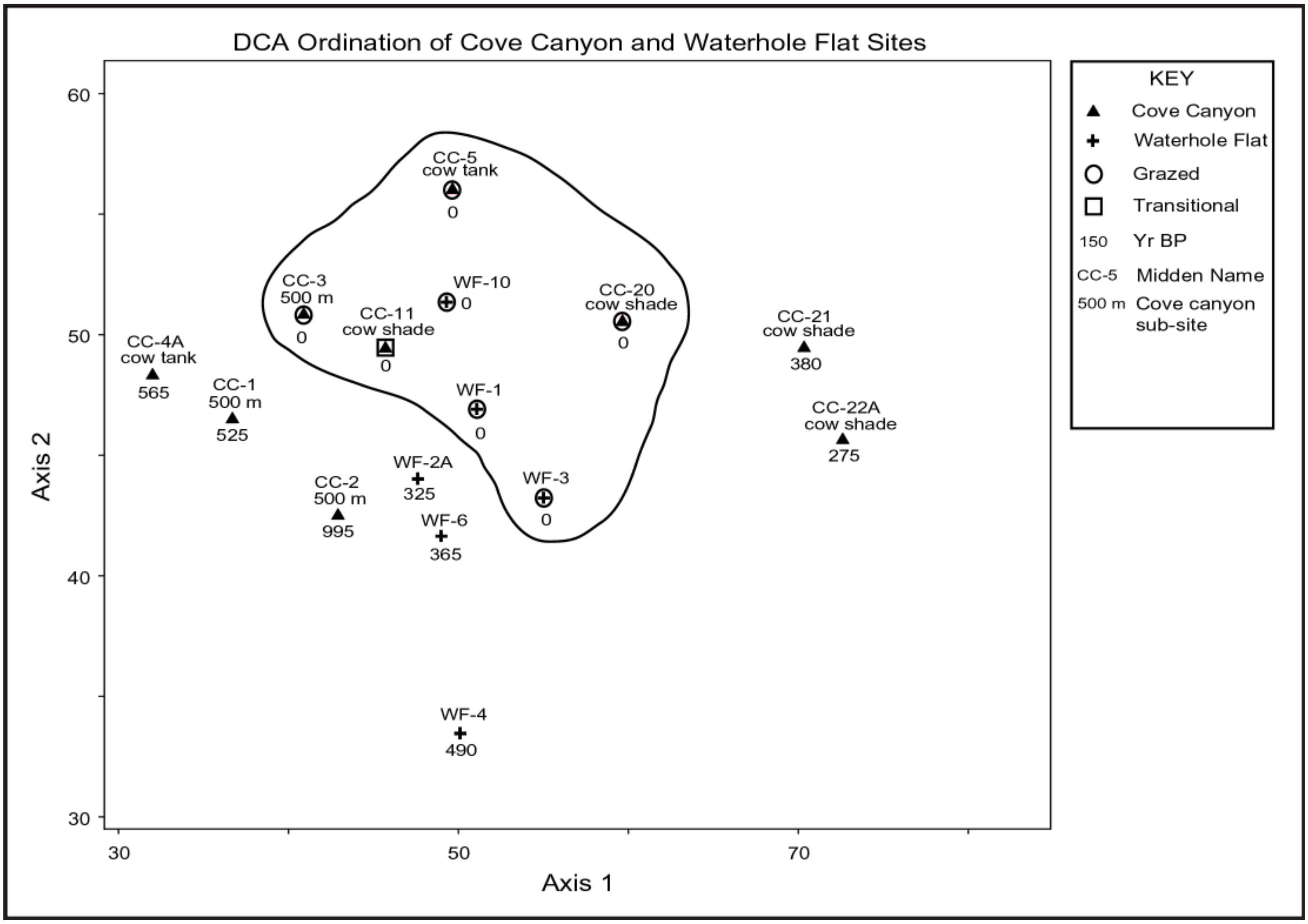

Figure 10. Detrended Correspondence Analysis (DCA) ordination of Cove Canyon (CC) and Waterhole Flat (WF) sub-sites.

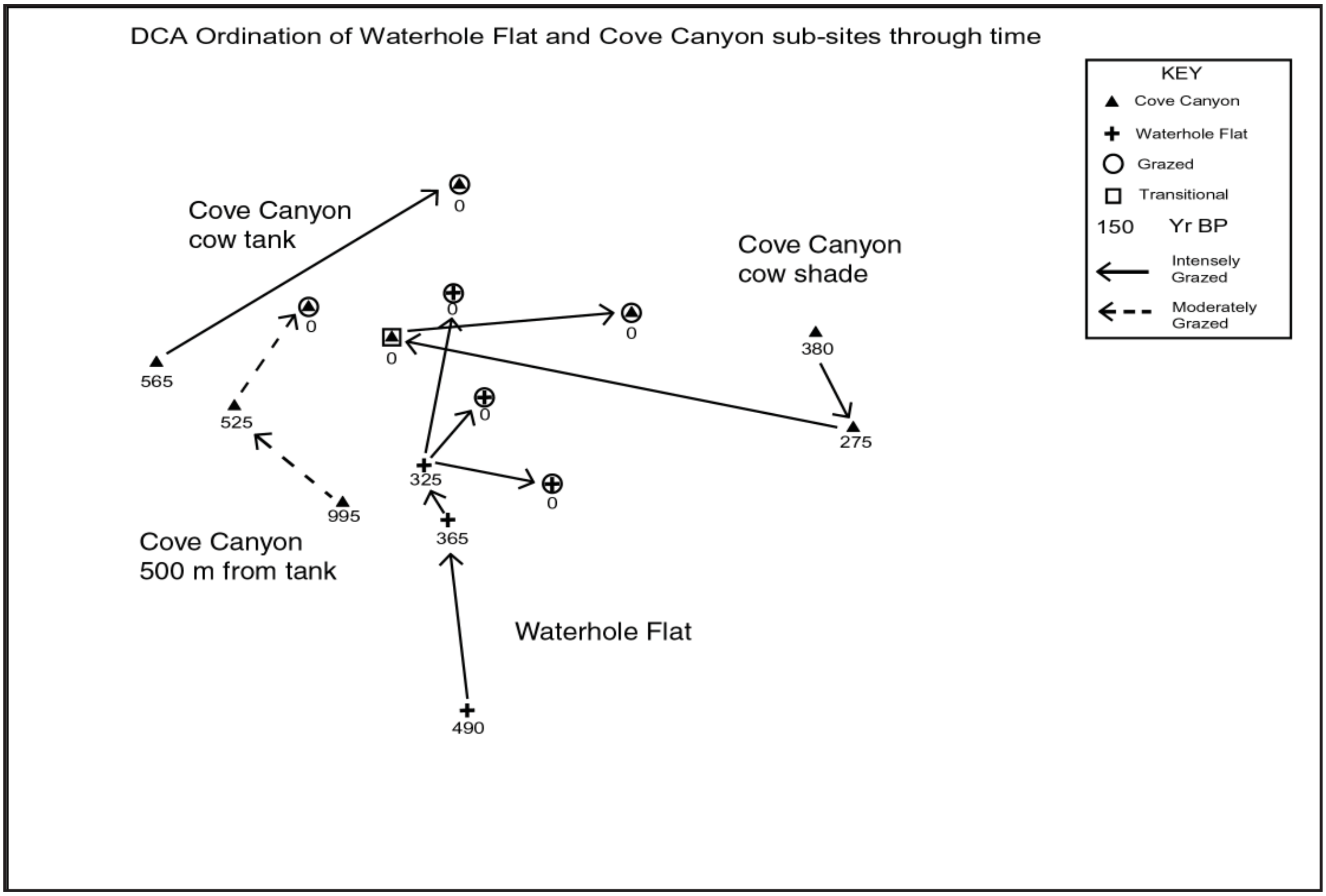

Figure 11. Detrended Correspondence Analysis (DCA) ordination of Waterhole Flat (WF) and Cove Canyon (CC) sub-sites through time.

middens contained a more diverse set of genera (19.1 ± 5.4 & 21.2 ± 4.2 genera/midden respectively [Appendix F]) than the 6 post-settlement grazed middens (14.5 ± 6.2 genera/midden). Comparing the modern grazed middens versus the ungrazed middens (presettlement & modern) yields a significant difference between the groups (t-test; P = 0.046).

Individual Plant Trends

Another ordination demonstrates how the plant concentrations in the middens affected midden placement on the graph (Fig. 12). This ordination only shows middens from the CC and WF sites, both pre- and post-grazing introduction. Just as the middens cluster, the plants also cluster when graphed using DCA. Plants found close together on the graph are often found together in middens. Plants closer to a midden are found in that midden, while plants far from a midden might be found in smaller quantities, or not in that midden at all.

We predicted that more native grasses and palatable shrubs would be associated with pre-settlement middens, while unpalatable shrubs would be found more closely related to the post-settlement middens. Examining the DCA ordinations, most of the plants behaved as predicted, while some did not. Grasses were correlated with the ungrazed middens, except the exotic cheatgrass, which was associated with the grazed middens (Fig. 12). Unpalatable shrubs such as snakeweed, barberry, white sagebrush, and yucca were found more predominantly in the grazed middens. Palatable shrubs, like winterfat, shadscale, wooly plantain, and globemallow are mainly found in the ungrazed middens. One explanation for this is that cattle preferentially eat palatable plants near the site of the grazed middens, leaving the unpalatable plants in greater abundance for packrats to collect.

These findings indicate that grazing does influence the structure of the plant communities. This is consistent with findings from the midden and grazing study in Capitol Reef (Cole et al., 1997; Cole and Murray, 1999), which documented broom snakeweed associated with post-settlement middens, and native grasses associated with pre-settlement middens. Table 1 shows some of the key grazing indicator plants for this region of the Southwest, how their populations are expected to change with the influence of grazing, and how they changed in this study.

Five plants did not change as expected with grazing. Desert princesplume (*Stanleya pinnata*), sagebrush, prickly pear, ephedra, and rabbitbrush all decreased or remained the same when they were expected to increase, since they are of low palatability value. There could be several reasons for this.

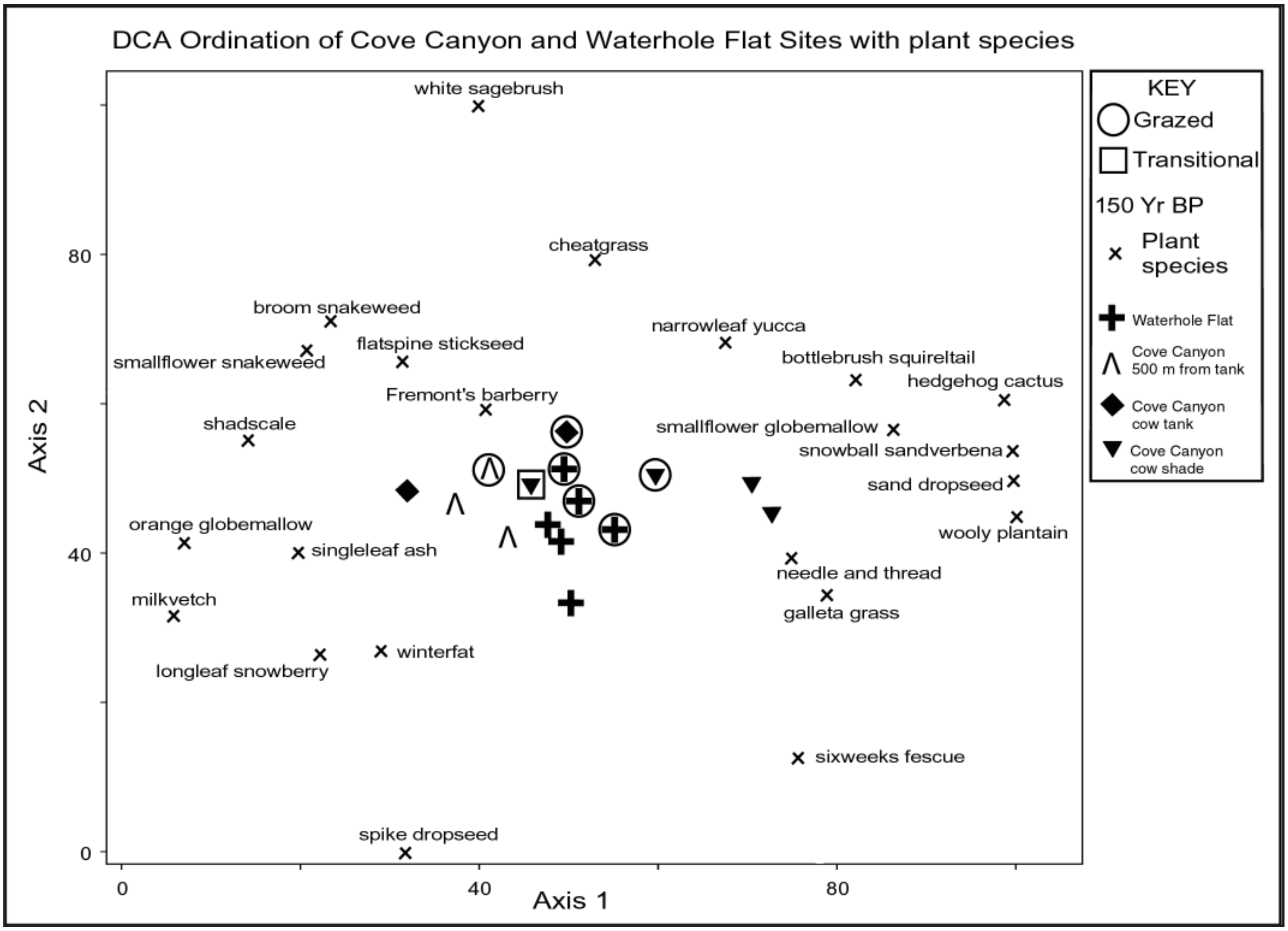

Figure 12. Detrended Correspondence Analysis (DCA) ordination of Cove Canyon (CC) and Waterhole Flat (WF) sub-sites with plant species.

Desert princesplume was only recorded in two middens, so the sample size for this plant might not be high enough for a significant response. Sagebrush, although not highly palatable, could be a food source of last resort as preferred grasses disappear, which would cause it to decrease. Also, sagebrush is impacted if trampling becomes widespread. Alternately, its reduction could have occurred in the Nineteenth Century due to sheep grazing (Cole et al., 1997). Prickly pear and ephedra are two plants that are highly valued by packrats as food items, and also as defensive nesting material. These plants are likely preferred by the packrats over other plants, and so might not be ideal grazing indicators. Both of these plants remained at similar levels through time and space with the macrofossils, even though decreases in pollen percentages were evident.

Rabbitbrush (*Ericameria nauseosa*, recently *Chrysothamnus nauseosus*) is often expected to increase with grazing, but the identification of these shrubs is complicated by interspecific, and likely intergeneric, hybridization. Also, different subspecies of rabbitbrush have a great range of palatability for cattle (Hanks et al. 1975). The consistent presence of these plant parts in both fossil and ungrazed middens versus only three achenes found in one post-grazing midden from the least impacted grazing site (CC 500 m from tank) strongly implies the reduction of these plants from the Ericameria/Chrysothamnus complex from these grazed areas.

The observed changes were consistent with our predictions for 13 of the 20 species for which there were clear predictions. Not all applications of the three methods (time, space, and pollen) demonstrated directional change since the three methods differ in their ability to record different species. But when a change was detected using one or more methods, the change was in the expected direction. Fremont's barberry, prickly Russian thistle, Utah serviceberry, roundleaf buffaloberry, blackbrush, skunkbush sumac, and native grasses all responded convincingly as recorded by two or three methods. Changes in longleaf snowberry, snakeweed, Utah juniper, globemallow, fourwing saltbush, Mexican cliffrose, exotic grasses, and filaree were less definitive, showing the expected trend in one method but having no definitive trend in the other.

Two species showed mixed trends. Shadscale and winterfat both decreased, as expected, with time, but increased over space. Pollen from the family Chenopodiaceae, attributed to

Table 1. Expected versus observed outcomes of macrofossils from Glen Canyon National Recreation Area (GLCA) middens.

PLANT	Palatability Level	Expected Change with Grazing	Time	Space	Pollen	Expected versus Observed Outcome
desert princesplume	0	↑	↓	↓	n/a	X
longleaf snowberry	1	↑	-	↑	n/a	√
snakeweed	1	↑	↑	-	n/a	√
rabbitbrush	1	↑	↓	↓	n/a	X
Utah juniper	2	↑	-	↑	-	√
Fremont’s barberry	2	↑	↑	↑	-	√√
sagebrush	3	↑	↓	↓	-	X
prickly pear	3	↑	-	-	↓	X
prickly Russian thistle	3	↑	↑	↑	↑	√√
ephedra	3	↑	-	-	-	X
globemallow	4	↓	-	-	↓	√
Utah serviceberry	4	↓	↓	↓	n/a	√√
roundleaf buffaloberry	4	↓	↓	↓	-	√√
blackbrush	4	↓	↓	↓	↓	√√
fourwing saltbush	5	↓	-	-	↓	√
shadscale	5	↓	↓	↑	↓	√
skunkbush sumac	5	↓	↓	↓	n/a	√√
Mexican cliffrose	6	↓	-	↓	n/a	√
winterfat	6	↓	↓	↑	n/a	√
Native Grasses	6	↓	↓	↓	↓	√√
Exotic Grasses	6	↓ or ↑	-	↓	n/a	√
filaree	6	↓ or ↑	-	↓	n/a	√

Table 1 Key

Palatability level key	Expected key	Time=	Space=	Pollen=	Outcome
0=poisonous 1=not palatable 2=poor 3=neutral (drought) 4=fair 5=palatable 6=highly palatable	↑ = increase ↓= decrease ↓ or ↑= depending on situation - = no change	modern grazed middens compared to Late Holocene middens	modern grazed middens compared to modern ungrazed middens	modern grazed middens compared to Late Holocene middens	X= 2+ variables wrong √= 1 variable right √√= 2+ variables right

both of them, increased through time. There were no shadscale fossils present in any modern ungrazed middens, most likely because they do not grow on the relict mesas (Tuhy and MacMahon, 1988). Although winterfat does grow on the mesas, it is not abundant, and no fossils were present in these middens. These results caution that just as the plant communities are highly variable from place to place, the effects of grazing can also be variable.

Conclusion

It is well-documented that the fossil plants and pollen found in packrat middens can serve as useful tools for analyzing climate and vegetation changes on the landscape (Anderson and Van Devender, 1991; Betancourt et al., 1990). This study shows that, if carefully analyzed, they can also be used to document more subtle vegetative changes brought about by such things as grazing or exotic plant introductions. The study also suggests a new way of examining vegetation change, contrasting both the spatial and temporal dimensions. The results of this comparison suggest that within the geologically and topographically diverse arid southwest, spatial comparisons between sites may be problematic due to pre-existing site differences.

The comparisons between grazed versus ungrazed middens within GLCA suggest that grazing reduced the frequencies of some plant species, leading to a homogenization of the plant associations and a lowering of the species number recorded in middens. These changes were evident in both the temporal comparisons of the number of midden taxa, and the spatial comparisons of midden taxa and ordinations of assemblages. While no species were eliminated from the grazed areas, some groups, such a native grasses, were noticeably reduced.

The predictions of grazing effects on individual species were often supported, although this was not the case for all species. This suggests that grazing effects may be highly specific to certain regions, grazing animals, seasonality, and intensity, and should not be uncritically applied to every situation. The effects of grazing on exotic species, especially cheatgrass, was to reduce the number of these plants on the grazed areas. This was probably a consequence of the cattle spending the winter and spring on these areas, when these species would be especially palatable.

These data demonstrate that since the introduction of domestic herbivores, these grazed areas have undergone a measurable reduction in taxa, especially native grasses, that did not occur on adjacent ungrazed areas.

Management Implications

When considering restoration schemes aiming to return the environment to its “original” condition, it is imperative to define the meaning of “original” state. Packrat midden research assists with this by showing which plants are the “building blocks” for a particular site. The macrofossils and pollen from these storehouses of information open a doorway to the past and allow us to understand how different environmental variables have determined which plants grow where. It is only through discovering and understanding what has transpired in the past that we will be able to provide context for making wise and informed decisions about how to manage the future.

This study was conducted in order provide data useful to the management of grazing at Glen Canyon National Recreation Area. From the DCA ordinations comparing the different Cove Canyon sub-sites, this study shows that the plant communities in moderately grazed areas change less dramatically than in heavily grazed areas. This would indicate moderate grazing has less impact on plant community character than heavy grazing. This has been shown to be true in other studies as well, where moderate grazing can even have a positive effect on abundance, richness, and diversity of certain species on the landscape (Valone and Kelt, 1999).

Exotic plants were not as abundant in the post-settlement middens as expected. Only four exotic species- prickly Russian thistle, filaree, cheatgrass, and red brome- were found in the middens. In addition, larger amounts of exotics were found on the relict mesas than were expected. The exotic grasses are wind-dispersed, which is the most likely explanation for their presence on the mesas. Filaree was found only on Mazuki Point. As well as being dispersed in the hooves and coats of animals, it is avian-dispersed, which could account for its establishment on this inaccessible area. Filaree was never recorded on a relevè or a modern plant plot at the grazed areas, so it is possible that it is not growing at those areas presently. Alternatively, it is possible that the cattle ate it all before our field season began, as this plant is highly palatable in the springtime.

Future Work

Glen Canyon National Recreation Area is a large expanse of land with numerous caves, canyons, and mesas. Much more exploration could be done to find more packrat middens for further study. Similar studies could be repeated in other National Park Units in the area such as Bryce Canyon National Park, Zion National Park, Arches National Park, Canyonlands National Park, and Grand Staircase- Escalante National Monument. Also, more work could be done comparing the modern plant transects to the modern midden assemblages. As well, the middens could be re-examined to see if any other paleoecologic indicators might be useful in documenting environmental changes. Insect remains, bones, and *Peromyscus* spp. and *Neotoma* spp. pellets have already been separated into vials, and could be analyzed for this purpose.

As this study shows, there is a great potential for applying paleoecological studies to some of the more difficult issues threatening our native environments today. The design incorporated in this study, analyzing effects through both time and space simultaneously, is fairly unique, and it could be applied in the study of other variables in addition to grazing.

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References Cited

Abbott, M.L., Fraley, L. Jr., Reynolds, T.D., 1991, Root profiles of selected cold desert shrubs and grasses in disturbed and undisturbed soils. Environmental and Experimental Botany 31, 165-178.

Anderson, P.B., Chidsey Jr.,T.C. Sprinkel, D.A., Willis, G.C., 2000, Geology of Glen Canyon National Recreation Area, Utah-Arizona. In: Sprinkel, D.A., Chidsey Jr., T.C. Anderson, P.B. (Eds.), Geology of Utah's Parks and Monuments. Utah Geological Association, Publication 28, Publishers Press, Salt Lake City, pp. 301-336.

Anderson, R.S., Van Devender, T.R., 1991, Comparison of pollen and macrofossils in packrat (*Neotoma*) middens: a chronological sequence from the Waterman Mountains of Southern Arizona, U.S.A. Review of Palaeobotany and Palynology 68, 1-28.

Anderson, R.S., Van Devender, T.R., 1995, Vegetation history and paleoclimates of the coastal lowlands of Sonora, Mexico- pollen records from packrat middens. Journal of Arid Environments 30, 295-306.

Anderson, R.S., Betancourt, J.L., Mead, J.I., Hevly, R.H., Adam, D.P., 2000, Middle- and late- Wisconsin paleobotanic and paleoclimatic records from the southern Colorado Plateau, USA. Palaeogeography, Palaeoclimatology, Palaeoecology 155, 31-57.

Arnberger, L.P., 1982, Flowers of the Southwest Mountains. Southwest Parks and Monuments Association, Tucson, AZ.

Barrow, J.R., 1997, Natural asexual reproduction in fourwing saltbush *Atriplex canescens* (Pursh) Nutt. Journal of Arid Environments 36, 267-270.

Bashkin, M., Stohlgren, T.J., Otsuki, Y., Lee, M., Evangelista, P., Belnap, J., 2003, Soil characteristics and plant exotic species invasions in the Grand Staircase-Escalante National Monument, Utah, USA. Applied Soil Ecology 22, 67-77.

Benson, L., 1982, The Cacti of the United States and Canada. Stanford University Press, Stanford, CA.

Betancourt, J.L., 1990, Late Quaternary biogeography of the Colorado Plateau. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 259-292.

Betancourt, J.L., Davis, O.K., 1984, Packrat middens from Canyon de Chelly, northeastern Arizona: paleoecological and archaeological implications. Quaternary Research 21, 56-64.

Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), 1990, Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson.

Bock, C., Saab, V., Rich, T., Dobkin, D., 1993, Effects of livestock grazing on neotropical migratory landbirds in western North America. In: Finch, D., Stangel, P. (Eds.), Status and Management of Neotropical Migratory Birds. USDA Forest Service General Technical Report. RM-229.

Brown, J.H., Whitham, T.G., Ernest, S.K.M., Gehring, C.A., 2001, Complex species interactions and the dynamics of ecological systems: long-term experiments. Science 293, 643- 646.

Cibils, A.F., Swift, D.M., Hart, R.H., 2000, Gender-related differences of shrubs in stands of *Atriplex canescens* with different histories of grazing by cattle. Journal of Arid Environments 46, 383-396.

Cinnamon, S.K., 1988, The Vegetation Community of Cedar Canyon, Wupatki National Monument as Influenced by Prehistoric and Historic Environmental Change. Unpublished M.S. thesis, Northern Arizona University, Flagstaff.

Cole, K.L., 1985, Past rates of change, species richness, and a model of vegetational inertia in the Grand Canyon, Arizona. American Naturalist 125, 289-303.

Cole, K.L., Murray, L.K., 1999, Paleoenvironments of Capitol Reef National Park reconstructed from fossil packrat middens. In: van Riper, C. III (Ed.), Proceedings of the 4th biennial Conference on Research on The Colorado Plateau, USGS, Flagstaff, AZ, pp. 3-24.

Cole, K., Henderson, N., Shafer, D., 1997, Holocene vegetation and historic grazing impacts at Capitol Reef National Park reconstructed using packrat middens. Great Basin Naturalist 57, 315-326.

Davis, O.K., Anderson, R.S., 1987, Pollen in packrat (*Neotoma*) middens: pollen transport and the relationship of pollen to vegetation. Palynology 11, 185-198.

Davis, O.K., Turner, R.M., 1986, Palynological evidence for the historic expansion of juniper and desert shrubs in Arizona, U.S.A. Review of Palaeobotany and Palynology 49, 177-193.

de Soyza, A.G., Van Zee, J.W., Whitford, W.G., Neale`, A., Tallent-Hallsel, N., Herrick, J.E., Havstad, K.M., 2000, Indicators of Great Basin rangeland health. Journal of Arid Environments 45, 289-304.

Delorit, R.J., 1970, An Illustrated Taxonomy Manual of Weed Seeds. Agronomy Publications, River Falls, WI.

Dial, K.P., Czaplewski, N.J., 1990, Do woodrat middens accurately represent the animals' environments and diets? The Woodhouse Mesa study. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 43-58.

Dodge, N.N., 1985, Flowers of the Southwest Deserts. Southwest Parks and Monuments Association, Tucson, AZ.

Durrant, S.D., Dean, N.K., 1959, Mammals of Glen Canyon. In: Woodbury, A.M. (Ed.), 1959. Ecological Studies of Flora and Fauna in Glen Canyon. Anthropological Papers, Department of Anthropology, University of Utah.

Earle, L.R., 2003, Rapid development of an unusual peat-accumulating ecosystem in the Chilean Altiplano. Quaternary Research 59, 2-11.

Elmore, F.H., 1976, Shrubs and Trees of the Southwest Uplands. Southwest Parks and Monuments Association, Globe, AZ.

Epple, A.O., 1995, A Field Guide to the Plants of Arizona. Falcon Publishing, Helena, MT.

Faegri, K., Iverson, J., 1989, Textbook of Pollen Analysis. John Wiley & Sons, New York.

Fall, P.L., Lindquist, C.A., Falconer, S.E., 1990, Fossil hyrax middens from the Middle East: A record of paleovegetation and human disturbance. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 408-427.

Fisher, J., 2005, Using Packrat Middens to assess how Grazing Influences Vegetation Change in Glen Canyon National Recreation Area, Utah. M.S. Thesis, Northern Arizona University.

Fisher, R.F., Bourn, C.N., Fisher, W.F., 1995, Opal phytoliths as an indicator of the floristics of prehistoric grasslands. Geoderma 68, 243-255.

Flather, C., Joyce, L., Bloomgarden, C., 1994, Species endangerment patterns in the United States. USDA Forest Service General Technical Report. RM-241.

Fleischner, T., 1994, Ecological costs of livestock grazing in western North America. Conservation Biology 8, 629-644.

Flora of North America Editorial Committee. Flora of North America. Volume 2, 1993, Oxford University Press, New York, NY.

Flora of North America Editorial Committee. Flora of North America. Volume 25, 2003, Oxford University Press, New York, NY.

Flowers, S., 1959,. Vegetation of Glen Canyon. In: Woodbury, A.M. (Ed.), 1959. Ecological Studies of Flora and Fauna in Glen Canyon. Anthropological Papers, Department of Anthropology, University of Utah.Gauch, H.G., Jr., 1982, Multivariate Analysis in Community Structure. Cambridge University Press, Cambridge.

Glen Canyon National Recreation Area, 2004a, Checklist of Mammals. Unpublished manuscript on file.

Glen Canyon National Recreation Area, 2004b. 2004 Glen Canyon National Recreation Area Profile. Retrieved June 13, 2004 from the World Wide Web: http://data2.itc.nps.gov/parks/glca/ppdocuments/glcaprofile.pdf

Glickman, G., 1997, Part 1: science, conservation, policy, and the public. In: Pickett, S., Ostfeld, R., Shachak, M., Likens, G. (Eds.), The Ecological Basis of Conservation: Heterogeneity, Ecosystems, and Biodiversity. Chapman and Hall, New York. pp.11-15.

Guenther, D., Stohlgren, T.J., Evangelista, P., 2004, A comparison of a near-relict site and a grazed site in a pinyon-juniper community in the Grand Staircase-Escalante National Monument, Utah. In: van Riper, C. III, Cole, K. L. (Eds.), The Colorado Plateau: Cultural, Biological, and Physical Research. The University of Arizona Press, Tucson, pp. 153-162.

Hanks, D. L., E.D. McArthur, A.P. Plummer, B. C. Giunta, and A. C. Blauer, 1975. Chromatographic recognition of some palatable and unpalatable subspecies of rubber rabbitbrush in and around Utah. Journal of Range Management 28: 144-148.

Harlow, W.M., 1946, Fruit and Twig Key to Trees and Shrubs. Dover Publications, New York.

Harper, K.T., Belnap, J., 2001, The influence of biological soil crusts on mineral uptake by associated vascular plants. Journal of Arid Environments 47, 347-357.

Harris, J.G., Harris, M.W., 2001, Plant Identification Terminology: An Illustrated Glossary. Spring Lake Publishing, Payson, UT.

Hickman, J.C. (Ed.), 1993, The Jepson Manual: Higher Plants of California. University of California Press, Berkeley, CA.

Hiernaux, P., Bielders, C.L., Valentin, C., Bationo, A., Fernández-Rivera, S., 1999, Effects of livestock grazing on physical and chemical properties of sandy soils in Sahelian rangelands. Journal of Arid Environments 41, 231-245.

Hitchcock, A.S., 1971,. Manual of the Grasses of the United States (2^{nd} edition revised by Agnes Chase). Dover Publications, New York, NY.

Holmgren, C.A., Betancourt, J.L., Rylander, K.A., Roque, J., Tovar, O., Zeballos, H., Linares, E., Quade, J., 2001, Holocene vegetation history from fossil rodent Middens near Arequipa, Peru. Quaternary Research 56, 242-251.

Holmgren, C.A., Peñalba, M.C., Rylander, K.A., Betancourt, J.L., 2003, A 16,000 ^{14}C yr B.P. packrat midden series from the USA–Mexico Borderlands. Quaternary Research 60, 319-329.

Jones, A., 2000, Effects of cattle grazing on North American arid ecosystems: a quantitative review. Western North American Naturalist 60, 155-164.

Jones, K., 1981, Effects of grazing on lizard abundance and diversity in western Arizona. Southwestern Naturalist 26, 107-115.

Kearney, T.H., Peebles, R.H., 1969, Arizona Flora. University of California Press, Berkeley, CA.

King, J.E., Van Devender, T.R., 1977, Pollen analysis of fossil packrat middens from the Sonoran Desert. Quaternary Research 8, 191-204.

Knapp, P.A., 1996, Cheatgrass (*Bromus tectorum* L.) dominance in the Great Basin desert. Global Environmental Change 6, 37-52.

Koehler, P.A., Anderson, R.S., 1995, Thirty thousand years of vegetation changes in the Alabama Hills, Owens Valley, California. Quaternary Research 43, 238-248.

Koehler, P.A., Anderson, R.S., Spaulding, W.G., 2005, Development of vegetation in the Central Mojave Desert of California during the late Quaternary. Palaeogeography, Palaeoclimatology, Palaeoecology 215, 297-311.

Lavoie, M., Filion, L. 2001, Holocene vegetation dynamics of Anticosti Island, Quebec, and consequences of remoteness on ecological succession. Quaternary Research 56, 112- 127.

LeCain, D.R., Morgan, J.A., Schuman, G.E., Reeder, J.D., Hart, R.H., 2002, Carbon exchange and species composition of grazed pastures and exclosures in the shortgrass steppe of Colorado. Agriculture, Ecosystems & Environment, 93, 421-435.

Longland, W., 1994, Seed use by desert granivores. In: S.B. Monsen and S.G. Kitchen (compilers), Proceedings of the ecology and management of annual rangelands. General Technical Report INT-313. U.S. Forest Service, Intermountain Research Station, Ogden, UT, pp. 233-237.

Lovich, J. E. and D. Bainbridge, 1999, Anthropogenic degredation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environmental Management 24, 309-326.

Mack, R.N., 1981, Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. Agro-Ecosystems 7, 145-165.

McDougall, W.B. 1973, Seed Plants of Northern Arizona. The Museum of Northern Arizona, Flagstaff, AZ.

McCune, B., Grace, J.B. 2002, Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR.

McVickar, J.L., 1991, Holocene Vegetation Change at Cowboy Cave, Southeastern Utah, and its Effect upon Human Subsistence. Unpublished M.S. thesis, Northern Arizona University, Flagstaff, AZ.

Menke, J., Bradford, G.E., 1992, Rangelands. Agriculture, Ecosystems and Environment 42, 141-163.

National Park Service. 1999, Grazing Management Plan. Glen Canyon National Recreation Area, U.S. Department of Interior.

Nelson, D.J., Webb, R.H., Long, A., 1990, Analysis of Stick-Nest Rat (*Leporillus*: Muridae) Middens from Central Australia. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 428-434.

Nowak, C.L., Tausch, R.J., 1999, Probability that a fossil absent from a sample is also absent from the paleolandscape. Quaternary Research 54, 144-154.

O'Rourke, M.K., 1991, Pollen in packrat middens. Grana 30, 337- 341.

O'Rourke, M.K., Lebowitz, M.D., 1984, A comparison of regional atmospheric pollen with pollen collected at and near homes. Grana 23, 55-64.

Parker, K.F., 1972, An Illustrated Guide to Arizona Weeds. University of Arizona Press, Tucson, AZ.

Pearsall, D. M., 1989, Paleoethnobotany: a Handbook of Procedures. Academic Press, San Diego.

Public Law 92-593. 1972, Enabling Legislation for Glen Canyon National Recreation Area. U.S. Congress.

Rambo, J.L., Faeth, S.H., 1999, Effect of vertebrate grazing on plant and insect community structure. Conservation Biology 13, 1047-1054.

Ruyle, G.B., Young, D.J. (Eds.), 1997, Arizona Range Grasses: Their Description, Forage Value, and Grazing Management. Cooperative Extension, College of Arizona, The University of Arizona, Tucson.

Saab, V., Bock, C., Rich, T., Dobkin, D., 1995, Livestock grazing effects in western North America. In: Martin, T., Finch, D. (Eds.), Ecology and Management of Neotropical Migratory Birds: A Synthesis and Review of Critical Issues. Oxford University Press, London, pp. 311-353.

Salo, L.F., 2004, Population dynamics of red brome (*Bromus madritensis* subsp. *rubens*): times for concern, opportunities for management. Journal of Arid Environments 57, 291-296.

Savage, M. and T. W. Swetnam. 1990. Early 19th-century fire decline following sheep pasturing in a Navajo ponderosa pine forest. Ecology 71, 2374-2378.

Schmutz, E.M., Dennis, A.E., Harlan, A., Hendricks, D., Zauderer, J., 1976, An ecological survey of Wide Rock Butte in Canyon de Chelly National Monument, Arizona. Journal of the Arizona Academy of Science 11, 114-125.

Scott, L. 1990, Hyrax (Procaviidae) and Dassie Rat (Petromuridae) middens in paleoenvironmental Studies in Africa. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 398-407.

Spaulding, W.G., Peterson, K.L., 1980, Late Pleistocene and Early Holocene paleoecology of Cowboy Cave. In: Jennings, J.D., Cowboy Cave. University of Utah Anthropology Papers 104: 163-177.

Spence, J.R. 2005, Notes on significant collections and additions to the flora of Glen Canyon National Recreation Area, Utah and Arizona, between 1992 and 2004. Western North American Naturalist 65, 2005.

Spence, J.R., 2001, Climate of the Central Colorado Plateau, Utah and Arizona: Characterization and Recent Trends. In: van Riper, C. III; Thomas, K.A., Stuart, M.A. (Eds.), Proceedings of the Fifth Biennial Conference of Research on the Colorado Plateau, USGS, Flagstaff, AZ, pp. 187-204.

Spence, J., Zimmerman, J.A.C., 1996, Glen Canyon National Recreation Area: preliminary flora of Glen Canyon National Recreation Area. National Park Service: Unpublished Report.

Stohlgren, T., Schell, L., Heuvel, B., 1999, How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. Ecological Applications 9, 45-64.

Stubbendieck, J., Hatch, S.L., Butterfield, C.H., 1997, North American Range Plants. University of Nebraska Press, Lincoln, NE.

Stuber, R., 1985, Trout habitat, abundance, and fishing opportunities in fenced vs. unfenced riparian habitat along Sheep Creek, Colorado. pp.310-314 in: Johnson, R., Ziebell, C., Patton, D., & others (tech. cords.). Riparian ecosystems and their management: reconciling conflicting uses. USDA Forest Service General Technical Report. RM-120.

Stuiver, M., Reimer, P.J., 1993, Extended ^{14}C database and revised CALIB radiocarbon calibration program. Radiocarbon 35, 215-230.

Thompson, R.S., 1985, Palynology and *Neotoma* middens. American Association of Stratigraphic Palynologists Contributions Series 16, 89-112.

Topping, G., 1997, Glen Canyon and the San Juan Country. University of Idaho Press, Moscow, ID.

Tuhy, J.S., MacMahon, J.A., 1988, Vegetation and relict communities of Glen Canyon National Recreation Area. Final Report to the National Park Service. The Nature Conservancy.

United States Department of Agriculture, 1948, Woody-Plant Seed Manual. Miscellaneous Publication No. 654. United States Government Printing Office, Washington, D.C.

United States Department of Agriculture, 1988, Range Plant Handbook. Dover Publications, New York.

Utah Division of Wildlife Resources, 2004, Southeastern Utah's Mammals. Retrieved May, 14th, 2004 off the World Wide Web: http://www.wildlife.utah.gov/pdf/mammal.pdf.

Vaughan, T.A. 1990, Ecology of living packrats. In: Betancourt, J.L., Van Devender, T.R., Martin, P.S. (Eds.), Packrat Middens: The Last 40,000 Years of Biotic Change. University of Arizona Press, Tucson, pp. 15-27.

Vallentine, J., 1990, Grazing Management. Academic Press, San Diego.

Valone, T.J., Sauter, P. 2005, Effects of long-term cattle exclosure on vegetation and rodents at a desertified arid grassland site. Journal of Arid Environments 61, 161-170.

Vandersande, M. W., Glenn, E.P., Walworth, J.L., 2001, Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. Journal of Arid Environments 49, 147- 159.

Van Devender, T.R., King, J.E., 1971, Late Pleistocene vegetational records in western Arizona. Journal of the Arizona Academy of Science 6, 240-244.

Wan, C., Yilmaz, I., Sosebee, R.E., 2002, Seasonal soil-water availability influences snakeweed root dynamics. Journal of Arid Environments 51, 255-264.

Warren, E.R., 1910, The Mammals of Colorado: An account of the several species found within the boundaries of the state, together with a record of their habits and of their distribution. The Knickerbocker Press, New York.

Welsh, S.L., Atwood, N.D., Goodrich, S., Higgins, L.C. (Eds.), 1993, Utah Flora, Brigham Young University, Provo.

Whitson, T.D. (Ed.), Burrill, L.C., Dewey, S.A., Cudney, D.W., Nelson, B.E., Lee, R.D., Parker, R. 1991, Weeds of the West. University of Wyoming Press, Jackson, WY.

Willey, D.W., 1994, Effects of livestock grazing on grassland birds in Capitol Reef National Park, Utah. Technical Report, High Desert Research Collective, Flagstaff, AZ.

Appendix A. Midden Locations

Table A-1. Glen Canyon National Recreation Area midden locations.

Midden name	Elevation (m)	Elevation (ft)	Substrate	Slope aspect (degree)	Slope angle (degree)	UTM E	UTM N
Cove Canyon 1	1596	5237	Sandstone	unknown	unknown	566949	4199710
Cove Canyon 2	1598	5244	unknown	191	18	566949	4199707
Cove Canyon 3	1600	5250	unknown	unknown	unknown	566976	4199708
Cove Canyon 4A	1603	5260	unknown	unknown	unknown	567208	4199345
Cove Canyon 5	1603	5260	unknown	unknown	unknown	567210	4199360
Cove Canyon 11	1626	5334	White Rim Sandstone	unknown	unknown	565758	4204473
Cove Canyon 20	1612	5290	White Rim Sandstone	unknown	0	565908	4204116
Cove Canyon 21	1603	5258	White Rim Sandstone	unknown	unknown	565881	4204124
Cove Canyon 22A	1607	5272	White Rim Sandstone	unknown	unknown	565910	4204140
Waterhole Flat 1	1638	5373	Cedar Mesa Sandstone	140	12	574499	4210044
Waterhole Flat 2A	1638	5373	Cedar Mesa Sandstone	140	12	574499	4210044
Waterhole Flat 3	1637	5371	unknown	unknown	unknown	574492	4210047
Waterhole Flat 4	1645	5397	unknown	unknown	unknown	574464	4210044
Waterhole Flat 6	1651	5416	unknown	unknown	unknown	574417	4210030
Waterhole Flat 10	1645	5397	unknown	unknown	unknown	574464	4210044
Gandolf's Staircase 1	1621	5317	unknown	240	10	573201	4205097
Gandolf's Staircase 2	1621	5317	unknown	240	10	573201	4205097
Gandolf's Staircase 3	1625	5331	unknown	unknown	unknown	573183	4205096
Gandolf's Staircase 4	1623	5324	unknown	unknown	unknown	573159	4205006
5381 Mesa 1	1625	5333	Navajo Sandstone	125	20	546230	4178928
5381 Mesa2	1625	5333	Navajo Sandstone	125	20	546230	4178928
5381 Mesa 3	1625	5333	Navajo Sandstone	125	20	546230	4178928
5381 Mesa 4B	1417	4649	unknown	120	20	547367	4178248
5381 Mesa 5	1411	4629	unknown	unknown	unknown	547374	4178226
Mazuki Point 1	1431	4694	unknown	unknown	unknown	485095	4111735
Mazuki Point 2	1409	4623	unknown	unknown	unknown	485191	4112217
Mazuki Point 3	1402	4600	unknown	unknown	unknown	485218	4112095

Appendix B. Midden Weights

Table B-1. Glen Canyon National Recreation Area midden weights.

Midden name	Indurated weight (grams)	Dried matrix (grams)	Pellet weight (grams)	Rock weight (grams)	Net midden weight (grams)
Cove Canyon 1	1180.0	190.0	91.7	7.9	90.4
Cove Canyon 2	364.0	45.4	14.7	-	30.7
Cove Canyon 3	320.0	185.9	13.8	44.6	127.5
Cove Canyon 4A	330.0	68.0	13.0	9.7	45.3
Cove Canyon 5	321.0	213.0	70.0	-	143
Cove Canyon 11	615.0	116.0	20.5	4.8	90.7
Cove Canyon 20	330.0	145.7	24.2	36.9	84.6
Cove Canyon 21	205.0	68.3	28.3	2.9	37.1
Cove Canyon 22A	651.0	135.9	43.1	0.5	92.3
Waterhole Flat 1	165.0	103.9	4.1	7.1	92.7
Waterhole Flat 2A	508.0	136.8	23.0	-	113.8
Waterhole Flat 3	89.2	14.2	4.1	0.7	9.4
Waterhole Flat 4	265.9	44.2	15.8	2.4	26.0
Waterhole Flat 6	159.6	43.2	16.2	-	27.0
Waterhole Flat 10	268.9	188.6	41.1	19.76	124.3
Gandolf's Staircase 1	188.1	109.0	3.2	39.1	145.8
Gandolf's Staircase 2	449.0	205.1	28.0	14.4	162.7
Gandolf's Staircase 3	428.0	105.8	12.1	2.8	81.9
Gandolf's Staircase 4	463.5	77.7	23.3	0.4	54.0
5381 Mesa 1	475.4	157.6	17.3	8.1	132.2
5381 Mesa2	679.3	171.2	23.98	6.61	140.6
5381 Mesa 3	129.4	129.4	15.8	4.5	109.1
5381 Mesa 4B	706.7	191.8	34.0	2.2	155.6
5381 Mesa 5	178.5	178.5	21.7	15.7	141.1
Mazuki Point 1	191.1	109.5	11.67	22.35	75.2
Mazuki Point 2	158.2	118.3	21.57	18.49	77.8
Mazuki Point 3	193.3	122.5	12.91	19.66	89.6

Appendix C. Species Lists

Table C-1. Species list for Glen Canyon National Recreation Area middens.

Genus	Species	Variety or subspecies	Family	Common name	Author	Synonym(s)
Abronia	*fragrans*		NYCTAGINACEAE	snowball sandverbena	Nutt. ex Hook.	
Acer	*negundo*		ACERACEAE	box elder	L.	
Achnatherum	*aridum*		POACEAE	arid needlegrass	(M.E. Jones) Barkworth	*Stipa arida*
Achnatherum	*hymenoides*		POACEAE	Indian ricegrass	(Roemer & J.A.Shultes)	*Oryzopsis hymenoides, Stipa hymenoides*
Achnatherum	*speciosum*		POACEAE	desert needlegrass	(Trin. & Rupr.) Barkworth	*Stipa speciosa*
Allium	*macropetalum*		LILIACEAE	largeflower onion	Rydb.	
Ambrosia	*acanthicarpa*		ASTERACEAE	bursage ragweed	Hook.	
Amelanchier	*utahensis*		ROSACEAE	Utah serviceberry	Koehne	
Amsonia	*tomentosa*	var. *stenophylla*	APOCYNACEAE	wooly bluestar	Kearney & Peebles	*A.arenaria, A. eastwoodiana*
Arabis	*perennans*		BRASSICACEAE	perennial rockcress	S. Wats.	
Argemone	*corymbosa*		PAPAVERACEAE	Mohave pricklypoppy	Greene	
Aristida	*purpurea*		POACEAE	purple three awn	Nutt.	
Artemisia	*ludoviciana*		ASTERACEAE	white sagebrush	Nutt.	
Artemisia	*tridentata*		ASTERACEAE	big sagebrush	Nutt.	
Artemisia	*bigelovii*		ASTERACEAE	Bigelow's sagebrush	Gray	
Artemisia	*filifolia*		ASTERACEAE	sand sagebrush	Torr.	
Astragalus	*zionis*		FABACEAE	Zion milkvetch	M.E. Jones	
Astragalus	*amphioxys*		FABACEAE	crescent milkvetch	Gray	
Astragalus	*desperatus*		FABACEAE	rimrock milkvetch	M.E. Jones	
Astragalus	*newberryi*		FABACEAE	Newberry's milkvetch	Gray	
Astragalus	*sabulonum*		FABACEAE	gravel milkvetch	Gray	
Astragalus	sp.		FABACEAE	milkvetch	L.	
Atriplex	*canescens*		CHENOPODIACEAE	fourwing saltbush	(Pursh) Nutt.	
Atriplex	*confertifolia*		CHENOPODIACEAE	shadscale	(Torr. & Frém.) S. Wats.	
Brickellia	*microphylla*		ASTERACEAE	littleleaf bricklebush	(Nutt.) Gray	
Bromus	*rubens*		POACEAE	red brome	L.	*B. madritensis* ssp. *rubens*
Bromus	*tectorum*		POACEAE	cheatgrass	L.	
Calochortus	*flexuosus*		LILIACEAE	weakstem mariposa lily	S. Wats.	
Castilleja	*angustifolia*		SCROPHULARIACEA	Northwestern Indian	(Nutt.) G. Don	
Ceanothus	*greggii*		RHAMNACEAE	desert ceanothus	Gray	
Celtis	*laevigata*	var. *reticulata*	ULMACEAE	netleaf hackberry	(Torr.) L. Benson	*C. reticulata*
Cercocarpus	*intricatus*		ROSACEAE	littleleaf mountain mahogany	S. Wats.	*C. ledifolius* var. *intricatus*
Chaenactis	*macrantha*		ASTERACEAE	bighead dustymaiden	D.C. Eat.	
Chaenactis	*stevioides*		ASTERACEAE	Steve's dustymaiden	Hook. & Arn.	
Chaetopappa	*ericoides*		ASTERACEAE	rose heath	(Torr.) Nesom	*Aster arenosus, Leucelene ericoides*
Chamaesyce	*fendleri*		EUPHORBIACEAE	Fendler's sandmat	(Torr. & Gray) Small	*Euphorbia fendleri*
Chenopodium	*leptophyllum*		CHENOPODIACEAE	narrowleaf goosefoot	(Moq.) Nutt. ex S. Wats.	*C. album* var. *leptophyllum*
Chrysothamnus	*greenei*		ASTERACEAE	Greene's rabbitbrush	(Gray) Greene	*Ericameria filifolia*
Cirsium	*arizonicum*		ASTERACEAE	Arizona thistle	(Gray) Petrak	
Cirsium	*neomexicanum*		ASTERACEAE	New Mexico thistle	Gray	
Coleogyne	*ramosissima*		ROSACEAE	blackbrush	Torr.	
Comandra	*umbellata*		SANTALACEAE	bastard toadflax	(L.) Nutt	
Corispermum	*villosum*		BORAGINACEAE	hairy bugseed	Rydb.	
Cryptantha	sp.		BORAGINACEAE	cryptantha	Lehm. ex G. Don	
Cryptantha	cf. *confertiflora*		BORAGINACEAE	roundleaf cryptantha	(Greene) Payson	
Dasyochloa	*pulchella*		POACEAE	fluffgrass	(Kunth) Willd. ex Rydb.	*Erioneuron pulchellum, Tridens pulchellus*

Table C-1. Species list for Glen Canyon National Recreation Area middens.—Continued

Genus	Species	Variety or subspecies	Family	Common name	Author	Synonym(s)
Echinocereus	sp.		CACTACEAE	hedgehog cactus	Engelm.	
Elymus	*elymoides*		POACEAE	bottlebrush squirreltail	(Raf.) Swezey	*Sitanion hystrix*
Ephedra	*viridis/ cutleri*		EPHEDRACEAE	ephedra	Coville/ Peebles	
Ephedra	*torreyana*		EPHEDRACEAE	Torrey's ephedra	S. Wats.	
Eremocrinum	*albomarginatum*		LILIACEAE	lonely lily	(M.E. Jones) M.E. Jones	
Ericameria	*nauseosa*	var. *juncea*	ASTERACEAE	rubber rabbitbrush	(Greene) Nesom & Baird	*Chrysothamnus nauseosus ssp. junceus*
Ericameria	*nauseosa*	var. *nauseosa*	ASTERACEAE	rubber rabbitbrush	(Pallas ex Pursh) Nesom & Baird	*Chrysothamnus nauseosus*
Eriogonum	*corymbosum*		POLYGONACEAE	crispleaf buckwheat	Benth.	
Eriogonum	*wetherillii*		POLYGONACEAE	Wetherill's buckwheat	Eastw.	*E. sessile*
Erioneuron	*pilosum*		POACEAE	hairy tridens	(Buckl.) Nash	*Tridens pilosus*
Erodium	*cicutarium*		GERANIACEAE	filaree	(L.) L'Hér.ex Ait	
Fraxinus	*anomala*		OLEACEAE	singleleaf ash	Torr. ex S. Wats.	
Glossopetalon	*spinescens*	var. *aridum*	CROSSOSOMATACE	spiny greasebush	M.E. Jones	*Forsellesia nevadensis, G. nevadense*
Grayia	*spinosa*		CHENOPODIACEAE	spiny hopsage	(Hook.) Moq.	*Atriplex grayi*
Gutierrezia	*microcephala*		ASTERACEAE	smallflower snakeweed	(DC.) Grey	*Gutierrezia sarothrae* var. *microcephala*
Gutierrezia	*sarothrae*		ASTERACEAE	broom snakeweed	(Pursh) Britt. & Rusby	
Gutierrezia	sp.		ASTERACEAE	snakeweed	Lag.	
Helianthus	sp.		ASTERACEAE	sunflower	Nutt.	
Helianthus	*petiolaris*		ASTERACEAE	prairie sunflower	Nutt.	
Hesperostipa	*comata*	ssp. *comata*	POACEAE	needle and thread	(Trin. & Rupr.) Barkworth	*Stipa comata*
Hymenoxys	*cooperi*		ASTERACEAE	Cooper's rubberweed	(Gray) Cockerell	
Ipomopsis	sp.		POLEMONIACEAE	gilia	Michx.	
Isocoma	*acradenia*	var. a*cradenia*	ASTERACEAE	alkali goldenbush	Greene	*Happlopappus acradenius*
Juniperus	*osteosperma*		CUPRESSACEAE	Utah juniper	(Torr.) Little	
Juniperus	*scopulorum*		CUPRESSACEAE	Rocky Mountain juniper	Sarg.	
Krascheninnikovia	*lanata*		CHENOPODIACEAE	winterfat	(Pursh) A.D.J. Meeuse & Smit	*Eurotia lanata, Ceratoides lanata*
Lappula	*occidentalis*		BORAGINACEAE	flatspine stickseed	(S. Wats.) Greene	
Layia	*glandulosa*		ASTERACEAE	white tidytips	(Hook.) Hook. & Arn.	
Lepidium	*montanum*		BRASSICACEAE	mountain peppergrass	Nutt.	
Lepidium	sp.		BRASSICACEAE	peppergrass	L.	
Lepidium	*lasiocarpum*		BRASSICACEAE	hairypod peppergrass	Nutt.	
Lesquerella	*ludoviciana*		BRASSICACEAE	silver bladderpod	(Nutt.) S. Wats.	
Lesquerella	*rectipes*		BRASSICACEAE	straight bladderpod	Woot. & Standl.	
Lithospermum	*incisum*		BORAGINACEAE	narrowleaf stoneseed	Lehm.	
Machaeranthera	*canescens*		ASTERACEAE	hoary tansyaster	Pursh (Gray)	
Machaeranthera	*grindelioides*		ASTERACEAE	rayless tansyaster	(Nutt.) Shinners	
Machaeranthera	*canescens*	var. *leucanthemifolia*	ASTERACEAE	whiteflower tansyaster	(Greene) Welsh	*Aster leucanthemifolius*
Mahonia	*fremontii*		BERBERIDACEAE	Fremont's barberry	(Torr.) Fedde	*Berberis fremontii*
Muhlenbergia	sp.		POACEAE	muhly	Schreb.	
Opuntia	*erinacea*		CACTACEAE	prickly pear	Engelm. & Bigelow ex Engelm.	
Opuntia	cf. *chlorotica*		CACTACEAE	prickly pear	Engelm. & Bigelow	
Opuntia	cf. *erinacea*		CACTACEAE	prickly pear	Engelm. & Bigelow ex Engelm.	
Opuntia	cf. *phaecantha*		CACTACEAE	prickly pear	Engelm.	
Panicum	sp.		POACEAE	panic grass	L.	
Penstemon	sp.		SCROPHULARIACEAE	penstemon	Schmidel	
Phacelia	*crenulata*		HYDROPHYLLACEAE	notch-leaf scorpionweed	Torr. ex S. Watts	

Table C-1. Species list for Glen Canyon National Recreation Area middens.—Continued

Genus	Species	Variety or subspecies	Family	Common name	Author	Synonym(s)
Phacelia	*howelliana*		HYDROPHYLLACEAE	harlequin scorpionweed	Atwood	
Phacelia	sp.		HYDROPHYLLACEAE	scorpion-weed	Juss.	
Phoradendron	*juniperinum*		VISCACEAE	juniper mistletoe	Engelm. ex Gray	*P. ligatum*
Physaria	sp.		BRASSICACEAE	twinpod	(Nutt. ex Torr. & Gray) Gray	
Picea	*pungens*		PINACEAE	blue spruce	Engelm.	*P. parryana*
Pinus	*flexilis*		PINACEAE	limber pine	James	
Pinus	*edulis*		PINACEAE	pinyon pine	Engelm.	*P. cembroides* var. *edulis*
Plantago	*patagonica*		PLANTAGINACEAE	wooly plantain	Jacq.	*Plantago purshii*
Pleuraphis	*jamesii*		POACEAE	galleta grass	Torr.	*Hilaria jamesii*
Poa	*fendleriana*		POACEAE	muttongrass	(Steud.) Vassey	
Poa	*secunda*		POACEAE	big bluegrass	J. Presl	*P. sandbergii*
Pseudotsuga	*menziesii*		PINACEAE	Douglas fir	(Mirbel) Franco	
Psoralidium	*junceum*		FABACEAE	rush lemonweed	(Eastw.) Rydb.	*Psoralea juncea*
Psorothamnus	*thompsoniae*		FABACEAE	Thompson's dalea	(Vail) Welsh & Atwood	
Purshia	*mexicana*		ROSACEAE	Mexican cliffrose	(D. Don) Henrickson	*Cowania mexicana*
Rhus	*trilobata*		ANACARDIACEAE	skunkbush sumac	Nutt.	
Ribes	*leptanthum*		GROSSULARIACE	trumpet gooseberry	Gray	
Rosa	*woodsii*		ROSACEAE	Wood's rose	Lindl.	
Rumex	sp.		POLYGONACEAE	dock	L.	
Salsola	*tragus*		CHENOPODIACEAE	prickly Russian thistle	L.	*S. iberica*
Sclerocactus	sp.		CACTACEAE	fishhook cactus	Britt. & Rose	
Selaginella	sp.		SELAGINELLACEAE	spikemoss	Beauv.	
Shepherdia	*rotundifolia*		ELAEAGNACEAE	roundleaf buffaloberry	Parry	
Sphaeralcea	*ambigua*		MALVACEAE	desert globemallow	Gray	
Sphaeralcea	*coccinea*		MALVACEAE	orange globemallow	(Nutt.) Rydb.	
Sphaeralcea	*parvifolia*		MALVACEAE	smallflower globemallow	A. Nels	
Sphaeralcea	sp.		MALVACEAE	globemallow	St.-Hil.	
Sporobolus	*cryptandrus*		POACEAE	sand dropseed	(Torr.) Gray	
Sporobolus	*contractus*		POACEAE	spike dropseed	A.S. Hitchc.	
Stanleya	*pinnata*		BRASSICACEAE	desert princesplume	(Pursh) Britt.	
Symphoricarpos	*longiflorus*		CAPRIFOLIACEAE	longleaf snowberry	Gray	
Tetradymia	*canescens*		ASTERACEAE	gray horsebrush	DC.	
Tetraneuris	*acaulis*	var. *acaulis*	ASTERACEAE	stemless four-nerve daisy	(Pursh) Greene	*Actinea acaulis, Hymenoxys acaulis*
Townsendia	sp.		ASTERACEAE	Townsend's daisy	Hook.	
Tridens	*muticus*		POACEAE	slim tridens	(Torr.) Nash	
Vulpia	*octoflora*		POACEAE	sixweeks fescue	(Walt.) Rydb.	
Yucca	*angustissima*		AGAVACEAE	narrowleaf yucca	Engelm. ex Trel.	
Zea	*mays*		POACEAE	corn	L.	

Appendix D. Midden Ages

Table D-1. Glen Canyon National Recreation Area midden ages.

Midden name	C14 lab number	Radiocarbon date	Calendar year 1 Sigma	Calendar year 2 Sigma	Average in AD/DC (1 Sigma)	Cal yr BP (Cal years before 1950)	dC13	C14 material
Cove Canyon 3	-	Modern						
Cove Canyon 5	-	Modern						
Cove Canyon 11	-	Modern						
Cove Canyon 20	-	Modern						
Waterhole Flat 1	-	Modern						
Waterhole Flat 3	AA57199	Modern				0	-26.5	*Krascheninnikovia lanata* leaves
Waterhole Flat 10	-	Modern						
Gandolf’s Staircase 1	-	Modern						
5381 Mesa 3	-	Modern						
5381 Mesa 5	-	Modern						
Mazuki Point 1	-	Modern						
Mazuki Point 2	-	Modern						
Mazuki Point	-	Modern						
Gandolf’s Staircase 2	A-12850	220 +/- 45	1642-1947	1522-1949	1795	195	-23.7	*Neotoma* pellets
5381 Mesa 2	A-13046	250 +/- 45	1524-1946	1493-1947	1735	298	-24.2	*Neotoma* pellets
Cove Canyon 22A	A-12479	275 +/- 40	1522-1662	1488-1798	1592	362	-21.7	*Neotoma* pellets
Waterhole Flat 2A	A-12004	325 +/- 55	1494-1638	1451 -1656	1566	391	-17.9	*Neotoma* pellets
Waterhole Flat 6	A-12847	365 +/- 40	1468-1627	1446-1636	1548	417	-19.6	*Neotoma* pellets
Gandolf’s Staircase 3	A-12844	370 +/- 40	1454-1625	1444-1635	1540	426	-22.9	*Neotoma* pellets
Cove Canyon 21	A-12008	380 +/- 40	1448-1622	1440-1634	1535	438	-20.6	*Neotoma* pellets
5381 Mesa 4B	A-13047	435 +/- 40	1430-1481	1410-1622	1456	495	-24.6	*Neotoma* pellets
5381 Mesa 1	A-13045	480 +/- 40	1411-1445	1332-1481	1428	520	-25.8	*Neotoma* pellets
Waterhole Flat 4	OS-42078	490 +/- 55	1332-1465	1304-1613	1399	526	-24.6	*Krascheninnikovia lanata* leaves
Cove Canyon 1	A-11305	525 +/- 50	1329-1439	1303-1452	1384	546	-22.6	*Neotoma* pellets
Cove Canyon 4A	OS-36106	565 +/- 35	1322-1417	1303-1428	1370	597	-26.3	*Krascheninnikovia lanata* leaves
Gandolf’s Staircase 4	A-12846	955 +/- 40	1023-1156	1002-1186	1090	856	-22.8	*Neotoma* pellets
Cove Canyon 2	A-12005	995 +/- 65	983-1157	897-1208	1070	901	-21.2	*Neotoma* pellets

Appendix E. Midden Pollen

Table E-1. Pollen found at Glen Canyon National Recreation Area sub-sites, Cove Canyon (CC) 3, CC-5, CC-11, CC-20, and Waterhole Flat (WF) 1.

Pollen type	CC-3 modern	CC-5 modern	CC-11 modern	CC-20 modern	WF-1 modern
Tracers	199	204	287	263	236
Trees					
Abies	-	-	-	1	1
Betula	-	1	-	-	-
cf. *Fraxinus*	2	-	-	1	-
cf. *Juglans*	-	1	-	-	-
Picea	1	-	-	-	4
Pinus Undifferentiated	11	12	13	71	166
Pinus diploxylon	4	1	4	3	7
Pinus haploxylon, lg	1	1	2	2	-
Pinus haploxylon, sm	117	50	38	55	113
Quercus	5	1	2	3	4
Ulmus	-	-	1	-	-
Shrubs					
Ambrosia	6	7	8	5	5
Artemisia	23	11	44	23	10
Asteraceae, other	9	23	12	42	9
Cercocarpus-type	7	-	7	2	-
cf. *Coleogyne*	10	4	-	3	-
Cheno-Am	24	39	30	21	15
Ephedra trifurca-type	-	1	-	2	-
Ephedra viridis-type	4	3	6	13	7
Eriogonum	-	-	-	-	-
Fabaceae	-	1	-	1	-
Mahonia	-	-	2	-	1
Opuntia	-	9	-	2	2
Rosaceae	-	-	-	-	-
cf. *Salsola*	-	-	4	-	-
Sarcobatus vermiculatus	-	1	1	-	-
Shepherdia rotundifolia	-	2	-	3	-
Sphaeralcea	1	1	-	-	1
Sclerocactus-type	1	8	2	-	-
Yucca	-	-	-	-	-
Herbs					
Boerhavia	-	-	-	-	-
Caryophyllaceae	-	-	-	-	-
Lamiaceae	1	1	-	1	-
Onagraceae	-	-	-	-	-
cf. *Phacelia*	-	-	-	-	-
Poaceae	-	1	3	2	2
cf. *Portulacaceae*	-	-	-	-	-
Rumex	1	1	-	-	-
Other					
Deteriorated	9	8	6	9	7
Unknown	1	1	-	1	-
Sporormiella	-	4	-	-	2
Trilete spore, Sculptured	-	-	-	-	1
SUM	238	193	185	266	357
CONC. (grains per gram)	22,258	14,855	18,585	23,217	42,965

Table E-2. Pollen found at Glen Canyon National Recreation Area sub-sites, Cove Canyon (CC) 22-A, Waterhole Flat (WF) 2-A, CC-21, CC-1, CC-4A, and CC-2.

Pollen type	CC-22A 275+/- 40	WF-2A 325+/- 55	CC-21 380+/- 40	CC-1 525+/- 50	CC-4A 565+/- 35	CC-2 995+/- 65
Tracers	65	54	215	23	107	280
Trees						
Abies.	-	-	-	-	-	-
Betula	-	-	-	-	-	-
cf. *Fraxinus*	1	1	-	-	-	-
cf. *Juglans*	-	-	-	-	-	-
Picea	-	-	1	-	-	-
Pinus Undifferentiated	28	97	30	62	56	82
Pinus diploxylon	-	3	1	1	-	-
Pinus haploxylon, lg	4	-	1	5	27	1
Pinus haploxylon, sm	9	82	20	36	19	67
Quercus	3	2	1	1	-	1
Ulmus	-	-	-	-	-	-
Shrubs						
Ambrosia	17	4	4	1	4	5
Artemisia	24	10	24	7	17	24
Asteraceae, other	19	6	22	9	17	9
Cercocarpus-type	-	4	-	1	-	3
cf. *Coleogyne*	10	5	1	1	2	2
Cheno-Am	70	60	92	36	51	14
Ephedra trifurca-type	2	-	-	2	-	-
Ephedra viridis-type	11	8	6	2	1	1
Eriogonum	1	3	2	1	1	-
Fabaceae	-	-	1	1	-	-
Mahonia	-	-	-	-	-	-
Opuntia	8	46	41	-	17	10
Rosaceae	-	-	-	2	2	-
cf. *Salsola*	-	-	-	-	-	-
Sarcobatus vermiculatus	-	1	3	-	1	-
Shepherdia rotundifolia	-	-	-	-	-	-
Sphaeralcea	5	3	4	1	4	1
Sclerocactus-type	4	1	2	1	7	16
Yucca	-	-	-	-	1	1
Herbs						
Boerhavia	1	-	-	-	-	-
Caryophyllaceae	-	-	-	-	-	1
Lamiaceae	1	-	1	2	-	18
Onagraceae	-	1	-	-	-	1
cf. *Phacelia*	-	-	-	-	1	-
Poaceae	5	1	1	3	8	-
cf. *Portulacaceae*	1	-	-	-	-	-
Rumex	-	-	1	-	-	-
Other						
Deteriorated	9	4	7	5	15	10
Unknown	4	18	-	-	-	-
Sporormiella	-	-	-	-	-	-
Trilete spore, sculptured	-	-	-	-	-	-
SUM	237	360	266	180	251	267
CONC. (grains per gram)	89,733	162,989	60,584	137,761	115,376	70,294

Appendix F. Quantitative Plant Lists for Glen Canyon National Recreation Area Middens

Table F-1. Quantitative plant list for Cove Canyon sample site CC-1, with a ^{14}C age of 525 and Std. +/- 50.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		23 florets	23
Amelanchier	*utahensis*		4 twigs, 9 twig buds, 2 leaves, 5 bracts	20
Artemisia	*bigelovii*		4 leaves	4
Atriplex	*canescens*		6 leaves	6
Atriplex	*confertifolia*		49 leaves, 24 seeds, 25 twigs	82
Cercocarpus	*intricatus*		11 leaves	11
Chamaesyce	*fendleri*		2 leaves	2
Coleogyne	*ramosissima*		250 leaves, 1 seed, 150 twigs	401
Comandra	*umbellata*		1 berry	1
Juniperus	*osteosperma*		1300 twigs, 200 male cones, 170 seeds	1670
Krascheninnikovia	*lanata*		1 bud, 5 leaves	6
Lepidium	sp.		2 stems with persistent pedicels	2
Machaeranthera	*canescens*		2 involucres	2
Mahonia	*fremontii*		4 leaf pieces, 1 spine	5
Opuntia	cf. *phaecantha*		110 spines, 65 areoles, 3 seeds	178
Pinus	*edulis*		150 needles, 2 male cones, 1 seed piece	153
Pleuraphis	*jamesii*		1 spikelet	1
Townsendia	sp.		4 achenes	4

Number of Genera: 18
Other Midden Components: *Peromyscus* sp. pellets, insects, bird feather, 4 vials of unknowns

Table F-2. Quantitative plant list for Cove Canyon sample site CC-2, with a ^{14}C age of 955 and Std. +/- 65.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		6 florets	6
Amelanchier	*utahensis*		2 leaves, 1 berry	2
Artemisia	*bigelovii*		40 leaves & buds	40
Astragalus	sp.		2 leaves	2
Atriplex	*canescens*		12 leaves, 1 seed	13
Atriplex	*confertifolia*		6 twigs, 10 leaves, 4 seeds	20
Chamaesyce	*fendleri*		5 leaves	5
Coleogyne	*ramosissima*		60 twigs, 200 leaves, 4 seed coats, 7 involucres	271
Ephedra	*viridis/ cutleri*		2 seed coats	2
Fraxinus	*anomala*		3 leaf pieces	3
Hesperostipa	*comata*	ssp. *comata*	2 awn pieces	2
Juniperus	*osteosperma*		210 twigs, 4 berries	214
Krascheninnikovia	*lanata*		35 leaves	35
Lappula	*occidentalis*		1 seed	1
Mahonia	*fremontii*		1 leaf	1
Opuntia	cf. *erinacea*		100 spines & areoles, 14 seeds	114
Physaria	sp.		1 leaf	1

Table F-2. Quantitative plant list for Cove Canyon sample site CC-2, with a ^{14}C age of 955 and Std. +/- 65.—Continued

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Pinus	*edulis*		30 needles, 2 seed coat pieces	32
Sclerocactus	sp.		2 spines, 1 seed	3
Sporobolus	*contractus*		10 rachillas	10
Yucca	*angustissima*		2 leaf tips	2

Number of Genera: 21
Other Midden Components: insects, bones, feather, hair, 2 vials of unknowns

Table F-3. Quantitative plant list for Cove Canyon sample site CC-3, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		28 florets	28
Artemisia	*bigelovii*		52 flowers, 110 leaves, 50 twigs	212
Atriplex	*confertifolia*		11 seeds, 25 leaves, 6 twigs	45
Chaenactis	*stevioides*		1 achene	1
Chamaesyce	*fendleri*		3 leaves	3
Coleogyne	*ramosissima*		7 seeds, 160 leaves, 5 involucres, 250 twigs	422
Ephedra	*viridis/ cutleri*		7 seed coats, 27 twigs	34
Fraxinus	*anomala*		2 seeds, 1 leaf	3
Gutierrezia	*sarothrae*		120 involucres, 30 twigs, 50 leaves, 20 achenes	220
Isocoma	*acradenia*	var. *acradenia*	3 achenes	3
Juniperus	*osteosperma*		1 male cone, 1800 twigs, 39 seeds	1840
Lepidium	sp.		3 stems with persistent pedicels	3
Machaeranthera	*canescens*	var. *leucanthemifolia*	1 inflorescence, 8 leaves, 4 stems	13
Mahonia	*fremontii*		1 leaf	1
Opuntia	cf. *erinacea*		2 seeds, 1 pad piece, 14 spines,	17
Pinus	*edulis*		15 new growth twigs, 4 immature cone scales, 4 cones, 1850 needles, 19 seed coats	1892
Symphoricarpos	*longiflorus*		3 seeds	1
Yucca	*angustissima*		11 leaves	11

Number of Genera: 18
Other Midden Components: insects, bones, 1 vial of unknowns

Table F-4. Quantitative plant list for Cove Canyon sample site CC-4A, with a ^{14}C age of 565 and a Std. +/- 35.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		3 florets	3
Artemisia	*bigelovii*		4 leaves	4
Astragalus	sp.		7 seeds, 2 leaves	9
Atriplex	*canescens*		56 leaves	56
Atriplex	*confertifolia*		27 leaves, 20 stems	47
Coleogyne	*ramosissima*		29 twigs, 70 leaves, 2 flower parts & sepals	101
Ephedra	*viridis/ cutleri*		4 twigs	4
Gutierrezia	*microcephala*		5 involucres	5
Gutierrezia	*sarothrae*		6 involucres, 15 leaves	21

Table F-4. Quantitative plant list for Cove Canyon sample site CC-4A, with a ^{14}C age of 565 and a Std. +/- 35.—Continued

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Juniperus	*osteosperma*		18 sticks,150 twigs, 23 seeds	191
Krascheninnikovia	*lanata*		37 leaves, 3 twigs	40
Machaeranthera	*grindelioides*		6 leaves, 1 twig, 1 involucre, 1 achene	9
Mahonia	*fremontii*		1 leaf, 2 twigs	3
Opuntia	cf. *phaecantha*		17 seeds, 150 spines, 80 areoles, 7 pads	254
Pinus	*edulis*		3 needles, 1 male cone, 1 female cone piece, 1 seed piece	6
Sclerocactus	sp.		1 seed	1
Sphaeralcea	*coccinea*		3 seed & case, receptacle	3
Symphoricarpos	*longiflorus*		1 seed coat	1
Tetraneuris	*acaulis*	var. *acaulis*	5 leaf bases	4
Yucca	*angustissima*		3 leaf tips	3

Number of Genera: 20
Other Midden Components: insects, bones, 1 vial of unknowns

Table F-5. Quantitative plant list for Cove Canyon sample site CC-5, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		5 florets	5
Artemisia	*ludoviciana*		2 leaves	2
Atriplex	*canescens*		160 leaves, 17 seeds, 100 twigs	277
Bromus	*tectorum*		4 florets	4
Chrysothamnus	*greenei*		3 achenes	3
Coleogyne	*ramosissima*		80 leaves, 12 seeds, 100 twigs	192
Ephedra	*viridis/ cutleri*		10 twigs, 5 seed coats, 4 fruit involucres, 9 flwr. involucres	28
Gutierrezia	*sarothrae*		30 involucres	30
Juniperus	*osteosperma*		60 big twigs, 700 twigs, 40 seeds (blue and naked)	800
Lappula	*occidentalis*		1 seed	1
Lepidium	*montanum*		35 siliques and membranes	35
Mahonia	*fremontii*		35 leaves	35
Opuntia	cf. *erinacea*		10 pads, 170 spines & areoles, 40 seeds	220
Pinus	*edulis*		1 seed, 1 emergent twig	2
Salsola	*tragus*		1 involucre	1
Tetraneuris	*acaulis*	var. *acaulis*	2 stem bases	2
Yucca	*angustissima*		20 leaves, 7 seeds, 4 capsule pieces	33

Number of Genera: 17
Other Midden Components: insects, bones, reptile bones, rabbit pellets, 4 vials of unknowns

Table F-6. Quantitative plant list for Cove Canyon sample site CC-11, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		2 florets	2
Achnatherum	*speciosum*		I root piece	1
Amelanchier	*utahensis*		1 leaf	1
Artemisia	*tridentata*		5 leaves, 4 twigs	9
Atriplex	*canescens*		1 leaf	1
Atriplex	*confertifolia*		50 leaves & seeds, 30 twigs	80
Bromus	*tectorum*		1 spikelet	1
Coleogyne	*ramosissima*		1 seed, 1 twig	2
Ephedra	*viridis/ cutleri*		40 twigs, 7 seed coats, 3 sepals	50
Ericameria	*nauseosa*	var. *nauseosa*	1 achene	1
Gutierrezia	*sarothrae*		2 involucres	2
Juniperus	*osteosperma*		40 seeds, 7 chewed seeds, 1 berry, 11 male cones, 400 twigs, and 20 sticks	479
Krascheninnikovia	*lanata*		1 leaf, 1 bud, 1 twig	3
Mahonia	*fremontii*		12 leaves, 2 twigs, 1 berry	15
Opuntia	cf. *erinacea*		1 spine, 1 areole	2
Phacelia	*howelliana*		1 seed	1
Pinus	*edulis*		5 needles	5
Purshia	*mexicana*		6 leaves, 8 twigs	14
Symphoricarpos	*longiflorus*		5 twigs	5
Zea	*mays*		1 cob	1

Number of Genera: 20
Other Midden Components: insects, 2 vials of unknowns

Table F-7. Quantitative plant list for Cove Canyon sample site CC-20, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		10 florets	10
Ambrosia	*acanthicarpa*		1 involucre	1
Astragalus	*sabulonum*		4 legume pieces	4
Atriplex	*canescens*		4 seeds, 20 leaves	24
Bromus	*tectorum*		4 florets	4
Ephedra	*viridis/ cutleri*		15 twigs, 2 male cones, 20 seed coats, 6 involucres	43
Gutierrezia	*sarothrae*		1 involucre	1
Juniperus	*osteosperma*		400 twigs, 30 naked seeds, 24 blue berries, 2 male cones	456
Mahonia	*fremontii*		1 leaf	1
Opuntia	cf. *erinacea*		4 spines, 4 seeds	8
Sphaeralcea	*ambigua*		4 seed coats	4

Number of Genera: 11
Other Midden Components: insects, bones, Neotoma skull, rabbit pellets, 1 vial of unknowns

Table F-8. Quantitative plant list for Cove Canyon sample site CC-21, with a ^{14}C age of 380 and a Std. +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		25 leaves	25
Achnatherum	*hymenoides*		3 florets	3
Atriplex	*canescens*		12 seeds, 9 twigs, 70 leaves	91
Chamaesyce	*fendleri*		3 seed heads	3
Coleogyne	*ramosissima*		35 leaves, 1 seed	36
Echinocereus	sp.		3 spines	3
Ephedra	*viridis/ cutleri*		45 twigs, 2 seed coats	47
Juniperus	*osteosperma*		250 needles, 3 seeds	253
Lepidium	*lasiocarpum*		12 seed coats	12
Mahonia	*fremontii*		1 leaf	1
Opuntia	cf. *erinacea*		70 spines, 11 seed pieces	81
Pinus	*edulis*		1 seed coat piece	1
Plantago	*patagonica*		1 seed, 1 petiole	2
Sphaeralcea	*parvifolia*		25 leaves & seeds	25
Sporobolus	*cryptandrus*		1 rachilla	1
Yucca	*angustissima*		10 leaf tips, 2 seed pieces	12

Number of Genera: 16
Other Midden Components: insects, feather, rabbit pellet, 4 vials of unknowns

Table F-9. Quantitative plant list for Cove Canyon sample site CC-22A, with a ^{14}C age of 275 and a Std. +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		4 seeds, 1 leaf	5
Achnatherum	*hymenoides*		40 florets	40
Artemisia	*bigelovii*		4 leaves	4
Artemisia	*tridentata*		15 leaf pieces	15
Astragalus	*sabulonum*		30 pods, 100 seeds	130
Atriplex	*canescens*		2 twigs, 18 seeds, 230 leaves	250
Coleogyne	*ramosissima*		25 leaves	25
Corispermum	*villosum*		15 seeds	15
Cryptantha	sp.		6 leaves	6
Elymus	*elymoides*		1 floret	1
Ephedra	*viridis/ cutleri*		45 twigs, 35 seed cases, 3 involucres	83
Hesperostipa	*comata*	ssp. *comata*	3 florets, 1 stem	4
Juniperus	*osteosperma*		200 twigs, 6 seeds	206
Lepidium	*lasiocarpum*		10 seed cases	10
Opuntia	cf. *erinacea*		50 spines, 5 seed pieces	55
Panicum	sp.		1 floret	1
Phoradendron	*juniperinum*		6 involucres	6
Pinus	*edulis*		2 needle pieces	1
Plantago	*patagonica*		30 seeds & cases	30
Pleuraphis	*jamesii*		4 florets	4
Sphaeralcea	*parvifolia*		20 leaves, 35 seeds & cases	55
Sporobolus	*cryptandrus*		2 rachillas	2
Vulpia	*octoflora*		9 lemmas	9
Yucca	*angustissima*		3 leaves	3

Number of Genera: 25
Other Midden Components: *Peromyscus* sp. pellets, insects, bones, 4 vials of unknowns

Table F-10. Quantitative plant list for Waterhole Flat sample site WF-1, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		2 florets	2
Atriplex	*canescens*		5 leaves, 10 twigs	15
Coleogyne	*ramosissima*		5 twigs, 1 leaf	6
Ephedra	*viridis/ cutleri*		52 stems, 4 seed coats	56
Juniperus	*osteosperma*		210 needles, 28 seeds, 9 chewed seeds, 11 blue seeds, 50 male cones	308
Lepidium	sp.		1 twig	1
Mahonia	*fremontii*		20 leaves, 2 twigs	22
Opuntia	cf. *erinacea*		3 pads, 25 spines, 3 seeds	31
Pinus	*edulis*		230 needles, 9 twigs, 4 seeds, 8 emergent needles, 3 cone scales, and 3 cones	257

Number of Genera: 9
Other Midden Components: insects, rabbit pellets, 2 vials of unknowns

Table F-11. Quantitative plant list for Waterhole Flat sample site WF-2A, with a ^{14}C age of 325 and a Std. of +/-55.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		7 florets	7
Atriplex	*canescens*		40 leaves, 8 twigs	48
Chenopodium	*leptophyllum*		1 seed	1
Coleogyne	*ramosissima*		1 seed, 50 leaves, 12 twigs	63
Ephedra	*viridis/ cutleri*		2 seeds, 4 seed coats, 1 twig	7
Gutierrezia	*sarothrae*		6 leaves, 2 twigs, 10 involucres	18
Juniperus	*osteosperma*		70 needles, 2 male cones	72
Krascheninnikovia	*lanata*		12 leaves, 1 twig	13
Opuntia	cf. *erinacea*		40 spines, 40 seeds	80
Pinus	*edulis*		90 needles, 4 seed coats, 1 cone scale	95
Pleuraphis	*jamesii*		1 root	1
Sphaeralcea	*coccinea*		1 leaf	1

Number of Genera: 12
Other Midden Components: insects, bones, 3 vials of unknowns

Table F-12. Quantitative plant list for Waterhole Flat sample site WF-3, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Atriplex	*canescens*		25 leaves, 8 twigs, 1 fruit	34
Ephedra	*viridis/ cutleri*		1 twig	1
Juniperus	*osteosperma*		30 needles, 5 seeds, 4 male cones	39
Krascheninnikovia	*lanata*		7 leaves	7
Mahonia	*fremontii*		2 leaves, 3 twigs	5
Opuntia	cf. *erinacea*		80 spines, 32 seeds, 1 leaf	113
Pinus	*edulis*		5 needles, 2 twigs	7
Sphaeralcea	*parvifolia*		3 leaves	3

Number of Genera: 8
Other Midden Components: *Peromyscus* sp. pellets, insects, 1 vial of unknowns

Table F-13. Quantitative plant list for Waterhole Flat sample site WF-4, with a ^{14}C age of 490 and a Std. of +/-55.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Atriplex	*canescens*		60 leaves, 22 twigs	82
Coleogyne	*ramosissima*		24 leaves; 5 twigs	29
Ephedra	*viridis/ cutleri*		3 twigs	3
Juniperus	*osteosperma*		100 needles, 11 seeds, 12 male cones, 4 immature female cones	127
Krascheninnikovia	*lanata*		14 leaves	14
Opuntia	cf. *erinacea*		300 spines, 15 seeds, 20 pad pieces, 4 leaves	339
Pinus	*edulis*		5 needles; 1 seed coat piece; 1 cone scale	7
Sporobolus	*contractus*		2 rachillas, 10 roots	12
Symphoricarpos	*longiflorus*		1 seed	1
Vulpia	*octoflora*		2 lemmas	2

Number of Genera: 10
Other Midden Components: *Peromyscus* sp. pellets, insects, bones, 6 vials of unknowns

Table F-14. Quantitative plant list for Waterhole Flat sample site WF-6, with a ^{14}C age of 365 and a Std. of +/- 40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Artemisia	*bigelovii*		10 leaves	10
Atriplex	*canescens*		15 twigs, 1 seed, 50 leaves	66
Coleogyne	*ramosissima*		20 leaves, 10 twigs	30
Juniperus	*osteosperma*		80 needles, 4 seeds, 10 male cones	94
Krascheninnikovia	*lanata*		8 leaves	8
Lepidium	*montanum*		3 silicles	3
Mahonia	*fremontii*		20 leaves, 10 twigs, 20 petioles	50
Opuntia	cf. *erinacea*		200 spines, 90 seeds, 40 pad pieces, 12 leaves	342
Pinus	*edulis*		5 needles, 2 seed coat pieces	7
Vulpia	*octoflora*		4 lemmas	4

Number of Genera: 10
Other Midden Components: *Peromyscus* sp. pellets, insects, bones, 3 vials of unknowns

Table F-15. Quantitative plant list for Waterhole Flat sample site WF-10, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		20 florets, 6 roots	26
Artemisia	*bigelovii*		1 leaf	1
Artemisia	*ludoviciana*		1 leaf	1
Atriplex	*canescens*		100 leaves, 5 seeds, 50 twigs	155
Bromus	*tectorum*		5 lemmas	5
Coleogyne	*ramosissima*		200 twigs, 25 leaves, 1 involucre, 3 seed coat pieces	229
Elymus	*elymoides*		1 rachilla, 1 floret	2
Ephedra	*torreyana*		1 twig	1
Ephedra	*viridis/ cutleri*		40 seed coats, 25 twigs, 3 involucres, 1 seed	69
Gutierrezia	*microcephala*		35 involucres, 10 twigs, 8 leaves	53
Hesperostipa	*comata*	ssp. *comata*	1 floret, 2 awn pieces	3

Table F-15. Quantitative plant list for Waterhole Flat sample site WF-10, with a ^{14}C age of modern.—Continued

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Juniperus	*osteosperma*		200 needles, 35 twigs, 8 male cones, 25 seeds	268
Krascheninnikovia	*lanata*		20 leaves	20
Lappula	*occidentalis*		2 seeds	2
Lepidium	*montanum*		6 siliques, 4 pedicels	10
Machaeranthera	*canescens*		10 leaves	10
Mahonia	*fremontii*		35 leaves, 10 twigs	45
Opuntia	cf. *erinacea*		200 spines, 35 seeds, 4 leaves, 15 pad pieces	254
Pinus	*edulis*		1 cone, 5 cone scales, 22 seed pieces, 60 needles, 5 twigs, 1 male cone	94
Sclerocactus	sp.		12 spines	12
Sphaeralcea	*parvifolia*		3 seed coats, 8 leaves	11
Sporobolus	*contractus*		1 inflorescence stalk	1
Vulpia	*octoflora*		1 floret	1
Yucca	*angustissima*		2 leaves, 4 seeds	6

Number of Genera: 24
Other Midden Components: insects, bones, rabbit pellets, 3 vials of unknowns

Table F-16. Quantitative plant list for Gandolf's Staircase sample site GS-1, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		7 florets	7
Achnatherum	*speciosum*		10 florets and awns; 3 rachillas	13
Cercocarpus	*intricatus*		5 leaves	5
Coleogyne	*ramosissima*		300 twigs, 120 leaves, 6 involucres, 3 seeds	429
Echinocereus	sp.		4 spines	4
Ephedra	*viridis/ cutleri*		60 twigs, 4 seed coats	64
Ericameria	*nauseosa*	var. *nauseosa*	1 involucre, 8 achenes	9
Juniperus	*osteosperma*		300 twigs, 4 scales, 15 seeds, 7 male cones	326
Krascheninnikovia	*lanata*		6 twigs, 10 leaves	16
Lappula	*occidentalis*		10 leaves, twig	10
Lepidium	*montanum*		20 seeds, 7 pedicels with membranes	27
Opuntia	cf. *phaecantha*		1 seed, 1 gloccid	2
Phacelia	*crenulata*		1 seed	1
Pinus	*edulis*		15 seed coat pieces, 43 needles, 4 female cone pieces, 6 male cone pieces	68
Sclerocactus	sp.		6 spines	2
Shepherdia	*rotundifolia*		12 leaves	12
Stanleya	*pinnata*		2 siliques	2
Vulpia	*octoflora*		4 florets	4

Number of Genera: 18
Other Midden Components: insects, bones, rabbit pellet, 5 vials of unknowns

Table F-17. Quantitative plant list for Gandolf's Staircase sample site GS-2, with a ^{14}C age of 220 and a Std. of +/-45.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		40 florets	40
Achnatherum	*speciosum*		3 florets, 4 awns	7
Cercocarpus	*intricatus*		2 leaves	2
Chaetopappa	*ericoides*		1 achene	1
Coleogyne	*ramosissima*		300 leaves, 500 twigs, 20 seed coats, 20 involucres	840
Echinocereus	sp.		1 seed, 10 spines, 10 fleshy pieces	21
Elymus	*elymoides*		30 florets & awns	30
Ephedra	*viridis/ cutleri*		250 twigs, 20 seed coats	270
Ericameria	*nauseosa*	var. *nauseosa*	2 achenes	2
Erioneuron	*pilosum*		1 spikelet	1
Gutierrezia	*microcephala*		6 achenes, 2 involucres	8
Gutierrezia	*sarothrae*		60 involucres & twigs, 25 leaves, 5 achenes	90
Helianthus	sp.		1 achene	1
Hesperostipa	*comata*	ssp. *comata*	2 florets, 2 awns	4
Juniperus	*osteosperma*		500 twigs, 15 seeds, 40 male cones, 10 weird twigs	565
Krascheninnikovia lanata			50 leaves & twigs	50
Lappula	*occidentalis*		5 seeds, 25 leaves	30
Lepidium	*montanum*		50 silicles and seeds, 20 twigs, 30 leaves	100
Machaeranthera	*canescens*		1 involucre	1
Opuntia	cf. *phaecantha*		20 spines	20
Phacelia	*crenulata*		10 seeds, 20 involucre pieces	30
Pinus	*edulis*		200 needles, 100 seed coat pieces, 2 female cone parts	302
Rhus	*trilobata*		15 seed pieces	15
Shepherdia	*rotundifolia*		30 leaves & twigs	30
Sporobolus	*cryptandrus*		2 rachillas	2
Stanleya	*pinnata*		30 siliques, 25 twigs	55
Symphoricarpos	*longiflorus*		2 stems, 1 seed	3
Yucca	*angustissima*		2 leaves	2

Number of Genera: 28
Other Midden Components: insects, interesting bones, 6 vials of unknowns

Table F-18. Quantitative plant list for Gandolf's Staircase sample site GS-3, with a ^{14}C age of 370 and a Std. of +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		4 florets	4
Artemisia	*bigelovii*		3 leaves	3
Artemisia	*ludoviciana*		1 leaf	1
Bromus	*tectorum*		2 spikelets	2
Coleogyne	*ramosissima*		100 leaves, 60 twigs, 5 involucres, 2 seeds	167
Echinocereus	sp.		10 spines, 1 skin piece	11
Elymus	*elymoides*		2 florets	2
Ephedra	*viridis/ cutleri*		200 twigs, 10 seeds coats	210
Ericameria	*nauseosa*	var. *nauseosa*	1 involucre	1
Erioneuron	*pilosum*		1 lemma	1
Gutierrezia	*microcephala*		2 involucres, 7 leaves	9
Gutierrezia	*sarothrae*		5 leaves, 3 flowers, 1 involucre	9
Juniperus	*osteosperma*		600 twigs, 25 seeds, 18 male cones	643
Krascheninnikovia	*lanata*		1 twig	1
Lappula	*occidentalis*		2 seeds	2
Lithospermum	*incisum*		1 seed	1

Table F-18. Quantitative plant list for Gandolf's Staircase sample site GS-3, with a ^{14}C age of 370 and a Std. of +/-40.—Continued

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Opuntia	cf. *phaecantha*		40 spines, 7 leaves	47
Pinus	*edulis*		800 needles, 15 seed coats, 10 male cones, 6 "weird" needles, 12 emergent needles, 25 "little cone things"	868
Poa	*secunda*		1 lemma	1
Sclerocactus	sp.		8 spines	8
Shepherdia	*rotundifolia*		1 leaf	1
Tetraneuris	*acaulis*	var. *acaulis*	4 leaf bases	4
Yucca	*angustissima*		30 leaves	30

Number of Genera: 23
Other Midden Components: insects, 2 vials of unknowns

Table F-19. Quantitative plant list for Gandolf's Staircase sample site GS-4, with a ^{14}C age of 955 and a Std. of +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		12 florets	12
Artemisia	*bigelovii*		3 leaves	3
Astragalus	sp.		2 seeds	2
Cercocarpus	*intricatus*		2 leaves	2
Coleogyne	*ramosissima*		35 twigs, 90 leaves, 2 seeds	127
Echinocereus	sp.		25 spines, 1 skin piece	26
Ephedra	*viridis/ cutleri*		75 twigs, 40 seed coats, 10 involucres	125
Ericameria	*nauseosa*	var. *nauseosa*	2 achenes	2
Gutierrezia	*sarothrae*		20 leaves/sticks/involucres	20
Juniperus	*osteosperma*		450 twigs, 32 seeds, 40 male cones, 2 female seeds	524
Krascheninnikovia	*lanata*		4 leaves	4
Lappula	*occidentalis*		1 seed, 20 leaves	21
Opuntia	cf. *phaecantha*		45 spines, 1 leaf, 3 seeds	49
Phacelia	*crenulata*		1 seed	1
Pinus	*edulis*		51 needles, 40 seed coat pieces, 7 emergent needles, 2 "weird" needles, 1 male cone	101
Rhus	*trilobata*		1 berry	1
Shepherdia	*rotundifolia*		1 leaf	1
Tetraneuris	*acaulis*	var. *acaulis*	10 leaf bases	10
Townsendia	sp.		1 achene	1
Yucca	*angustissima*		5 seeds, 20 leaves	25

Number of Genera: 20
Other Midden Components: insects, bones, 3 vials of unknowns

Table F-20. Quantitative plant list for 5381 Mesa sample site 5M-1, with a ^{14}C age of 480 and a Std. of +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		1 leaf	1
Achnatherum	*hymenoides*		30 florets	30
Achnatherum	*speciosum*		150 roots, 40 stems	190
Amsonia	*tomentosa*	var. *stenophylla*	5 seed pieces, 1 leaf piece	6
Artemisia	*bigelovii*		2 leaves, 35 twigs	37
Astragalus	*amphioxys*		2 leaves	2
Bromus	*tectorum*		1 floret	1
Coleogyne	*ramosissima*		120 leaves, 130 twigs, 3 seed coats, 2 involucre parts	255
Cryptantha	cf. *confertiflora*		2 leaves	2
Ephedra	*viridis/ cutleri*		50 twigs	50
Ericameria	*nauseosa*	var. *juncea*	40 involucres	40
Eriogonum	*corymbosum*		1 twig, 4 leaves	5
Eriogonum	*wetherillii*		2 twigs	2
Gutierrezia	*microcephala*		20 involucres, 12 twigs	32
Juniperus	*osteosperma*		20 twigs, 1 seed piece	21
Opuntia	*erinacea*		1 spine cluster	1
Psorothamnus	*thompsoniae*		35 twigs, 1 leaf	36
Rhus	*trilobata*		5 seeds, 8 leaf pieces	13

Number of Genera: 19
Other Midden Components: *Peromyscus* sp. pellets, insect & bones (in one vial), 6 vials of unknowns

Table F-21. Quantitative plant list for 5381 Mesa sample site 5M-2, with a ^{14}C age of 250 and a Std. of +/-45.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		4 leaf pieces	4
Achnatherum	*hymenoides*		50 florets, 20 roots	70
Amsonia	*tomentosa*	var. *stenophylla*	8 seed pieces, 2 pod pieces	10
Arabis	*perennans*		60 seeds, 20 siliques	80
Astragalus	*amphioxys*		10 pods, 25 seeds	35
Astragalus	*desperatus*		50 leaves	50
Bromus	*tectorum*		2 paleas	2
Coleogyne	*ramosissima*		50 twigs, 250 leaves, 15 seed pieces	315
Ephedra	*viridis/ cutleri*		30 twigs, 1 seed coat	31
Eremocrinum	*albomarginatu*		1 bulb scale	1
Ericameria	*nauseosa*	var. *juncea*	8 involucres	8
Eriogonum	*corymbosum*		1 leaf	1
Gutierrezia	*microcephala*		20 involucres	20
Hesperostipa	*comata*	ssp. *comata*	1 floret	1
Juniperus	*osteosperma*		30 needles, 2 male cones	32
Opuntia	*erinacea*		7 spines, 1 seed	8
Phacelia	*crenulata*		2 seeds	2
Psoralidium	*junceum*		70 involucres	70
Psorothamnus	*thompsoniae*		10 twigs, 30 leaves	40
Rhus	*trilobata*		15 seed pieces	15
Shepherdia	*rotundifolia*		3 leaf pieces	3
Sphaeralcea	*parvifolia*		20 leaves, 5 seeds	25

Number of Genera: 22
Other Midden Components: insects, bones, 8 vials of unknowns

Table F-22. Quantitative plant list for 5381 Mesa sample site 5M-3, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*speciosum*		20 roots	20
Amsonia	*tomentosa*	var. *stenophylla*	6 seed pieces, 40 leaf pieces	46
Arabis	*perennans*		1 silique	1
Artemisia	*bigelovii*		2 leaves	2
Astragalus	*amphioxys*		3 pod pieces, 10 leaves, 5 involucres	18
Bromus	*rubens*		2 panicles & glumes, 20 florets	22
Bromus	*tectorum*		20 panicles & glumes, 20 florets, 1 rachilla	40
Calochortus	*flexuosus*		1 capsule	1
Coleogyne	*ramosissima*		700 twigs, 50 leaves, 30 involucres, 2 seeds	782
Cryptantha	cf. *confertiflora*		3 leaves	3
Dasyochloa	*pulchella*		40 florets	40
Ephedra	*torreyana*		25 twigs	25
Ephedra	*viridis/ cutleri*		45 twigs	45
Eremocrinum	*albomarginatu*		20 bulb scales	20
Ericameria	*nauseosa*	var. *juncea*	15 involucres, 7 achenes	15
Eriogonum	*corymbosum*		9 leaves, 15 twigs, 10 involucres, 5 bracts	39
Juniperus	*osteosperma*		30 needles	30
Machaeranthera	*canescens*		1 twig & leaf	1
Psoralidium	*junceum*		6 involucres	6
Psorothamnus	*thompsoniae*		50 twigs, 25 leaves and involucres	75
Rhus	*trilobata*		3 leaves	3
Shepherdia	*rotundifolia*		25 leaves, 1 twig	26
Sphaeralcea	*parvifolia*		12 seed coats	12
Sporobolus	*contractus*		1 rachilla	1
Yucca	*angustissima*		3 pods, 30 seeds, 1 leaf	34

Number of Genera: 25
Other Midden Components: insects, 1 vial of unknowns

Table F-23. Quantitative plant list for 5381 Mesa sample site 5M-4B, with a ^{14}C age of 435 and a Std. of +/-40.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		1 seed	1
Achnatherum	*hymenoides*		10 florets	10
Achnatherum	*speciosum*		1 awn, 20 leaves	21
Astragalus	*amphioxys*		24 seeds	24
Astragalus	*desperatus*		12 pod pieces, 1 seed	13
Coleogyne	*ramosissima*		400 twigs, 200 leaves, 25 seeds, 1 involucre	626
Dasyochloa	*pulchella*		15 glumes, 40 florets	55
Ephedra	*torreyana*		120 twigs	120
Ephedra	*viridis/ cutleri*		20 twigs	20
Ericameria	*nauseosa*	var. *juncea*	40 involucres, 25 achenes	65
Grayia	*spinosa*		10 leaves	10
Gutierrezia	*microcephala*		50 involucres	50
Opuntia	*erinacea*		150 spines, 7 seeds	157
Phacelia	sp.		1 involucre	1
Pleuraphis	*jamesii*		40 roots, 2 spikelets	42
Poa	*fendleriana*		20 pairs of glumes	20
Psorothamnus	*thompsoniae*		130 twigs, 4 leaves, 1 involucre	134
Rhus	*trilobata*		1 seed	1
Sclerocactus	sp.		1 seed	1
Shepherdia	*rotundifolia*		3 leaves	3

Table F-23. Quantitative plant list for 5381 Mesa sample site 5M-4B, with a ^{14}C age of 435 and a Std. of +/-40.—Continued

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Sphaeralcea	*parvifolia*		10 seed coats	10
Vulpia	*octoflora*		1 floret	1
Yucca	*angustissima*		15 leaves	15

Number of Genera: 23
Other Midden Components: *Peromyscus* sp. pellets, insects, bones, 6 vials of unknowns

Table F-24. Quantitative plant list for 5381 Mesa sample site 5M-5, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		5 florets	5
Arabis	*perennans*		1 silique	1
Astragalus	*amphioxys*		30 leaves, 40 pod pieces	70
Atriplex	*canescens*		3 seeds, 25 leaves	28
Bromus	*tectorum*		12 florets	12
Coleogyne	*ramosissima*		1000 twigs, 50 leaves, 4 seeds, 30 involucres	1084
Ephedra	*torreyana*		60 twigs	60
Ephedra	*viridis/ cutleri*		60 twigs	60
Ericameria	*nauseosa*	var. *juncea*	12 involucres, 3 achenes	15
Eriogonum	*corymbosum*		1 leaf	1
Opuntia	*erinacea*		40 spines	40
Pleuraphis	*jamesii*		30 roots	30
Psorothamnus	*thompsoniae*		200 twigs, 15 leaves, 3 involucres	218
Sphaeralcea	*parvifolia*		16 seed coats, 8 leaves	24
Sporobolus	*contractus*		1 rachilla	1

Number of Genera: 15
Other Midden Components: *Peromyscus* sp. pellets, insects, carnivore scat, 2 vials of unknowns

Table F-24. Quantitative plant list for Mazuki Point sample site MP-1, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		6 florets, 3 roots	9
Achnatherum	*speciosum*		1 stem, 1 floret & awn	2
Amelanchier	*utahensis*		20 leaves, 4 stems	24
Aristida	*purpurea*		1 pair of glumes	1
Artemisia	*bigelovii*		25 leaves	25
Artemisia	*ludoviciana*		25 leaves	25
Astragalus	*amphioxys*		20 pod pieces, 10 leaves, 15 seeds	45
Astragalus	*desperatus*		5 pods	5
Astragalus	*newberryi*		1 pod piece, 1 seed, 30 leaves	32
Atriplex	*canescens*		15 leaves, 3 seeds, 28 twigs	46
Bromus	*tectorum*		12 florets, 2 sets of glumes	14
Chaenactis	*stevioides*		1 achene	1
Coleogyne	*ramosissima*		700 twigs, 300 leaves, 20 involucres, 50 seed coat pieces	1170

Ephedra	*torreyana*		1 twig	1
Ephedra	*viridis/ cutleri*		10 twigs, 6 seed coats	16
Ericameria	*nauseosa*	var. *juncea*	1 achene	1
Erodium	*cicutarium*		1 seed & beak, 2 beaks	3
Fraxinus	*anomala*		18 leaves, I samara	19
Lepidium	*montanum*		5 siliques	5
Opuntia	*erinacea*		200 spines, 70 seeds, 1 fruit	271
Purshia	*mexicana*		100 leaves, 2 twigs, 10 involucres, 60 seeds	172
Rhus	*trilobata*		1 seed, 2 seed piece`	3
Shepherdia	*rotundifolia*		1 leaf, 1 twig	2
Yucca	*angustissima*		1 seed piece, 10 leaves, 1 pod piece	12

Number of Genera: 24
Other Midden Components: insects, 2 vials of unknowns

Table F-25. Quantitative plant list for Mazuki Point sample site MP-2, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Abronia	*fragrans*		1 seed	1
Achnatherum	*hymenoides*		1 floret	1
Achnatherum	*speciosum*		1 awn	1
Allium	*macropetalum*		30 bulb sheaths	30
Artemisia	*bigelovii*		1 leaf	1
Artemisia	*ludoviciana*		10 leaves	10
Astragalus	*amphioxys*		3 pod pieces, 1 leaf	4
Atriplex	*canescens*		22 twigs, 35 leaves, 3 fruits	60
Bromus	*rubens*		10 florets & caryopses	10
Bromus	*tectorum*		80 florets & caryopses, 6 glumes	86
Coleogyne	*ramosissima*		25 twigs, 20 leaves, 12 seed coat pieces, 4 involucres	61
Ephedra	*viridis/ cutleri*		30 twigs, 2 seed coats, 1 involucre	33
Erodium	*cicutarium*		3 beaks	3
Lepidium	*montanum*		1inflorescence stalk	1
Machaeranthera	*canescens*		5 leaves	5
Opuntia	*erinacea*		100 pad pieces, 200 spines, 80 seeds	380
Plantago	*patagonica*		2 seeds	2
Pleuraphis	*jamesii*		2 roots	2
Poa	*secunda*		2 lemmas, 1 rachilla	3
Purshia	*mexicana*		20 leaves, 2 seeds	22
Rumex	sp.		1 leaf	1
Sphaeralcea	*parvifolia*		1 leaf, 3 twigs	4
Vulpia	*octoflora*		1 floret, 1 pair of glumes, 1 spikelet	3
Yucca	*angustissima*		8 seed pieces, 10 leaves	18

Number of Genera: 24
Other Midden Components: *Peromyscus* sp. pellets, insects, shell, 5 vials of unknowns

Table F-26. Quantitative plant list for Mazuki Point sample site MP-3, with a ^{14}C age of modern.

Genus	Species	Variety or subspecies	Fossil Types	Total Number of Fossils
Achnatherum	*hymenoides*		1 floret	1
Achnatherum	*speciosum*		1 awn, 45 root pieces	46
Amelanchier	*utahensis*		2 twigs	2
Artemisia	*bigelovii*		30 leaves	30
Astragalus	*amphioxys*		5 pod pieces, 25 leaves, 1 seed	31
Astragalus	*desperatus*		1 seed	1
Atriplex	*canescens*		35 twigs, 150 leaves, 3 seeds	188
Bromus	*tectorum*		125 florets	12
Cirsium	*neomexicanum*		4 phyllaries, 2 phyllary spines	6
Coleogyne	*ramosissima*		350 twigs, 200 leaves, 20 involucres, 200 seed coat pieces	770
Ephedra	*viridis/ cutleri*		300 twigs, 1 seed	301
Ericameria	*nauseosa*	var. *juncea*	2 achenes	2
Eriogonum	*corymbosum*		4 flowers	4
Lepidium	*montanum*		1 pedicel	1
Opuntia	*erinacea*		150 spines 12 pad pieces, 6 seeds	167
Plantago	*patagonica*		1 seed, 1 seed case, 3 flowers, 3 inflorescence stalks	8
Pleuraphis	*jamesii*		1 rachilla	1
Purshia	*mexicana*		50 leaves, 6 involucres	56
Sphaeralcea	*parvifolia*		12 leaves, 2 seedcases	14
Tetraneuris	*acaulis*	var. *acaulis*	1 stem base	1
Yucca	*angustissima*		10 leaves, 4 seed pieces	14

Number of Genera: 21
Other Midden Components: *Peromyscus* sp. pellets, insects, bone, 2 vials of unknowns

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