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Holocene vegetation and historic grazing impacts at Capitol Reef National Park reconstructed using packrat middens

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HOLOCENE VEGETATION AND HISTORIC GRAZING IMPACTS AT CAPITOL REEF NATIONAL PARK RECONSTRUCTED USING PACKRAT MIDDENS

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ABSTRACT.—Mid- to late-Holocene vegetation change from a remote high-desert site was reconstructed using plant macrofossils and pollen from 9 packrat middens ranging from 0 to 5400 yr in age. Presettlement middens consistently contained abundant macrofossils of plant species palatable to large herbivores that are now absent or reduced, such as winterfat (*Ceratoides lanata*) and ricegrass (*Stipa hymenoides*). Macrofossils and pollen of pinyon pine (*Pinus edulis*), sagebrush (*Artemisia* spp.), and roundleaf buffaloberry (*Shepherdia rotundifolia*) were also recently reduced to their lowest levels for the 5400-yr record. Conversely, species typical of overgrazed range, such as snakeweed (*Gutierrezia sarothrae*), viscid rabbitbrush (*Chrysothamnus visidiflorus*), and Russian thistle (*Salsola* sp.), were not recorded prior to the historic introduction of grazing animals. Pollen of Utah juniper (*Juniperus osteosperma*) also increased during the last 200 yr. These records demonstrate that the most severe vegetation changes of the last 5400 yr occurred during the past 200 yr. The nature and timing of these changes suggest that they were primarily caused by 19th-century open-land sheep and cattle ranching. The reduction of pinyon and sagebrush concurrent with other grazing impacts suggests that effects of cattle grazing at modern stocking levels may be a poor analog for the effects of intense sheep grazing during drought.

Key words: Holocene vegetation history, grazing impacts, packrat middens, fossil pollen, presettlement vegetation.

STUDY AREA

This purpose of this study was to produce a Holocene vegetation history of Capitol Reef National Park, reconstructing past changes in vegetation and relating those changes to their most probable causes. Packrat midden chronologies were developed from several sites (Cole 1992), but only the most complete series from a single site, collected from the Hartnet Draw site, is reported here. Seven fossil and 2 modern middens were collected from Hartnet Draw in northern Capitol Reef National Park (38°15′N, 111°20′W; Fig. 1). This site, at 1920 m elevation in Wayne County, Utah, was chosen because of its remote location, free from most anthropogenic disturbances other than grazing, and the abundant fossil packrat middens.

The site is underlain by the Salt Creek Member of the Morrison Formation, which forms many overhangs protecting the fossil packrat middens (Fig. 2A). Today, the most abundant plant species are Utah juniper (*Juniperus osteosperma*), Bigelow sagebrush (*Artemisia biglovii*), big sagebrush (*A. tridentata*), snakeweed (*Gutierrezia sarothrae*), Torrey ephedra (*Ephedra torreyana*), viscid rabbitbrush (*Chrysothamnus visidiflorus*), and central pricklypear (*Opuntia polyacantha*; Table 1). Low areas with thicker soil support a sparse growth of grasses: ricegrass (*Stipa hymenoides*), sand dropseed (*Sporobolus cryptandrus*), and blue grama (*Bouteloua gracilis*). Plant taxonomy follows Welsh et al. (1987).

Mean annual precipitation at the site is close to the 18 cm yr^{-1} recorded at Fruita, 15 km to the southwest at 1670 m elevation (Heil et al. 1993). Precipitation is bi-seasonal, with winter and late summer peaks. Temperature extremes are great at this arid continental site: a mean January minimum temperature at Fruita of −8°C and a mean July maximum of 33°C.

GRAZING HISTORY.—Historical records mention no disturbances to this area other than the introduction of exotic herbivores during the mid-19th century. Native large herbivores that may have been present in the study area during the last 5000 yr include bighorn sheep (*Ovis canadensis*), mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), and possibly bison (*Bison bison*) and elk (*Cervus elaphus;* Van Gelder 1928, Mead et al. 1991).

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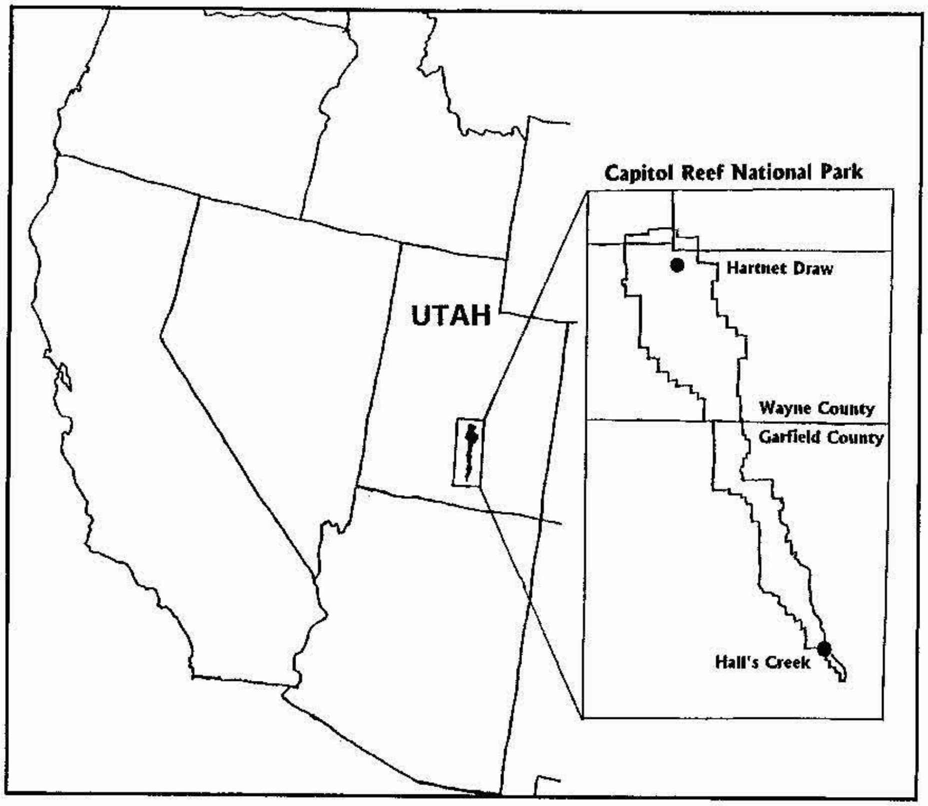

Fig. 1. Map showing site location.

Native North American equids (horses and asses) became extinct before 10,000 yr B.P. (Mead and Meltzer 1984). Eurasian horses and asses (*Equus* spp.) were introduced to New Mexico by Spanish colonists as early as A.D. 1598 (Underhill 1971). By the late 1600s feral horses were reported in parts of the West, but it is not likely that they existed in the study area prior to the 1800s.

In the late 1800s introduced herbivore populations increased dramatically in southern Utah with the widespread increase in open-land grazing. Livestock grazing within and near Capitol Reef National Park has been documented since at least the 1870s (Frye 1995). The earliest detailed herbivore population estimates from the Capitol Reef area are from summer grazing permits issued for Powell (now part of Dixie) National Forest (Frye 1995). In 1909 the Forest Service issued permits for 67,000 sheep and 11,000 cattle. The animals grazing these high summer pastures presumably spent the winter in the lower adjacent areas of Capitol Reef National Park.

A Bureau of Land Management survey described past use at the Hartnet Draw site:

> Prior to the passage of the Taylor Grazing act in 1934, large numbers of livestock were brought from Wayne, Sevier, and Emery Counties to winter on these lands. Many of the animals remained on the range yearlong, resulting in the progressive destruction of soils and vegetation. Reports from stockmen in the area indicate that many trespass horses used the area until about 1955. Prior to 1946 there were at least 163 cattle and 20 horses yearlong in this area (Hartnet Allotment File, 1966).

Currently, the area is grazed under an allotment issued by Capitol Reef National Park.

RECONSTRUCTING PAST VEGETATION.—Fossil packrat middens are valuable sources of paleoecological information in arid regions of the southwestern United States (Betancourt et al. 1990, Cole 1990). Plant fossils in packrat middens, often identifiable to the species level, grew close to the midden, most likely within 50 m. Because plant identification and location can be precisely known, this method has extremely high spatial and taxonomic resolution compared to other methods of reconstructing past vegetation.

Studies comparing trees and shrubs at midden sites with plant specimens from modern middens typically report similarities exceeding

Fig. 2. A, Photograph of Hartnet Draw study site showing shelter where middens #'s 1–4 were collected. B, Reconstructed image of study site with presettlement vegetation as visualized from fossil data.

TABLE 1. Plant macrofossil concentrations from Hartnet Draw middens in $\log_{10}$ concentration/kg of washed matrix. Modern percent cover classes are estimated from a relevé of 30-m radius. Coverage classes: 3 = >3% cover, 2 = 1–3% cover, 1 = <1% cover, R = rare (located outside of relevé).

	Midden #	#3	#2	#8	#1a	#7b	#9	#5	#6
	Midden age (yr B.P.)	0	330	630	1020	1275	2570	3615	5450
	Modern relevé (Cover class)	$\log_{10}$ concentration/kg of washed matrix							
TREES, SHRUBS, AND SUCCULENTS									
Artemisia (sec. tridentatae)	3	0.9	1.8		2.8	2.8	1.8	1.3	2.0
Atriplex spp.	2	2.8	3.3	3.0	4.3	3.1	3.2	2.8	4.1
Brickellia scabra	2	1.3							
Chrysothamnus sp.	2	1.6							
Cowania mexicana	2	2.0	1.9	1.9	2.6	3.1	2.5	2.9	1.2
Ephedra spp.	2	1.7	0.5			3.1	1.3		2.3
Ceratoides lanata			2.0	1.7	3.6	2.4	2.5	2.3	3.0
Gutierrezia sarothrae	3	2.0	1.3						
Heterotheca sp.	1	0.9							1.8
Hymenopappus	1	1.9							
Juniperus osteosperma	3	3.4	3.9	3.8	4.3	4.3	4.3	4.0	4.1
Machaeranthera grindeliodes	1	0.4							
Opuntia polyacantha	2	3.1	3.7	3.1	4.3	4.2	3.5	3.9	3.9
Pediocactus/Echinocereus	1		1.1		1.4		2.1	2.4	2.1
Pinus edulis	R		2.0	2.8	4.7	2.6	4.1	3.0	2.0
Salsola sp.	1	1.3							
Sarcobatus sp.	R	1.0							
Shepherdia rotundifolia	1			2.5		1.8			3.0
Yucca angustissima	R	1.0						1.9	
HERBS AND GRASSES									
cf. *Amaranthus* sp.		2.3				1.7	1.9	1.6	1.6
Astragalus mollissimus	1	0.9							
Aristida purpurea	2								
Bouteloua gracilis	3		1.7		1.4	2.2			
Chryptantha spp.	3	0.8	0.5			1.3			1.2
Descurania pinnata	3								
Eriogonum sp.		1.0				1.8			
Erioneuron pulchellum	1								
Euphorbia sp.	1		1.7						1.7
Hilaria sp.								1.3	
Hymenoxys acaulis	1								
Lappula occidentalis	1	0.4	0.9		0.8	1.8			
Lepidium densiflorum	1	1.8	0.5			1.3			2.3
Peanut shell		0.9							
Phacelia							1.3		
Plantago			0.9			1.4			
Sphaeralcea coccinea	1		1.3		1.2	2.2			2.5
Sporobolis spp.	3		0.9					1.3	
Stipa hymenoides	3		1.5	1.7	1.6	1.3	2.8	1.9	1.7
Stipa sp.							1.3		1.2
Streptanthella longirostris	1								

80% using a Sorensen's index of similarity (Cole 1985, Cole and Webb 1985, Spaulding et al. 1990, Frase and Sera 1993), especially when small macrofossils (<2 mm) are identified using a 10X microscope. Similarity with forbs and grasses has been reported to be lower (Frase and Sera 1993), but inventories of current forbs are usually incomplete due to seasonal and yearly variability in the forb flora, and identification of diverse forbs and grasses within midden assemblages is very challenging.

The quantitative correlation between species abundance and midden specimens is complex (Spaulding et al. 1990). Plant species producing abundant, readily identifiable plant parts (e.g., *Atriplex* leaves), or packrat food items (e.g., juniper), or plants having deterrence values in protecting packrats from predators (e.g., cactus spines), tend to occur in the highest numbers within middens. But perennial species that are abundant near middens are most often represented by high numbers of plant specimens, while less abundant species, or those further from middens, are represented by fewer specimens. As a result, interpreting changes from midden assemblages requires experience with macrofossil types (leaves, twigs, flowers, seeds) and abundances typically found for that species. This element of judgment is present in any retrospective study. For example, fossil pollen magnifies the presence of wind-pollinated plants while insect-pollinated species may not be represented at all. Phytolith studies detect only those species producing identifiable opal phytoliths. Historical writings record only those species of interest to the writers. Repeat photography is useful only for those species identifiable in photographs. Midden records can be viewed as representing something similar to a plant relevé (Mueller-Dombois and Ellenberg 1974) from the past. This relevé contains a detailed species list, but also more complex information on past species abundance comparable to coverage classes.

Fossil pollen within middens can also be analyzed (King and Van Devender 1977, Thompson 1985, Davis and Anderson 1988), emphasizing different types of vegetation and representing a larger source area than the plant macrofossils. Interpretation of fossil pollen abundances, like macrofossil abundances, requires caution and experience, as some species are better represented than others. By considering both macrofossil and pollen records, we can achieve a more comprehensive understanding of past environments.

MATERIALS AND METHODS

We collected 7 of the 8 middens within a radius of about 200 m from a small shelter (Fig. 2). The 8th was found 1 km east of the shelter. Using a hammer and chisel, we separated approximately 1 kg of each midden from larger masses and returned the samples to the laboratory. Samples were then dissected, producing horizontally stratified subsamples typically measuring about 15 × 20 cm and several centimeters thick. Weathering rinds and large rocks were removed from each subsample, yielding 300–600 g of hardened midden material. This sample was then weighed and disaggregated in water. Two unconsolidated middens (Hartnet Draw #'s 3 and 4) were considered modern because of the presence of green leafy material, cow feces, and a peanut shell.

Pollen samples were taken from the wash water after several days of soaking, and the pollen was separated using standard methods (Faegri and Iversen 1975). Macrofossils of 1 modern midden, Hartnet Draw #4, could not be analyzed because the midden had been burned, charring much of the plant debris. The pollen content of this midden, however, was not destroyed by the fire. Packrat debris piles are often burned in rangeland shelters, most likely to eliminate the rats that occupy a pleasant shelter.

After sieving vegetable debris, fecal pellets, and rocks from the dissolved middens with a 1-mm sieve, we mixed, dried, and weighed the resulting matrix, producing 100–200 g of washed midden matrix. The dried matrix was sorted by hand under a 10X dissecting microscope. Packrat fecal pellets and rocks were removed and weighed. Identifiable plant macrofossils, vertebrate bones, and insect fossils were identified, counted, labeled, and stored in plastic vials.

Six to 13 g of packrat fecal pellets were submitted to radiocarbon laboratories for dating. Hartnet Draw #5 was dated at 3615 ± 70 yr B.P. using a single *Pinus* needle after the initial pellet sample yielded an impossible result of 142% modern carbon. Some type of sample contamination with artificial carbon isotopes or sample mislabeling is suspected, as it is impossible to contaminate an old sample with enough modern natural carbon isotopes to yield such a high number. Calendar year ranges for radiocarbon ages were calculated using Stuiver and Reimer's (1993) calibration program.

Data on midden contents were quantified by number, weight, percent of identified specimens, and $\log_{10}$ of macrofossil concentration in midden matrix. To compensate for variability between middens, we adjusted midden matrix weights by subtracting the weight of rocks and pellets from the dried washed matrix weight before calculating the concentration as suggested in Betancourt (1990). Using $\log_{10}$ of macrofossil concentration calculates a number similar to the semi-quantitative abundance scale used by several other authors, but it has the advantage of being quantitative.

TABLE 2. Ages of middens based on radiocarbon dates. Radiocarbon ages are calibrated to calendar years based on Stuiver and Reimer (1993). %MC = percent modern carbon (sample postdates atmospheric testing of nuclear weapons).

Sample name	Radiocarbon date	$\delta^{13}C$	Lab ID No.	Calendar year range (at one sigma)	Material dated
Hartnet Draw #4	Modern debris pile (not dated)				
Hartnet Draw #3	137 ± 1.2 %MC	−22.2	A-5197	AD 1960–1986	*Neotoma* pellets
Hartnet Draw #2	330 ± 60	−21.8	A-5204	AD 1495–1643	*Neotoma* pellets
Hartnet Draw #8	630 ± 100	−21.2	GX-16259	AD 1280–1410	*Neotoma* pellets
Hartnet Draw #1a	1020 ± 70	−21.7	A-5203	AD 898–1152	*Neotoma* pellets
Hartnet Draw #7b	1275 ±110	−20.8	GX-15554	AD 640–890	*Neotoma* pellets
Hartnet Draw #9	2570 ±135	−21.8	GX-15553	889–434 BC	*Neotoma* pellets
Hartnet Draw #5	3615 ± 70		AA-6447	2128–1889 BC	*Pinus edulis* needle
Hartnet Draw #6	5450 ± 90	−21.8	A-5205	4363–4235 BC	*Neotoma* pellets

We used the program CONISS (Grimm 1987) on the plant macrofossil and pollen results to conduct a stratigraphically constrained cluster analysis using a square root transformation and Edwards and Cavalli-Sforza's chord distance as a dissimilarity coefficient. The square root transformation makes the skewed distributions of abundant species more closely conform to normal distributions. Plant taxa occurring in only a single midden sample were deleted from the analysis to eliminate false positive correlations due to shared absences. These deletions cause any differences between the modern and fossil middens to be understated.

RESULTS

MIDDEN AGE.—The 9 middens ranged in age from modern to 5450 yr B.P. (Table 2). Hartnet Draw #3 contained 137% modern carbon ("modern" is defined as A.D. 1950) and thus postdates atmospheric testing of nuclear weapons. Seven middens dated to presettlement times.

PLANT MACROFOSSILS.—All of the middens contain abundant macrofossils of Utah juniper (*Juniperus osteosperma*), saltbush (*Atriplex* spp.), cliff rose (*Cowania mexicana*), and prickly pear (*Opuntia* sp.), which are all plentiful at the site today (Table 1, Fig. 3). The presettlement middens also contain pinyon pine (*Pinus edulis*), winterfat (*Ceratoides lanata*), sagebrush (*Artemisia* sp.), and ricegrass (*Stipa hymenoides*), which are rare or absent from the single modern midden analyzed for macrofossils (Hartnet #3). Winterfat was not observed during the fieldwork, and pinyon pine was rare in the area. The rarity or absence of sagebrush and ricegrass from the modern midden suggests that they are less common now than prior to settlement. Similarly, globe mallow (*Sphaeralcea* sp.), needlegrass (*Stipa* sp.), blue grama (*Bouteloua gracilis*), dropseed (*Sporabolis cryptandrus*), and roundleaf buffaloberry (*Shepherdia rotundifolia*) are common in presettlement middens but absent from the 1 modern midden.

In contrast, Hartnet #3, the modern midden, is the only midden containing viscid rabbitbrush (*Chrysothamnus visidiflorus*), greasewood (*Sarcobatus vermiculatus*), and Russian thistle (*Salsola* sp.) macrofossils. Only the 2 most recent middens (#3 and #2) contain snakeweed (*Gutierrezia sarothrae*). Rabbitbrush, snakeweed, and Russian thistle are frequent at the site today. The absence of these species from presettlement middens indicates that these species were formerly absent, or so infrequent as to not be represented.

The cluster analysis (right side, Fig. 3) demonstrates the difference between the modern macrofossil assemblage and other assemblages. It is the primary branch in the dendrogram even though the single occurrences of rabbitbrush, greasewood, and Russian thistle in the modern midden were disregarded in the analysis.

POLLEN SAMPLES.—Results of the pollen analysis (Fig. 4) are similar to those from plant macrofossils. Presettlement middens contained much more pine and sagebrush pollen than the 2 modern samples (#3 and #4). Similarly, percentages of grass and buffaloberry pollen were generally higher in presettlement middens. In contrast, only the 2 modern middens contained pollen of the exotic Russian thistle and high amounts of juniper pollen. Like the macrofossil cluster analysis, the pollen cluster analysis (right side of Fig. 4) showed that modern samples are very different from all presettlement middens.

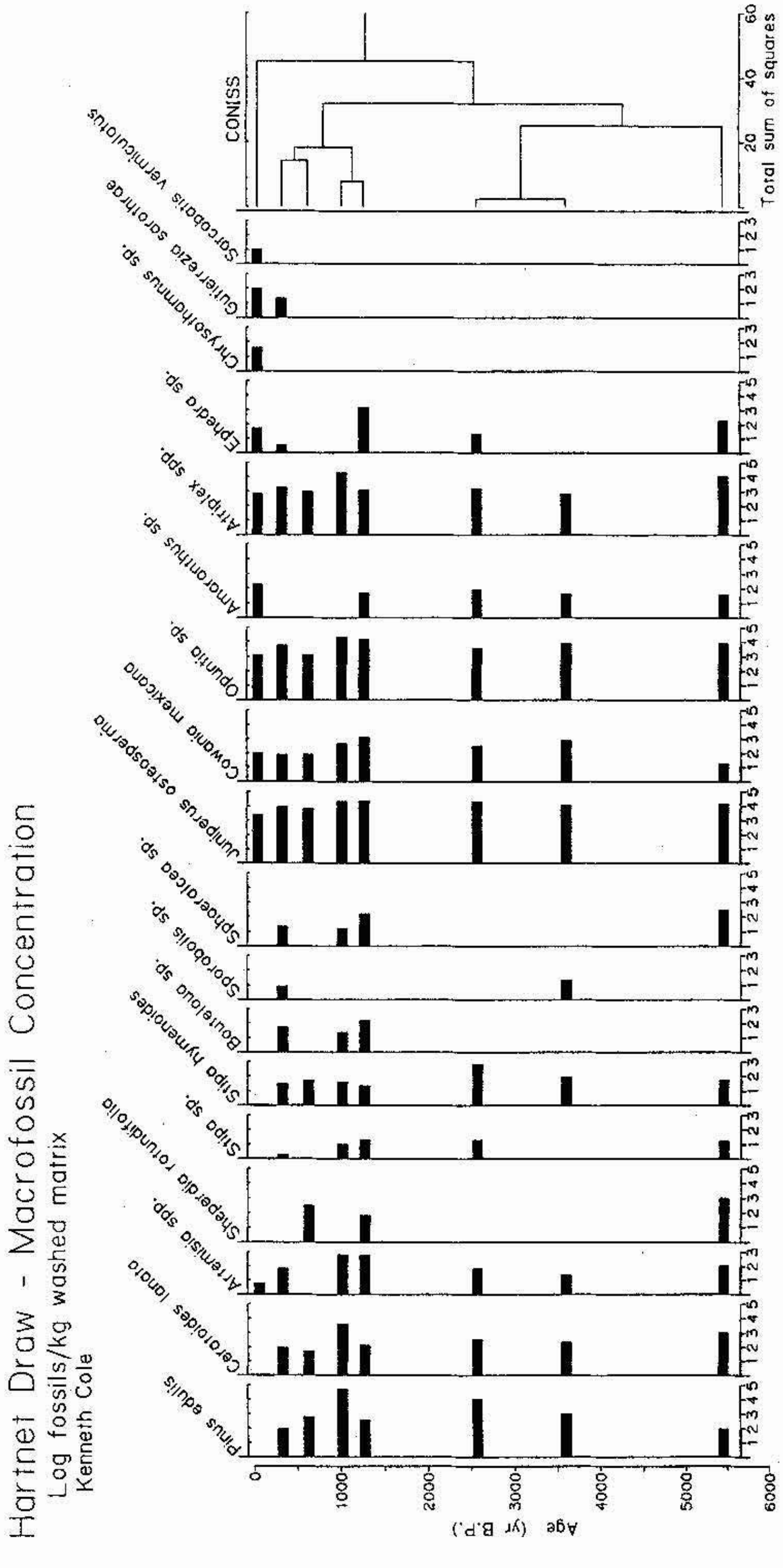

Fig. 3. Plant macrofossils from Hartnet Draw packrat middens.

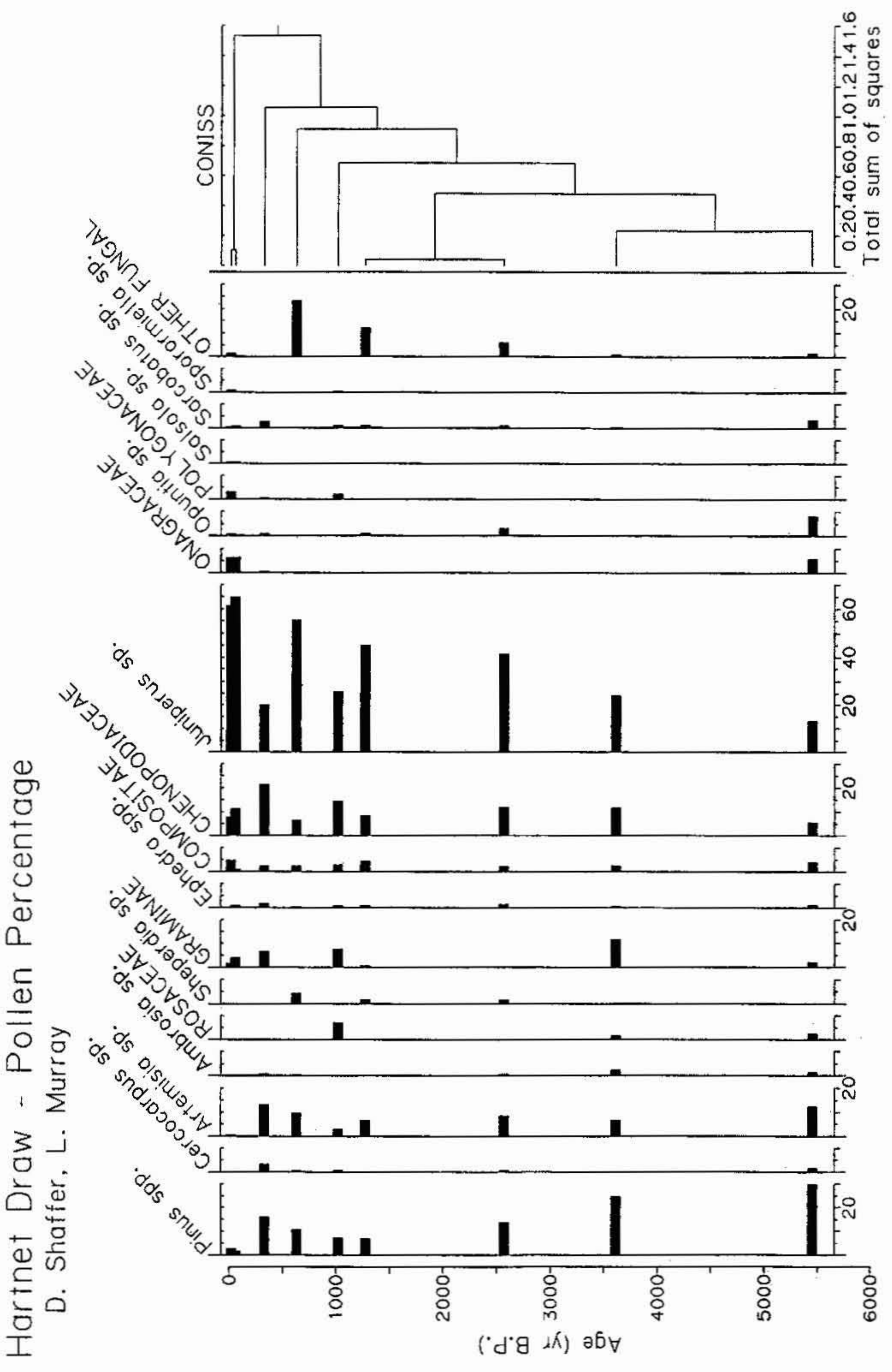

Fig. 4. Fossil pollen from Hartnet Draw packrat middens.

DISCUSSION

Figure 2 shows the site as it is now and a reconstructed image of how it may have looked prior to settlement. The reconstructed image shows greater coverage of grasses, winterfat, sagebrush, and pinyon inferred from the macrofossils and pollen found in the packrat middens. Although vegetation probably fluctuated continuously throughout the late Holocene, this midden record suggests that previous changes were minor compared to those of the last 200 yr. Sites similar in appearance to the reconstructed image are now present on ungrazed terraces that are inaccessible to large herbivores along Halls Creek, 90 km to the south (Heil et al. 1993). The presettlement plant community was undoubtedly more like the pinyon-juniper-grass community described by Heil et al. (1993) than the juniper-shrub community present at the site today.

It is clear from macrofossil and pollen analyses, reinforced by the 2 cluster analyses (Figs. 3, 4), that the modern midden plant contents are dramatically different from the presettlement middens. Furthermore, the presettlement middens are more similar to each other than to either of the modern middens. This suggests that the magnitude of change in vegetation during the last 200 yr was far greater than during the previous 5000 yr. Hypothetical causes of this vegetation change should account for both the timing of the change and the specific taxa that increased or decreased.

DROUGHT HISTORY.—Reductions in winterfat, pinyon pine, sagebrush, and ricegrass, and increases in juniper, rabbitbrush, and snakeweed might be attributed to droughts during the 19th or 20th centuries. However, an analysis of past drought frequency for southeastern Utah (Fig. 5) using 400 yr of tree-ring data compiled by Fritts (1991) suggests that droughts of the 19th century were not unusually severe when compared to the 17th century. Severe droughts, defined here as years with <165 mm of annual precipitation, reconstructed for Moab, Utah, occurred 9 times in the 17th century, 4 times in the 18th century, and 7 times in the 19th century. The 5 driest years, reconstructed from the tree-ring record, were A.D. 1667 (132 mm), 1684 (142 mm), 1668 (143 mm), 1879 (147 mm), and 1861 (150 mm). Exceptionally dry successive years were 1624–1626, 1666–1670, 1684–1685, 1728–1729, 1822–1823, 1879–1880, and 1899–1900.

Less is known about climatic variability in this region over the previous 5000 yr (prior to this tree-ring record), but it seems unlikely that any climatic event of the last 200 yr was sufficient to cause a change with no precedent during the previous 5000. Drought may have precipitated some of the dramatic vegetation changes of the last 200 yr, but it did not set the stage for them. This would require an event unprecedented during the previous 5000 yr.

FIRE HISTORY.—Some changes recorded in the middens could have been caused by changes in fire regime. The increase in juniper could have resulted from a decrease in fire frequency caused by elimination of grassy fuels by grazing. But this does little to explain the shift from palatable to nonpalatable species or the reductions of pinyon, sagebrush, and buffaloberry just at the time that fire frequency decreased. Fires of unprecedented severity could have been set during the settlement era, but this hypothesis has no data to support it. Studies of tree fire scars or sedimentary charcoal would have to be conducted to test this possibility.

GRAZING IMPACTS.—Impacts from introduced herbivores, especially large sheep herds in the late 19th and early 20th centuries, are the most likely cause of recent radical vegetation changes. The introduction of sheep, goats, cattle, and horses was without precedent during the previous 5000 yr. Overall, vegetation has shifted from palatable toward less palatable forage. Specifically, palatable grasses, winterfat, and buffaloberry decreased, while less palatable species, rabbitbrush, snakeweed, and greasewood, increased. Rabbitbrush and greasewood are poor forage, while snakeweed is typically an invader or increaser on overgrazed range (Benson and Darrow 1981, Heil et al. 1993, Cronquist et al. 1994).

Other studies conducted on grazing at Capitol Reef support this conclusion. Heil et al. (1993), in a survey of the vegetation of Capitol Reef National Park, suggest: "Some of the most preferred plant species (for grazers), e.g. *Ceratoides lanata* and *Stipa comata*, may have been locally extirpated by grazing." This packrat midden record demonstrates that, for the Hartnet Draw site, this was the case.

Additional research at Capitol Reef National Park indicates grazing has caused, and may

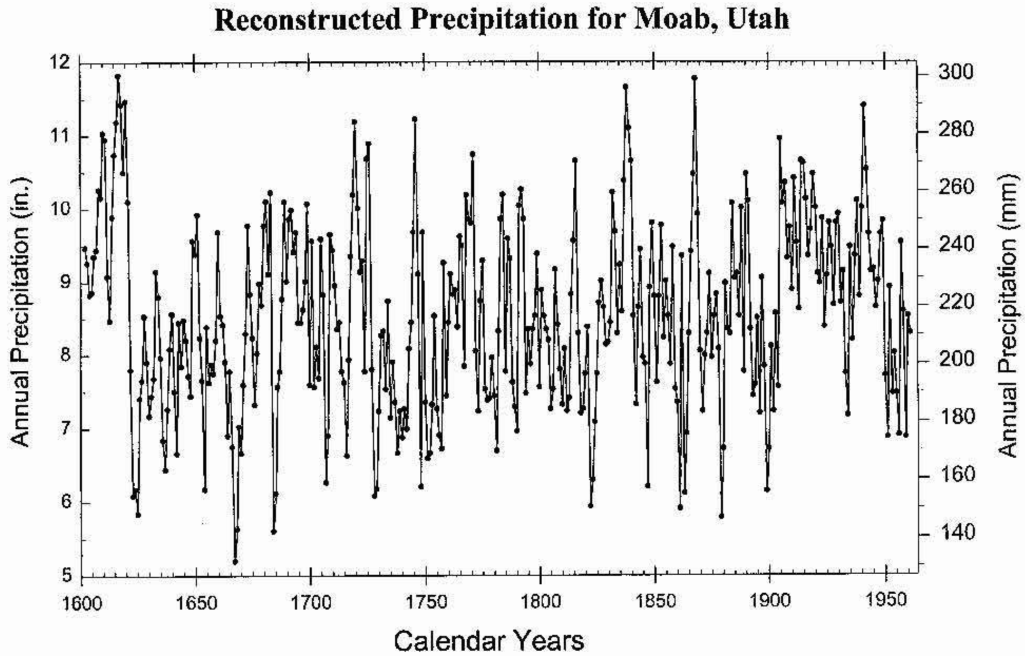

Fig. 5. Reconstruction of the last 400 yr of precipitation at Moab, Utah, from tree-ring data generated by a program distributed by Fritts (1991).

still be causing, changes to the natural habitat. Plant phytolith analysis in buried soil horizons shows a reduction of palatable grass species over the last several hundred years (Fisher et al. 1995). An analysis of riparian areas indicates that dramatic changes had occurred prior to the Taylor Grazing Act of 1934. Forage plants were heavily used, and in many instances cover was entirely removed. Recent grazing has perpetuated this removal or reduction of species and inhibited potential recovery (Barth and McCullough 1988). In a lightly grazed area palatable shrubs and grasses have increased significantly.

Dramatic declines in pinyon, sagebrush, and buffaloberry may also have been caused by the grazing history, but effects on these species are less well understood. These declines are also present in 14 additional middens from sites elsewhere in Capitol Reef National Park, such as along Hall's Creek (Murray 1989, Cole 1992).

Pinyon-juniper woodlands have reportedly increased during the historic period. This is especially evident when comparative photographic techniques are used (West et al. 1975, Tausch et al. 1981). This increase in pinyon-juniper woodlands is thought to be caused by reduced competition from grasses and forbs, which were eliminated by grazing and by consequent reductions in fire frequency. But studies discriminating between pinyon and juniper do not portray identical histories for both species. Pine and sagebrush both declined while juniper dramatically increased during the settlement period at Peck's Lake, Arizona (Davis 1987). A study of permanent plots in a presently ungrazed part of Pine Valley, Utah, demonstrated a significant decrease in juniper and significant increase in pinyon between 1933 and 1989 (Yorks et al. 1994). A study of tree-age structure on a presently ungrazed site in southwestern Utah's Needle Range found that during the 19th century many surviving juniper and few pinyon were established. By 1915 the situation had reversed, with far more surviving pinyon becoming established in this century (Tausch and West 1988). These results demonstrate that pinyon and juniper respond differently to changing regimes of grazing, fire, or climate. The observation that heavy grazing causes an expansion of pinyon-juniper woodland (West et al. 1975) does not equate with the expansion of both species in all habitats.

These results suggest that pinyon may be recovering now at some sites from a late 19th-century/early 20th-century decline caused by grazing impacts. This recovery has not yet occurred at Hartnet Draw. This hypothesis has support despite the lack of recent observations of pine removal by grazing cattle. Knowledge of the effects of cattle grazing at present stocking levels forms an inadequate basis for judging the effects of an overstocked sheep range during the droughts of the late 19th century. Although cattle will consume some pine when it is available (Pfister and Adams 1993), sheep readily consume pine needles and strip pine bark even in the absence of drought conditions (Anderson et al. 1985). Sheep accomplished the near complete elimination of the Bishop pine forest (*Pinus muricata*) on Santa Cruz Island, California, where they were not fenced out (Hobbs 1980).

Sagebrush populations may have a similar history despite observation of increases in sagebrush caused by the removal of their grass competitors (Young et al. 1978). Although sagebrush may be increasing on land presently grazed by cattle, this is not an appropriate analog for intense 19th-century sheep grazing. Sagebrush is consumed by sheep during droughts. During the late 19th century, sheep severely reduced populations of California sagebrush (*Artemisia californica*) on Santa Rosa Island, California, after first consuming the grass (Cole and Liu 1994).

MAGNITUDE OF CHANGE.—Recent vegetation changes recorded at Capitol Reef National Park are unique when compared to natural changes of the last 5000 yr. These results echo those of Davis et al. (1977), who found the vegetation change caused by domestic livestock reflected in fossil pollen at Wildcat Lake, Washington, to be greater than any other event of the last 1000 yr.

It is also possible that both climate and grazing combined to produce the dramatic vegetation shifts of the last 200 yr. There is little doubt that the most severe grazing damage occurs when high populations of herbivores compete for food during a severe drought. The droughts of 1879–1880 and 1899–1900 probably exacerbated damage caused by high herbivore populations. More severe earlier droughts, such as those during the 17th century, did not cause such changes because the large introduced herbivores were absent.

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