Chapter 2

ENVIRONMENT

Karen R. Adams and Kenneth Lee Petersen

INTRODUCTION

This chapter is organized into two major sections. The first section by Adams focuses on aspects of the modern environment that have the most relevance for foragers and agriculturalists. This begins with a description of the biotic communities present in the southwestern Colorado context area, and is followed by a discussion of the biotic communities found in each drainage-unit subdivision of the context area. Next, the geology, soils and available domestic water in the study area are described. There follows a discussion of climatic aspects particularly important for maize agriculture, such as precipitation, "corn growing degree day" units, and frost-free periods. In the final part of the first section, the drainage unit subdivisions are each evaluated in terms of the potential for both foragers and agriculturalists. The second major section of this chapter by Petersen presents a reconstruction of the paleoenvironment for southwestern Colorado.

MODERN ENVIRONMENT OF THE STUDY AREA: POTENTIAL FOR FORAGERS AND AGRICULTURALISTS

Description of Biotic Communities

Seven separate biotic communities occur in various combinations in the seven drainage units (Figure 2-1). A separate discussion of each biotic community is presented here, based on Brown (ed. 1982) and his colleagues, and arranged in order of relative position on the landscape from low to high elevations. Emphasis is placed on plants and animals that would be of interest to humans, and estimates are given of the relative amount of each biotic community in the study area as a whole. For extensive lists of plants and animals found in each biotic community, the reader is referred to Brown (ed. 1982).

Sagebrush-Saltbush (Great Basin Desertscrub)

Within this biotic community, which occupies approximately 19.6 percent of the study area, species diversity is usually low and big sagebrush (*Artemisia tridentata*) is dominant. Common taxa include other species of sagebrush (*Artemisia* spp.) and saltbush (*Atriplex*), along with rabbitbrush (*Chrysothamnus*) and winterfat (*Ceratoides*). These principal species are often much-branched aromatic shrubs with soft wood and evergreen leaves that have affinities with the most northerly of the North American deserts, the Great Basin (Turner 1982:145-155). Cholla and prickly pear (*Opuntia* spp.) cacti, along with hedgehog cacti (*Echinocereus*) are also present. If not eliminated by grazing, grasses can play an important role within this community. Mesic (wetter) areas host New Mexican privet (*Forestiera*) and greasewood (*Sarcobatus*). The sagebrush-saltbush community usually occurs between 1200 and 2200 m elevation. Succession within this community is most affected by fire and grazing, and by the introduction of weedy, aggressive annuals, largely from Eurasia (e.g., *Bromus* spp., *Salsola*, *Erodium*, *Sisymbrium*, *Hordeum*). Of interest to humans would be grasses, including ricegrass/needlegrass (*Stipa*), grama (*Bouteloua*), dropseed

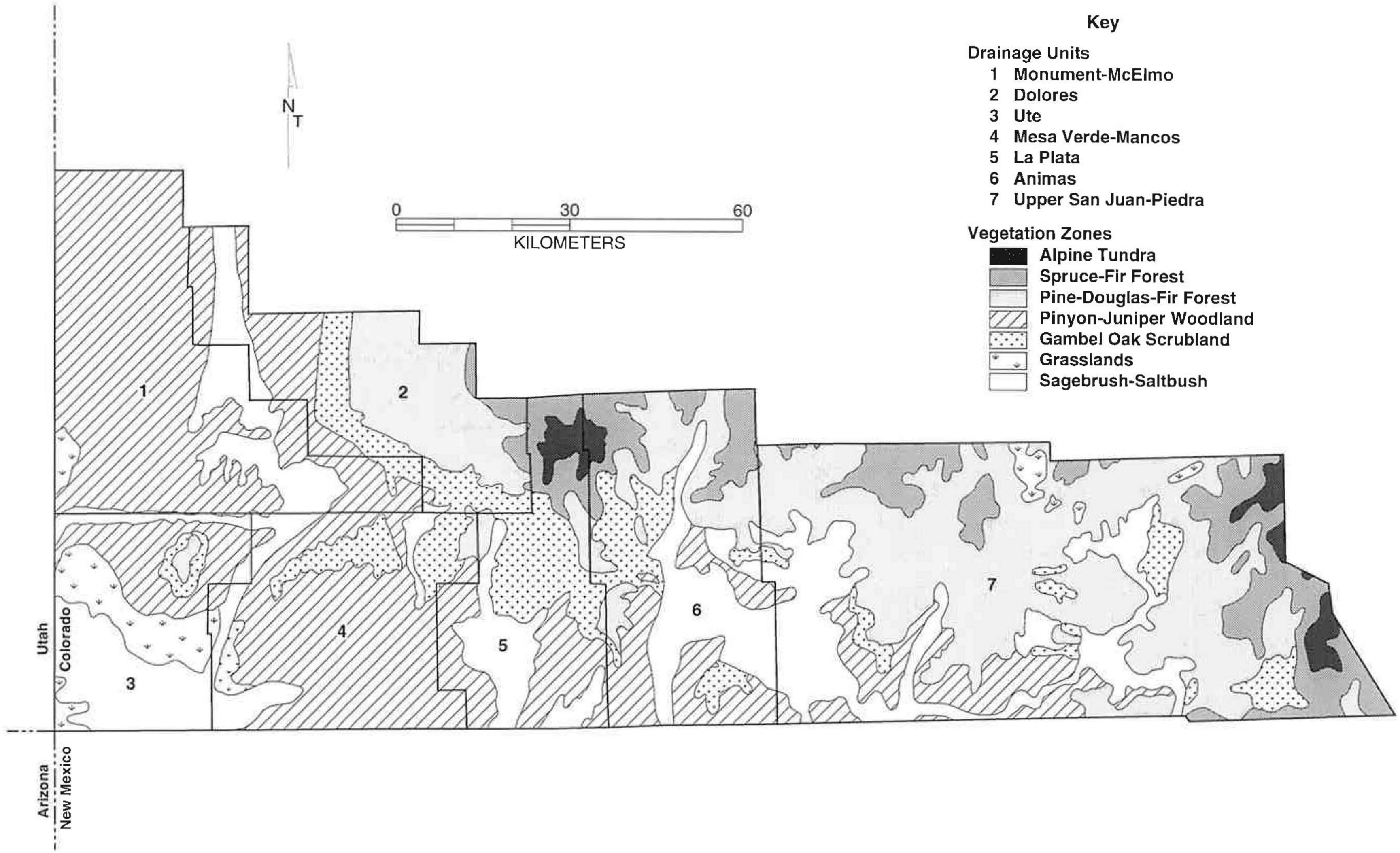

Figure 2-1. Biotic communities distributed within the seven drainage units (after Brown [ed. 1982] and Küchler [1975]). Biotic communities present in upper portions of Monument-McElmo, Dolores, La Plata and Animas drainage units have been estimated using the above references. (Reprinted with permission of Crow Canyon Archaeological Center.)

(*Sporobolus*), galleta (*Hilaria*) and fendlergrass (*Poa*). A variety of small mammals occupy this desertscrub, as do coyotes (*Canis*). Large ungulates are poorly represented, though antelope (*Antilocapra*) and (formerly) the desert bighorn (*Ovis)* likely were found here.

Grasslands (Plains and Great Basin Grasslands)

Grasslands in the American Southwest, now much-altered by historic activities, once formed nearly continuous, uninterrupted cover (Brown 1982c). They are often found on open, exposed plains susceptible to summertime lightning-set fires. Due to heavy domestic animal grazing, fire incidence has been reduced, and shrubs have encroached into this community. In the study area, both the Plains and the Great Basin grasslands intergrade, and occupy a relatively small amount (3.0 percent) of the landscape. The grasslands generally occur between 1200 and 2200 m elevation, blending into pinyon-juniper woodland, or on occasion into a *Pinus ponderosa* forest at their upper boundary. Lower elevations often grade into the Sagebrush-Saltbush community. The grasses in the study area are generally short and often perennial; some of potential value to humans in southwestern Colorado include species of grama (*Bouteloua*), ricegrass/needlegrass (*Stipa*), Junegrass (*Koeleria*), and dropseed (*Sporobolus*). Shrubs include saltbush (*Atriplex*), sagebrush (*Artemisia*), winterfat (*Ceratoides*), wild rose (*Rosa*), sumac (*Rhus*), yucca (*Yucca*), and rabbitbrush (*Chrysothamnus*). Snakeweed (*Gutierrezia*) is especially prominent on overgrazed lands. Various species of juniper (*Juniperus)* have invaded Southwestern grasslands within the past century. Species of cacti and many perennial and annual plants are also present. Animals include the antelope (*Antilocarpa*) and many smaller mammals, and a variety of birds.

Pinyon-Juniper Woodland (Great Basin Conifer Woodland)

This cold-adapted evergreen woodland, dominated by juniper (*Juniperus* spp.) and pinyon (*Pinus edulis*), occupies approximately 33.8 percent of the study area. It is often called the pygmy conifer woodland, as the trees rarely exceed 12 m in height (Brown 1982a). Structurally, these woodlands are among the simplest of Southwestern biotic communities. Habitats tend to be rocky, with thin soils. This woodland type derives from the Great Basin, is quite extensive, and can generally be found between 1500 and 2300 m in elevation. Various species of juniper *(Juniperus scopulorum, J. osteosperma, J. monosperma*) often share dominance with pinyon *(Pinus edulis)*. The pinyon tree produces a notoriously patchy and nondependable nut harvest, something humans cannot count on regularly. Even though pinyon trees cover huge areas (at times hundreds of square kilometers), nuts are generally produced sporadically across this region, and rarely are they produced in any quantity in the same area in successive years. Pinyon trees with abundant nuts are perhaps too few and too scattered to provide a staple food; however, prehistoric groups may have opportunistically harvested them when available to increase the caloric intake of the household, or to trade for other resources. In the community, some important understory grasses of interest to humans are Indian ricegrass (*Stipa hymenoides*), western wheatgrass (*Agropyron smithii*), species of dropseed grass (*Sporobolus* spp.) and Junegrass (*Koeleria*). Sagebrush (*Artemisia*), Gambel oak (*Quercus gambelii*), rabbitbrush (*Chyrsothamnus*), saltbush (*Atriplex*), skunkbush (*Rhus aromatica*), serviceberry (*Amelanchier*), mountain mahogany (*Cercocarpus*), and yuccas (*Yucca* spp.) are shrubby or low-growing members of this community of value to humans for food or material culture needs. Cacti include prickly pears (*Opuntia*) and hedgehogs (*Echinocereus*). The pinyon mouse (*Peromyscus*), capable of hoarding pinyon nuts, occupies this community, which also serves as important winter range for elk and mule deer. The pinyon-juniper woodland serves as a reasonably good hunting ground for both these larger animals.

Gambel Oak Scrubland (Great Basin Montane Scrubland)

This biotic community is often thought of as a deciduous scrubland (Brown 1982b), usually not over 6 m in height. It ranges between 2300 and 2750 m on mountainous slopes, and is especially prevalent on foothills in the Durango area. This community occupies roughly 9.9 percent of the entire study area. Aspect (facing direction) may play a role in presence of this community on a landscape, with oak scrub found on the more zeric south-facing slopes and coniferous woodland on the more mesic and cooler north-facing slopes at the same elevation. Gambel oak (*Quercus gambelii*) dominates, and one might expect acorns to provide a dependable resource for humans. The archaeological record of the region does not bear this out, perhaps in part due to the difficulty in segregating pieces of acorn nutshell from pinyon nutshells when specimens are broken and very small. However, even the durable acorn caps are rarely recovered. This community also includes mountain mahogany (*Cercocarpus*), serviceberry (*Amelanchier*), cliffrose/bitterbrush (*Purshia*), chokecherry (*Prunus*), hackberry (*Celtis*), wild rose (*Rosa*), elderberry (*Sambucus*), currant (*Ribes*), sumac (*Rhus*), and other plants of potential value for humans. This is an important vegetative type for mule deer (*Odocoileus hemionus*). Wild turkeys (*Meleagris gallopavo*) frequent this community in the fall and winter.

Pine–Douglas-Fir Forest (Rocky Mt. and Madrean Montane Conifer Forest)

Pines (*Pinus* spp.), douglas-fir (*Pseudotsuga)* and at times true firs (*Abies* spp.) dominate this forested community (Pase and Brown 1982a), which occurs in approximately 23.9 percent of the study area. Elevations range from 2000 m to as high as 3050 m. Two major subcommunities include ponderosa pine (*Pinus ponderosa*) at lower elevations, and douglas-fir (*Pseudotsuga*), fir (*Abies*), pine *(Pinus*), and aspen (*Populus tremuloides*) at higher elevations and in canyons and on north-facing slopes. In the southern Rocky Mountains, these forests are usually in contact with pinyon-juniper woodland, or grassland, at their lower elevational borders. Old growth ponderosa pine forests are often parklike, with a grassy or herbaceous understory. They are adapted to frequent, but light, understory fires. Other conifers, Gambel oak (*Quercus gambelii*), fruit-bearing shrubs (*Ribes, Rosa, Sambucus*), and a wide variety of grasses (Gramineae) and herbaceous plants are also found here. The higher elevation douglas-fir forests offer additional resources, and the aspen communities are rich wildlife habitats that provide abundant food and cover for many mammals and birds. Besides a wide variety of small mammals, the communities host mule deer (*Odocoileus hemionus*), elk (*Cervus llaphus*) and the gray wolf (*Canis lupus*), along with a long list of nesting avifauna including wild turkey (*Meleagris gallopavo*). This community is valuable for hunters.

Spruce-Fir Forest (Rocky Mt. Subalpine Conifer Forest)

In the Southern Rocky Mountains, this community is composed of a spruce (*Picea* spp.) and fir (*Abies* spp.) forest (Pase and Brown 1982b). Elevations range from 2450 to 2600 m up to timberline at 3500-3800 m, and this community occurs in approximately 8.4 percent of the study area. Aspen (*Populus tremuloides*) is a common successional species after a fire or other disturbance, attracting deer and other herbivores. Wetter areas host species of willow (*Salix*), alder (*Alnus*) and maple (*Acer*), and drier ridges support limber and bristlecone pines (*Pinus* spp.). Douglas-fir (*Pseudotsuga*), ponderosa pine (*Pinus ponderosa*), dwarf juniper *(Juniperus communis*), shrubs with edible fruits (*Sambucus, Ribes, Rubus*), and a wide variety of herbaceous plants are found in this community. Of the variety of mammals that live here, perhaps mule deer (*Odocoileus hemionus*) and elk (*Cervus llaphus*) are the most important in terms of human resources. A diversity of birds is present, but there are relatively few amphibians and reptiles because of the severity of winter temperatures.

Alpine Tundra

The very small amount of alpine tundra in the study area (roughly 1.5 percent) occurs above timberline in the La Plata and San Juan Mountains (Pase 1982:27-33). This vegetative type includes low-growing woody shrubs, herbaceous plants, mosses, and lichens, all subject to a brief growing season, severe subfreezing temperatures, physiological drought (due in part to wind), and intense insolation. In the San Juan Mountains alpine tundra usually occurs above 3500 m. Although the plant community is somewhat diverse, many plants do not occur in populations that would be of interest to humans, although some plants likely have medicinal qualities. Most mammals are medium to small sized, with the exception of bighorn sheep (*Ovis*) and other large-sized animals that pass through. Heavy historic grazing and recreational use has exerted considerable pressure on alpine tundra within this century.

Physiography and Biotic Communities of Each Drainage Unit

The physiography and biotic communities present in each drainage unit are presented below, based on a synthesis of biotic communities in the desert west (Brown ed. 1982) discussed above, on a reconstruction of potential vegetation (Küchler 1975), and on USGS topographic maps and other general maps for the region (DeLorme Mapping 1991). Relative proportions of each community within each drainage unit are estimated in Table 2-1. See also Figure 2-1.

Table 2-1. Estimated Proportions of each Biotic Community within each Drainage Unit (based on information in Brown (ed. 1982) and Küchler [1975]).

Drainage Unit No./Name	Sagebrush/ Saltbush (%)	Grass-lands (%)	Pinyon-Juniper Woodland (%)	Gambel Oak Scrub-land (%)	Pine–Douglas-Fir Forest (%)	Spruce-Fir Forest (%)	Alpine Tundra (%)
1. Monument/ McElmo	15.1	1.6	81.7	1.6	—	—	—
2. Dolores	9.5	—	24.0	19.9	41.8	4.8	—
3. Ute	43.1	23.9	27.0	4.1	1.8	—	—
4. Mesa Verde/ Mancos	13.8	3.1	68.1	13.7	1.3	—	—
5. La Plata	23.4	—	29.5	25.9	5.3	10.5	5.4
6. Animas	25.2	—	22.8	14.6	22.0	14.0	1.4
7. Upper San Juan/Piedra	17.7	1.4	10.1	4.9	48.1	15.7	2.4
Total for Entire Study Area	19.6	3.0	33.8	9.9	23.9	8.4	1.5

Monument/McElmo

Elevation in the Monument/McElmo drainage unit ranges from 2300 m in the northeast corner along the ridge of the Dolores Canyon, to just above 1525 m in the southwest corner where McElmo Canyon joins Yellowjacket Creek. Much of the area is between 1675 and 1980 m elevation, and hosts pinyon-juniper woodland and sagebrush-saltbush, with a small amount of grasslands along the western boundary adjacent to Utah (Brown ed. 1982). Many small and medium-sized canyons are present in the area. With the exception of the Dolores River Canyon that abuts into this drainage unit in the northeastern corner, drainages are ephemeral. Sand and silt transported by wind from the San Juan Basin is continually deposited in this drainage unit (Price et al. 1988), and as far east as the Durango region. Connolly (1992) surveyed local landowners for the locations of water sources independent of current irrigation canals, and documented numerous seeps and springs that are small in size and susceptible to occasional drying. A portion of this drainage unit has been farmed, historically as dry-land farming, and more recently with overhead sprinkler systems that tap into local aquifer sources via pump-operated wells. Farming is confined to the better upland soils, especially distributed along the south- and southwest-facing slopes of the tributary canyons to McElmo Creek.

Dolores

The Dolores drainage unit displays a fair amount of physiographic variability. Elevations range from 2300 m in the northwest corner above Dolores Canyon to more than 2750 m in the northeast and southeast corners. The land lowers to below 1830 m in the southwestern region of this drainage unit, where the Montezuma Valley is located. This topographic variability is reflected in environmental variability. Three biotic communities well represented in this drainage unit and distributed from east to west include pine–douglas-fir forest, Gambel oak scrubland, and pinyon-juniper woodland (Brown ed. 1982). A fourth community, sagebrush-saltbush, is present in small amounts along the western border with the Monument-McElmo drainage unit. Canyons are common in this drainage unit, with permanent water present in the Dolores and Mancos rivers.

Ute

In the southwestern corner of Colorado, the Ute drainage unit has little topographic variability, with the exception of Sleeping Ute Mountain in the northeastern corner. The bulk of the drainage unit ranges between 1525 and 1830 m, with Sleeping Ute Mountain reaching above 2835 m elevation. McElmo Creek skirts the northern drainage unit boundary, and the usually permanent Mancos River borders the southern edge. A few springs dot the landscape, but water is generally unavailable over the bulk of this drainage unit. The topographic regularity of this region is not reflected in the surprisingly diverse biotic communities that occupy this landscape. Sleeping Ute Mountain hosts Gambel oak scrubland in its lower reaches, and pine–douglas-fir forest at its top. The remainder of the drainage unit is composed of relatively equal portions of pinyon-juniper woodland to the north and east, grasslands in the middle, and sagebrush-saltbush in the southwest.

Mesa Verde/Mancos

Topography in the Mesa Verde/Mancos drainage unit ranges from the uplifted Mesa Verde reaching just above 2450 m, to the Mancos River canyon below 1550 m in the southwestern corner. The Mesa Verde is highest along a northern rim, and consists of a series of northwest/southeast- trending canyons cutting the landform into a series of fingers. The southern edge of the mesa is up to 900 m lower than the north rim at Park Point. The south-facing aspect of this higher elevation landform provides both warmer temperature and relatively more precipitation when compared to the cooler and drier lowlands below. Eolian soils have mixed with residual local sediments to form loamy soils of high quality for agriculture (Arrhenius and Bonatti 1965). The presence of springs or seeps at the heads of most major canyons provides relatively dependable, though at times perhaps relatively small, water sources. The usually flowing Mancos River traverses this drainage unit diagonally from northeast to southwest. The bulk of this drainage unit is occupied by pinyon-juniper woodland, with Gambel oak scrubland also present. Smaller amounts of sagebrush-saltbush and grasslands occur along its western boundary.

La Plata

The La Plata drainage unit includes a portion of the La Plata Mountains at elevations above 3200 m in the northern corner. However, much of this drainage unit ranges between 1830 and 2300 m. The La Plata River has headwaters in the mountains and traverses this area diagonally from northeast to southwest. Cherry Creek is also an important water source. The landscape is dissected by a number of canyons and includes the dominant landform of Red Mesa. The La Plata drainage unit has six separate biotic communities arranged across the landscape from northeast to southwest, and in relative descending order of elevation: alpine tundra (small amount), spruce-fir forest and pine–douglas-fir forest (moderate amounts), and notable portions of Gambel oak scrubland, pinyon-juniper woodland, and sagebrush-saltbush along the lower La Plata River.

Animas

The Animas drainage unit shares similarities with the adjacent La Plata drainage unit. The same biotic communities are arranged across the landscape from north to south, in relatively similar proportions as in the La Plata drainage unit. The elevational gradient starts in the north above 3200 m, and lowers to between 1830 and 2300 m for much of the region. The Animas River, with headwaters in the San Juan National Forest, drains across the area from north to south, roughly bisecting the Animas drainage unit.

Upper San Juan-Piedra

The Upper San Juan-Piedra drainage unit is the largest drainage unit in the study area. Elevations above 3200 m are found along the northern and eastern boundaries in the San Juan Mountains, and much of the drainage unit is above 2300 m. The most prevalent biotic community is the pine–douglas-fir forest, with smaller amounts of spruce-fir forest, and pinyon-juniper woodland. Sagebrush-saltbush occurs along the lower Los Pinos and Piedra River valleys, and there is a very small amount of land above timberline. The San Juan River traverses a portion of the southern boundary of the drainage unit. Creeks and springs can be found in numerous locations.

Discussion

It is clear that the individual drainage units differ appreciably from one another in terms of their physiography and biotic communities. The Monument/McElmo and Mesa Verde/Mancos drainage units are dominated by pinyon-juniper woodland. The Upper San Juan/Piedra drainage unit is primarily composed of a forest of pines and firs. The La Plata and Animas drainage units are similar to each other, with relatively equal amounts of six biotic communities within each of them. Finally, the Dolores and Ute drainage units are also diverse, with yet different arrangements of biotic communities. The Ute drainage unit is the only one with a notable amount of grasslands, though these have been heavily grazed in historic times.

Geology, Soils, and Available Domestic Water

Geology

The geology of southeastern Utah and southwestern Colorado is reported by Baker (1936), Witkind (1964) and Ekren and Houser (1965). In the study area to the east, the La Plata and San Juan mountains and their foothills are the main geological features. The Navajo section of the Colorado Plateau is prevalent in the western drainage units (Hunt 1956) where McElmo Creek and its smaller drainages dissect layered sedimentary formations of sandstones and shales that slope from southwest to northeast. The common occurrence of sandstone shelters in the region has allowed paleoecologists to utilize packrat (*Neotoma*) middens to reconstruct the late Pleistocene/Holocene vegetational history of portions of the desert west via materials contained within them (Betancourt et al. 1990). In the western portion of the study area, where Dakota Sandstone with remnants of Mancos Shale predominate, the Dakota Sandstone would have provided a supply of building stones for ancient dwellings, while the lower Morrison Formation offers a wide range of materials from coarse quartzite to chert to finer grained chalcedony for making chipped stone tools.

Force and Howell (1997) demonstrated how active the valley bottoms have been since the Pleistocene. By documenting cycles of dissection and filling along McElmo Creek, they recognized at least five separate episodes of alluviation within a 7.5 km stretch. They document entrenchment during the Pueblo I period, and aggradation through Pueblo II and III times, in some locations at a rate approaching 3 meters per 100 years (3 cm/year). They also documented the post-1880 entrenchment characteristic of the entire southern Colorado Plateau (Hereford and Webb 1992).

Soils

Soils in the westernmost drainage units are a combination of weathered sandstones and shales, and eolian materials transported by wind from the San Juan Basin (Price et al. 1988). The resulting loamy soils (Arrhenius and Bonatti 1965) can be considered relatively good for agriculture, when precipitation and growing season parameters are accommodating. The Soil Conservation Service has mapped many "soil units" in this region, and consider top-quality agricultural soils to include eolian-derived upland soils (for dry-farming pinto beans, winter wheat, and alfalfa), and alluvial soils along canyon terraces and lower flood plains (where fruit trees and small grains are grown). Their information includes estimates of potential natural plant productivity under varying climatic conditions for each soil type, plus modern crop-yield estimates for selected soils. A series of 7.5-minute digital elevation models (DEMs) are available from the National Cartographic Information Center (U.S.G.S) for the region. Summarized agricultural yield data applicable to the western drainage units are available in Burns (1983) and Van West (1994a). As one moves to the east, soils have less potential for agriculture because of reduced influx of eolian deposits, and shorter growing seasons associated with increased elevations.

Available Domestic Water

Permanent rivers are notable in some drainage units, e.g., in the Dolores, La Plata, Animas and Upper San Juan/Piedra units. However, over the rest of the region water is most often available in seeps and springs that occur at contacts between sandstone and shale layers. These water pockets occur at widely distributed canyon head settings, and were likely sufficient to satisfy prehistoric needs, at least when populations were low, although such a hypothesis should be tested with further research. Late Pueblo II and Pueblo III groups constructed reservoirs for collecting domestic water (Haase 1985; Rohn 1963; Wilshusen et al. 1997). Connolly (1992) reports on historically known springs in the Monument/McElmo drainage unit.

Wood for Fuel, Building, and Tools

Four of the seven biotic communities present in the study area (pinyon-juniper woodland, Gambel oak scrubland, pine–douglas-fir forest, spruce-fir forest) contain woody conifer and nonconifer species available for fuel use, as construction elements, and in tool making. Historic chaining and other land clearance activities have dramatically opened the pinyon-juniper woodland to agriculture and other modern uses, such that the woody appearance of this community has been much reduced. Three communities (sagebrush-saltbush, grasslands, alpine tundra) contain smaller shrubs useful in a more limited way for fuel or other needs.

Two archaeological studies of fuel wood suggest different levels of impact on the woody members of the environment during prehistoric occupation. In the Dolores River region (Dolores drainage unit), Pueblo I occupants utilized *Juniperus*, ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga*) in the period A.D. 800-850, then increased their reliance on pinyon (*Pinus edulis*) and cottonwood (*Populus*) as their use of juniper (*Juniperus*) declined from A.D. 850 to 900 (Matthews 1986; Kohler and Matthews 1988). Researchers speculate that a combination of resource depletion and changing regional population densities provided the impetus for these changing patterns of wood use. In the Sand Canyon locality (Monument/McElmo drainage unit), use of *Juniperus* and *Pinus* wood continued until the late A.D. 1200s (Adams and Bowyer 1998). Researchers there see an impacted woodland, but not one that experienced major forest reduction as occupation declined. Burned wood of a diversity of shrubs occurs often in archaeological sites of the region, representing intentionally gathered fuels (Adams 1993a; Adams and Bowyer 1998), or the discard of leftover materials from some other activity.

Construction elements are readily available in the four biotic communities (cited above) containing the woody conifer and nonconifer species. Prehistoric groups in the broad study area constructed their dwellings with beams of Douglas-fir (*Pseudotsuga*), ponderosa pine (*Pinus ponderosa*), juniper (*Juniperus*), and other pines (*Pinus* sp.) including pinyon (*Pinus edulis*). Smaller elements and roofing layers were often of nonconifer materials such as sagebrush (*Artemisia*) and mountain mahogany (*Cercocarpus*) (Adams 1993a:220). Choice of material depended in part on access and perhaps on human depletion of favored construction resources. In a study to determine the nature of construction element availability, Hovezak (1992) modeled supply versus demand for variably sized roof timbers in catchments around the late A.D. 1200s community of Sand Canyon Pueblo, and concluded that the largest category of major roof support posts would likely have been in short supply. His research did not address the issue of long-term occupation of the landscape with accompanying wood use prior to the thirteenth century, so it is possible that some of the smaller construction elements may also have become scarce by the late

1200s. Tools and other needs such as basketry elements can be acquired from stems of the shrubs of the region.

Climate

Precipitation

Trewartha (1954) described the region in the Koppen classification as a cold middle latitude, semiarid climate, in which potential atmospheric evaporation regularly exceeds the amounts of precipitation available. The area generally has a biseasonal moisture pattern, receiving snow in the winter months, and patchy summer thunderstorms during the summer period of July-September (Sellers 1960; Sellers and Hill 1974). This biseasonal pattern has apparently been in place for the period A.D. 966-1988, with the exception of the late prehistoric period from A.D. 1250 to 1450, as reconstructed from the tree-ring record (Dean 1996). The implications of a biseasonal pattern are important for dry-land agriculturalists needing winter soil moisture for planting crops and summer precipitation for maturing them.

Modern precipitation records from stations throughout southwestern Colorado have been compiled by Bradley and Barry (1973), and more recently are available on the Internet (http://www.wrcc.dri.edu/summary/climsmco.html). All appropriate weather stations within and adjacent to the study area, and for comparative purposes to the south in Arizona and New Mexico, were chosen to reflect both elevational and geographic variation within the study area. Basically, there is increased precipitation with increasing elevation (Table 2-2).

The regional precipitation records reveal that some areas are better for growing maize than others. Hack (1942:23) suggested a minimum of 12 inches of annual rainfall is needed for maize agriculture on the Colorado Plateau, and Petersen (1988:11) said at least 14 inches are required in the Mesa Verde region. Milo (1991) pointed out that annual precipitation is a poor predictor of growing season precipitation; therefore, in this document May-September precipitation has been calculated. In considering 17 locations in or near the study area (noted with an asterisk in Table 2-2), those above 2134 m (7000') elevation average 9.6 inches of precipitation during May-September, those between 1829 and 2134 m (6000 and 7000') average 6.2 inches, and those between 1524 and 1829 m (5000 and 6000') average 4.5 inches. The lone station below 1524 m (5000') receives 2.9 inches. Weather stations to the south in Arizona and New Mexico generally average less precipitation per elevation band than weather stations in the study area, yet in most cases the moisture would likely be adequate for maize (*Zea mays* L.) agriculture.

Corn (maize) Growing Degree Days

A unit known as Corn Growing Degree Days (CGDD) reflects an important aspect of temperature in the study area (Table 2-3). Corn growing degree units are computed as the difference between the daily average temperature and the base temperature (60 degrees), with one unit accumulated for each degree Fahrenheit that the average temperature is above the base temperature. Negative numbers are discarded, temperatures below 50 degrees are set to 50, and temperatures above 86 degrees are set to 86. The lower and upper limits are thresholds below and above which maize does not respond with increased growth.

Maize can be expected to mature with a minimum of 2,500 growing degree days (Siemer 1977). Petersen (1987e) notes there are a number of places in Colorado where maize has been

Table 2-2. Average Precipitation per Month (inches) for Selected Sites.

Weather Station	Elev. (m)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	May-Sept	Ann. Avg
Wolf Creek Pass	3244	3.70	3.95	5.04	3.18	2.07	1.77	3.48	4.40	4.43	4.42	4.22	4.49	16.15	45.16
Lemon Dam*	2466	2.25	2.58	2.57	1.82	1.62	1.37	2.94	4.37	3.58	2.56	3.29	2.34	13.88	31.29
Vallecito Dam*	2332	2.47	1.98	2.26	1.70	1.55	1.04	2.57	3.20	2.52	2.54	2.17	2.43	10.88	26.65
Fort Lewis*	2320	1.70	1.35	1.52	1.13	1.10	0.73	2.12	2.16	1.69	1.92	1.46	1.49	7.80	18.36
Los Alamos NM	2247	0.91	0.76	1.07	0.98	1.26	1.39	3.03	3.85	1.84	1.47	0.94	1.01	11.37	18.62
Pagosa Springs*	2177	1.97	1.42	1.60	1.36	1.22	0.96	1.85	2.54	1.87	2.24	1.39	1.78	8.44	19.98
Mesa Verde NP*	2152	1.88	1.51	1.69	1.25	1.11	0.65	1.82	2.00	1.46	1.74	1.48	1.64	7.04	18.39
Mancos*	2180	1.49	1.21	1.62	1.19	1.25	0.61	1.71	1.85	1.47	1.59	1.32	1.35	6.89	16.44
Yellow Jacket*	2088	1.18	1.27	1.33	0.92	1.26	0.58	1.46	1.72	1.61	1.87	1.50	1.31	6.63	16.01
Dulce NM	2083	1.39	1.38	1.46	1.11	1.13	0.83	2.09	2.47	1.58	1.44	1.31	1.37	8.10	17.57
Northdale*	2015	0.86	0.74	0.83	0.85	0.95	0.46	1.29	1.38	1.28	1.65	1.06	0.92	5.36	12.26
Durango*	2009	1.64	1.47	1.71	1.41	1.09	0.80	1.93	2.32	1.78	1.87	1.34	1.78	7.92	18.81
Ignacio*	1966	1.30	0.98	1.14	0.91	0.90	0.53	1.41	1.69	1.42	1.50	1.06	1.17	5.95	14.72
Zuni NM	1954	0.91	0.73	0.93	0.62	0.48	0.42	1.93	2.22	1.22	1.16	0.79	0.84	6.27	12.43
Keams Canyon AZ	1893	0.82	0.82	1.09	0.54	0.44	0.33	1.25	1.65	0.79	1.06	0.70	0.98	4.46	10.14
Cortez*	1890	1.03	1.01	1.22	0.96	0.90	0.49	1.20	1.56	1.39	1.45	0.98	1.06	5.54	13.12
Blanding UT*	1857	1.38	1.19	1.02	0.86	0.73	0.46	1.19	1.40	1.27	1.43	1.04	1.38	5.05	13.29
Bloomfield NM	1768	0.55	0.54	0.62	0.60	0.53	0.40	1.03	1.29	0.93	0.94	0.60	0.59	4.18	8.63
Navajo Dam NM*	1759	1.00	0.94	1.23	0.98	0.90	0.58	1.19	1.72	1.16	1.21	1.14	1.19	5.55	13.05
Kayenta AZ*	1732	0.46	0.47	0.55	0.38	0.39	0.28	1.18	1.40	0.75	0.87	0.44	0.48	4.00	7.81
Snowflake AZ	1720	0.74	0.69	0.80	0.54	0.51	0.47	2.06	2.54	1.44	1.05	0.72	0.77	7.02	12.35
Aztec Ruins NM*	1720	0.80	0.70	0.83	0.68	0.65	0.44	0.97	1.26	1.03	1.04	0.70	0.82	4.35	9.95
Espanola NM	1716	0.45	0.43	0.57	0.70	0.96	0.70	1.37	1.79	0.98	0.93	0.53	0.48	5.80	9.77
Hovenweep UT*	1613	0.95	0.99	1.05	0.82	0.74	0.35	0.91	1.09	1.03	1.35	1.10	1.00	4.12	11.04
Bernalillo 1 NNE NM	1540	0.45	0.45	0.55	0.54	0.61	0.49	1.40	1.54	0.92	0.96	0.44	0.52	4.96	8.97
Aneth Plant*	1439	0.76	0.85	0.76	0.58	0.50	0.22	0.68	0.69	0.82	1.13	0.72	0.74	2.91	8.88

* Weather stations located within or fairly close to the study area. The remaining stations are farther south in New Mexico and Arizona. Stations are organized in terms of decreasing elevation.

Table 2-3. Corn Growing Degree Days for Selected Sites.

Weather Station	Elev. (m)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	May-Sept	Annual
Wolf Creek Pass	3244	1	0	2	8	59	167	244	212	113	41	4	1	795	853
Lemon Dam*	2466	4	8	38	97	217	356	443	413	298	162	29	2	1727	2066
Vallecito Dam*	2332	2	7	33	114	231	381	474	438	329	192	44	6	1853	2252
Fort Lewis*	2320	1	5	30	111	242	393	489	447	327	183	35	3	1898	2267
Los Alamos NM	2247	6	17	57	148	281	466	556	492	351	194	48	8	2146	2624
Pagosa Springs*	2177	3	10	50	151	285	423	513	479	362	221	56	8	2062	2562
Mesa Verde NP*	2152	5	16	58	161	314	499	633	590	423	238	59	8	2459	3006
Mancos*	2180	3	18	78	177	309	441	537	536	396	240	52	3	2219	2790
Yellow Jacket*	2088	3	11	52	146	299	467	603	562	394	217	49	5	2325	2808
Dulce NM	2083	4	15	71	181	325	461	539	512	403	246	64	8	2240	2828
Northdale*	2015	2	10	49	154	304	460	567	537	398	226	48	4	2266	2760
Durango*	2009	6	19	73	177	315	453	548	521	398	248	78	13	2235	2850
Ignacio*	1966	5	18	74	191	340	477	561	534	408	259	74	11	2320	2952
Zuni NM	1954	28	56	125	240	380	512	615	583	455	309	121	42	2545	3467
Keams Canyon AZ	1893	15	41	109	226	361	514	634	603	457	290	98	21	2569	3369
Cortez*	1890	6	23	85	202	352	495	614	586	439	270	76	12	2486	3160
Blanding UT*	1857	4	19	79	189	343	514	655	617	438	250	63	7	2567	3177
Bloomfield NM	1768	9	38	129	258	426	567	698	664	499	304	96	17	2854	3704
Navajo Dam NM*	1759	2	25	109	219	380	549	707	670	471	282	69	3	2777	3488
Kayenta AZ*	1732	11	41	131	258	426	571	701	658	501	315	97	18	2857	3727
Snowflake AZ	1720	42	86	166	280	419	532	639	615	488	343	152	54	2693	3816
Aztec Ruins NM*	1720	13	46	139	268	416	534	661	635	485	316	102	19	2731	3635
Espanola NM	1716	20	68	164	287	429	549	650	613	474	336	433	37	2715	3760
Hovenweep UT*	1613	7	38	135	263	429	552	670	653	498	311	87	9	2802	3653
Bernalillo 1 NNE, NM	1540	49	99	202	341	477	578	701	662	525	369	155	56	2943	4215
Aneth Plant*	1439	9	57	184	301	484	641	770	755	560	343	106	13	3210	4222

* Weather stations located within or fairly close to the study area. The remaining stations are farther south in New Mexico and Arizona. Stations are organized in terms of decreasing elevation.

successfully grown that currently fall below this threshold, though his method of calculating the units slightly underestimated the actual CGDD. However, the 2,500 CGDD figure should be considered a rule of thumb, rather than a real threshold. Aspect can make a real difference in temperature relations. At a given elevation, south- and southwest-facing slopes receive more heat and have a longer frost-free growing season than those slopes that face other directions.

A look at CGDD in the region reveals a trend to increasing units with decreasing elevation. Focus is on the period May-September, which includes late spring months when soil warming would be critical to germination success. Weather stations in or adjacent to the study area above 2134 m (7000') average 2,000 CGDD for May-September, too few for successful maize agriculture. Stations between 1829 and 2134 m (6000 and 7000') average a barely adequate 2,345 units. However, within this elevational band farmers could choose field locations that were somewhat warmer than the average due to favorable aspect, accepting some risk of freezing along with the benefits of increased precipitation. Stations between 1524 and 1829 m (5000 and 6000') average 2792 units. The lone station below 1524 m (5000') has 3,210 units. Mesa Verde National Park (MVNP) stands out in the region by having 2,459 units, the only elevation above 2134 m (7000') with close to the needed heat units to mature maize. South-facing aspect and the general southern tilt of the land likely plays a significant role here. Six weather stations to the south have substantially higher CGDD for the same elevational bands as in the north.

At some point, having higher available CGDD days would become counterproductive, as higher evapotranspiration rates would accompany higher temperatures. Historically dry-land farming for corn and beans has been most successful between 1920 m (6300') (Cortez) and 2134–2164 m (7000–7100'), and has not been very productive below 1829–1890 m (6000–6200') elevation. In prehistory, on lands lower than 1829 m (6000'), dry-land farmers would have had to manage runoff or irrigate to supplement direct rainfall.

Frost-free Periods

Most maize varieties need at least 120 frost-free days to mature. Information on the length of frost-free periods where temperatures do not fall below 28.5 degrees Fahrenheit is summarized in Table 2-4. Instead of 32 degrees Fahrenheit, this temperature minimum was chosen to accommodate minor temperature fluctuations due to variable landscapes, and because maize can actually tolerate temperatures down to 26.6 degrees Fahrenheit during both germination and maturation (Chang 1968:101). It is in the midst of the growing season during flowering that maize is most sensitive to cold, when the region is much less likely to experience freezing temperatures.

Weather stations in and adjacent to the study area record an average of 104 frost-free days 90 percent of the time at elevations above 2134 m (7000'), too few for growing maize. Between 1829 and 2134 m (6000 and 7000'), there is a marginal average of 117.6 frost-free days for maize agriculture, and between 1524 and 1829 m (5000 and 6000') there is an adequate average of 155.5 frost-free days. The single station below 1524 m (5000') has 185 frost-free days. There are some notable exceptions that bear pointing out. While most elevations above 2134 m (7000') have too few frost-free days, MVNP at 2152 m (7060') has plenty (153 frost-fee days) for routinely maturing a maize crop. Yellow Jacket (135 frost-free days), Cortez (120 frost-free days) and Blanding (148 frost free days) would also likely mature maize crops 90 percent of the time, despite their presence at elevations above 1829 m (6000').

Table 2-4. Frost-free Days at 28.5 Degrees Fahrenheit for Selected Sites.

Weather Station	Elevation (m)	Shortest	90%	Longest	Latest
Wolf Creek Pass	3244	55	75	149	10/15
Lemon Dam*	2466	96	99	149	10/16
Vallecito Dam*	2332	76	97	165	10/22
Fort Lewis*	2320	78	96	172	10/31
Los Alamos NM	2247	126	151	221	11/15
Pagosa Springs*	2177	47	75	145	10/14
Mesa Verde NP*	2152	119	153	212	11/17
Mancos*	2180	78	91	153	10/9
Yellow Jacket*	2088	115	135	208	11/15
Dulce NM	2083	68	85	150	10/23
Northdale*	2015	92	107	161	10/30
Durango*	2009	108	114	182	11/5
Ignacio*	1966	97	108	198	11/10
Zuni NM	1954	121	143	206	11/16
Keams Canyon AZ	1893	126	138	202	11/12
Cortez*	1890	109	120	197	11/6
Blanding UT*	1857	115	148	233	11/17
Bloomfield NM	1768	123	163	224	11/16
Navajo Dam NM*	1759	143	169	236	11/22
Kayenta AZ*	1732	162	163	228	11/27
Snowflake AZ	1720	88	132	189	11/12
Aztec Ruins NM*	1720	111	146	202	11/9
Espanola NM	1716	155	161	182	11/1
Hovenweep UT*	1613	119	144	198	11/7
Bernalillo 1 NNE, NM	1540	153	164	245	11/18
Aneth Plant*	1439	169	185	247	11/19

* Weather stations are located within or fairly close to the study area. The remaining stations are farther south in New Mexico and Arizona. Stations are organized in terms of decreasing elevation. Shortest = shortest frost-free period on record; 90% = length of frost-free season 90% of the time; longest = longest frost-free period on record; latest = latest date of first fall frost on record.

Discussion

Combining the data on temperature, precipitation and average number of frost-free days permits a look at the study area as a whole. Above 2134 m (7000') elevation, MVNP has enough CGDD units, enough frost-free days 90 percent of the time, and adequate moisture to dry-land farm successfully. Between 1829 and 2134 m (6000 and 7000') elevation, moisture and CGDD units appear adequate in all locations, with Yellow Jacket, Cortez, and Blanding having the required number of frost-free days to most often bring crops to maturity. Generally, south- and southwest-facing slopes in this elevational band would likely have enough CGDD to routinely bring in a dry-land crop. Historically, in the western drainage units land between 1829 and 2195 m (6000 and 7200') was best for dry-land farming; this was likely the case in prehistory as well. Elevations below 1829 m (6000') could be farmed successfully, with some form of water enhancement. The lowest elevations in the study area (Hovenweep and Aneth) are marginal in terms of precipitation, and display some of the highest CGDD that could increase the likelihood of crop failures during drought periods.

Comparing the study area to six weathers stations to the south in Arizona and New Mexico reveals the effect of latitude on climatic variables. For comparative purposes, these six southernmost stations are from some of the places that Pueblo people did not abandon in the A.D. 1300s and 1400s. For a given elevational band, southern stations average less precipitation, higher CGDD units, and longer frost-free seasons (especially above 1829 m [6000']). Generally, the risks appear to be lower for maize growing to the south, except at the higher elevations. Although Los Alamos (at 2243 m [7360']) has adequate frost-free and precipitation variables, the CGDD units are low (2,294 for the period April-September), in comparison to Yellow Jacket in the heart of the northern San Juan dry-farming area (with 2,471 CGDD units). However, even Los Alamos farmers could increase the available CGDD by seeking out field locations with favorable aspect.

This effort to assess suitability for maize agriculture in the study area must be considered generally, for a number of reasons. For example, the environmental averages discussed here (precipitation, CGDD, and frost-free periods) represent a limited number of stations spread across a vast landscape, and do not express the range of variability that might be present. An 11-year daily climate record for a relatively small area (Chapin Mesa on Mesa Verde) suggests extreme local and seasonal variability, to the extent that ancient farmers may have faced constant risk of local crop failure or harvesting immature crops (Milo 1991). Also, the choice of variables and the methods of calculation influence results. Milo (1991) points out that length of the frost-free season is a poor predictor of growing season length, and advocates use of a more complicated set of growing season standards developed by U.S. and Canadian agronomists for maize (Brown 1977; Treidl 1977). Though these standards could be applied to the current study, the results would still have to be considered approximations of agricultural potential. Only intimate knowledge of the landscape, such as acquired by the Ancestral Puebloans through experience, would notably improve our efforts to accurately reconstruct agricultural potential in the study area.

Finally, modern weather variables cannot be assumed to directly mirror those of prehistory. Petersen (1988) extensively discussed moisture patterns in southwestern Colorado, using various proxy records (tree-ring, pollen) to reconstruct growing season length from the Ancestral Puebloan period to the present, and suggested a period of diminishing growing season length correlated with the end of Pueblo III occupation of the area. He has reconstructed the available dry-farm belt in southwestern Colorado between A.D. 600 and the present, and hypothesizes the farming belt was squeezed until it disappeared in the late A.D. 1200s, not returning until after A.D. 1850. It has already been mentioned above that precipitation patterns were particularly unstable in the region for the period A.D. 1250-1450 (Dean 1996). The implications of these climatic alterations for prehistoric agriculturalists are potentially large, and reveal the importance of efforts to reconstruct prehistoric climatic variables from the various proxy records available.

Potential for Foragers and Agriculturalists

Resources for Foragers

The region is clearly broken up into a variety of ecological zones, structured primarily by elevation. The resources of interest for foragers in each biological community are listed below, with the communities ranked in relative order of those with high, moderate or low resource potential for foraging humans (Table 2-5). The availability of resources may not always be predictable, depending on the environmental triggers responsible for flowering and fruit production (Adams and Bohrer 1998). Even slight differences in elevation and setting can cause a shift of up to two weeks in ripening of a single resource (Adams 1993c). As natural communities, most have relatively low species diversity. They are also difficult places in which to find resources during the prolonged winter dormancy when most foods, with the exception of starvation resources such as cactus pads and tree bark, are not available (Adams and Bohrer 1998). Drainage units with notable amounts of biotic communities of high potential for foragers, as judged in this study, include Ute (grassland, pinyon-juniper, sagebrush-saltbush), Monument/McElmo (pinyon-juniper, sagebrush-saltbush), and Mesa Verde/Mancos (pinyon-juniper). The remaining four drainage units have notable portions of biotic communities with low potential for foragers.

Table 2-5. Relative Ranking of Biotic Communities in the Study Area, in Terms of some Major Resources of Potential Importance for Foragers.

Biotic Community	Ranking	Resources: Plants	Resources: Animals
Grasslands (3.0%)	High	Variety of cool and warm season grasses, cacti	antelope; possibly bison
Pinyon-Juniper Woodland (33.8%)	Moderate	Variety of cool and warm season grasses, juniper berries, pinyon nuts, cacti, other berries, yucca	rabbits; mule deer and elk in the winter
Sagebrush-Saltbush (19.6%)	Moderate	Cool and warm season grasses	rabbits, antelope, desert bighorn sheep
Pine–Douglas-fir Forest (23.9%)	Low	Some grasses, fruit-bearing shrubs, acorns, yucca	mule deer, elk, turkeys
Gambel oak Scrubland (9.9%)	Low	Acorns and a variety of berries	mule deer, turkeys
Spruce-Fir Forest (8.4%)	Low	Berries	mule deer, elk
Alpine Tundra (1.5%)	Low	Some medicinal plants	bighorn sheep, deer, elk

* Numbers in parentheses are the percentages of each biotic community estimated in the study area as a whole.

Generally, the Four Corners region may not be the best place for foragers in the American Southwest (Matson 1991). It does not have the abundant resources of the Sonoran desert, with its diversity of cacti, legumes including mesquite (*Prosopis*), *Agave*, and grasses in dense stands. Wetlands are sparse and geographically spread out, and do not offer the abundance of sedges, rushes, cattail and waterfowl available in the Great Basin. The question of how foragers might have put together a seasonal round in the study area is addressed here. Starting in the springtime, cool-season grasses (ricegrass/needlegrass, Junegrass, fendlergrass), various native mustards, and shrubs such as three-leaved sumac produce fruits and greens that are edible, all located generally in the lower elevations below 2300 m. Late summer and early fall provide the greatest productivity and highest diversity of wild resources, including warm-season grass grains, cactus fruit, juniper berries, pinyon nuts (if the crop succeeds), acorns, and a variety of berries. Some of these resources are available above 2300 m, and would require travel into the uplands. As noted above, foragers would also need to harvest and store enough foodstuffs to sustain them through the relatively long winter dormant season. During that season, low-caloric foods would include tree bark, cactus pads, fruits still clinging to some plants (e.g., juniper berries, cactus fruit), and harvests raided from pack-rat and other rodent nests (Adams and Bohrer 1998). Animals would provide critical resources as well. Year-round occupation by foragers would undoubtedly have been difficult.

Anthropogenic Ecology

Given the natural communities available in the study area, ancient humans were able to promote plant and animal diversity by intentional use of fire or other land-altering activities (Adams 1994). For example, clearing for agriculture, long-term wood harvest for construction timbers and fuel wood, and long-term presence of humans on a landscape all have the power to substantially alter biotic diversity. Historically, the presence of domestic grazing animals, dry-land and irrigated agriculture, forest alteration for a variety of reasons, and the introduction of aggressive alien weeds join the list of land-altering activities. Efforts to understand human use of any biotic community must take into account the multitude of alterations possible by both prehistoric and historic groups, along with natural forces such as fires.

In the study area, a multiyear study after a major fire in pinyon-juniper woodland and sagebrush-bitterbrush shrubland on the Mesa Verde (drainage unit 4) documented a recovering landscape of burned and nonburned habitats sporting a variety of geographically adjacent resources of interest to humans (K. Adams 1991, 1993b). Such "mosaic" habitats can actually benefit humans by offering increased diversity of available food resources and other raw materials. For example, the burned pinyon-juniper plot had species of tobacco (*Nicotiana*), goosefoot (*Chenopodium fremontii*), fendlergrass (*Poa*) and mustards (Cruciferae) displaying significant vigor and vitality early in recovery, and twice the herbaceous plant diversity than the unburned plot. Vigorous stump-sprouting shrubs (*Cercocarpus, Purshia, Quercus gambelii, Symphoricarpos, Yucca baccata*) provided flexible stems for material culture needs. A large amount of sound, dry wood was available as fuel. The burned sagebrush-bitterbrush plot was dominated by serviceberry (*Amelanchier*) and snowberry (*Symphoricarpos*). A species of goosefoot (*Chenopodium leptophyllum*) and of globemallow (*Sphaeralcea coccinea*) both did well there, providing potential seed resources.

Disturbance of the landscape by agriculture and other land-use activities fosters plants able to survive in an open niche. Included would be a set of resources (often labeled "weeds")such as species of *Chenopodium, Amaranthus, Portulaca*, various mustards (Cruciferae), *Physalis, Mentzelia, Cleome*, and others. Regular field maintenance would likely have reduced the level of competition of these plants with the intended crops. However, it is also likely that ancient folks ate these native plants as young leafy "greens," and later in the season gathered their mature seeds. The archaeological record of the region commonly preserves seeds of these taxa in contexts suggestive of food use.

A recent attempt to reconstruct the landscape of late Pueblo III times suggests some level of human alteration of the environment in the Sand Canyon Locality (drainage unit 1), but not complete forest reduction (Adams and Bowyer 1998). Presence of archaeological charcoal of shrubs (*Chrysothamnus, Artemisia tridentata*) that play a successional role in fallow fields suggested presence of open parklands, while the range of agricultural by-products (maize leaves, stems, cobs) and consistent use of plants of disturbed habitats reveals that agricultural fields were likely near most habitations. Access to living or recently dead pinyon (*Pinus edulis*) and juniper (*Juniperus*) trees is inferred from recovery of smaller parts (twigs, needles, bark) in even the last fires built. In the Dolores area (drainage unit 2), Kohler (1992b) and Kohler and Matthews (1988) reconstructed from archaeological plant remains an even more heavily impacted late Pueblo I environment, where a pinyon-juniper forest had given way to significant clearing for agriculture and wood use, and people had became reliant on alternative shrubs and trees for fuel wood and other wood needs.

Various strategies might be employed by ancient humans to ameliorate effects of long-term land use and resource depletion. A case has been made in southwestern New Mexico (Nelson and Anyon 1996) that agriculturalists may have had relatively broad mobility ranges, coupled with long-term mobility cycles that allowed lands to recover and rejuvenate while groups moved elsewhere within the region. The result was abandonment or decreased intensity of use of a given area for some period of time while both the land and the wild resources recovered. Movements from valley to valley could be expected, with decades passing before a group's return. Examining the southwestern Colorado drainage units to assess whether such "fallow-valley" strategies operated in prehistory would be reasonable.

Agricultural Potential

Agriculturalists would have access to the same resources as foragers (see discussion above), but be constrained to areas having adequate soil structure/fertility, available moisture, adequate CGDD units, and a frost-free growing season conducive to growing maize (*Zea mays*), beans (*Phaseolus*), squash (*Cucurbita*), and gourds (*Lagenaria*). Cotton (*Gossypium*) cloth occurs in the region in prehistory, but currently there is little reason to believe it was grown there as a crop. Archaeologists who have studied the agricultural potential of the region are Burns (1983), Petersen (1988), and Van West (1994a).

Based on the temperature, precipitation, and frost-free period information given above, and assuming that alluvial soils or upland soils are adequate for growing crops, the biotic communities are ranked in terms of high, moderate, low or very low potential for successful agriculture (Table 2-6). At higher elevations that host fewer than 120 frost-free days, the growing season is generally too short. However, even in these high locations, there may have been limited areas where agriculture could be successful due to combinations of favorable aspect and protection from cold air drainage such as occur at Mesa Verde. In part, the archaeological record supports this by way of agriculturally dependent prehistoric populations in the Animas, La Plata, and Upper San Juan/Piedra drainage units. At lower elevations experiencing reduced precipitation but an adequate number of frost-free days, some type of enhanced water management would be needed to mature developing crops. Rainfall or runoff water management would likely be required below 1829 m (6000') elevation (Huckleberry and Billman 1998).

With this information, each drainage unit can be rated in terms of dry-land agricultural potential. Substantial portions of land with high agricultural potential occur in the

Monument/McElmo, Ute and Mesa Verde/Mancos drainage units; this agricultural land occurs in either pinyon-juniper woodland or sagebrush-saltbush shrubland. Moderate amounts of these biotic communities occur in the remaining four drainage units; however, their agricultural potential is considered very low because the number of frost-free and CGDD days are marginal for maize. The physiographic variability of these drainage units suggests that there would be some limited locations where aspect and location can combine to mature maize on a fairly regular basis. In the study area, Mesa Verde is one prime example of a landform above 2134 m (7000') elevation where all climatic variables are conducive to successfully growing maize. Portions of the Sand Canyon Locality (within drainage unit 1) also approach 2134 m (7000'), where highly productive areas of dry-land farming occur today.

Table 2-6. Relative Ranking of Biotic Communities in the Study Area, in Terms of Dry-land Agricultural Potential.

Biotic Community	Ranking	Comments
Pinyon-Juniper Woodland (33.8%)*	High	Within elevational band of 1524–1829 m, frost-free period is adequate, as it is for select locations (Yellow Jacket, Blanding, Cortez) above 1829 m. May require water enhanced management below 1829 m. CGDD adequate.
Sagebrush-Saltbush (19.6%)	High	Within elevational band of 1220–1829 m, frost-free period is adequate, as it is for select locations above 1829 m. May require water enhanced management below 1829 m. CGDD adequate.
Grasslands (3.0%)	Moderate	Within elevational band of 1220–1829 m, frost-free period is adequate. May require water enhanced management below 1829 m. CGDD adequate.
Pine–Douglas-fir Forest (23.9%)	Low	Frost-free period and CGDD adequate in one location (Mesa Verde) above 2134 m, and possibly in others.
Gambel Oak Scrubland (9.9%)	Very low	Frost-free period and CGDD marginal; possible in select locations.
Spruce-Fir Forest (8.4%)	Very low	Frost-free period and CGDD marginal; possible in select locations.
Alpine Tundra (1.5%)	None	Frost-free period and CGDD inadequate.

* Numbers in parentheses are the percentages of each biotic community in the study area as a whole.

Flood plain agriculture would also have been possible in drainage bottoms. In some drainage units (Animas, La Plata, Dolores, Upper San Juan/Piedra), fields adjacent to rivers would potentially suffer from cold air drainage, perhaps often enough to make farming relatively risky. However, in the remaining drainage units cold air drainage may have been less of a problem, and groups were able to successfully farm flood plains, or perhaps smaller side canyons. Perhaps the best way to assess potential of ancient flood plain agriculture in the study area would be to develop a map of valley bottoms where historic flood plain agriculture has been successful.

Summary

The ranked potentials of each drainage unit reveals that the Monument/McElmo, Ute and Mesa Verde/Mancos units have the most potential for both foraging and maize agriculture (Table 2-7). This table is based on the relative proportions of the different biotic communities within each unit, in conjunction with Tables 2-5 and 2-6. Within these units, dry-land farming would be favored between 1824 and 2195 m (6000 and 7200'), and below 1829 m (6000') some form of water enhancement would likely be needed. Careful selection of fields to maximize the effects of aspect and to minimize the effects of cold air drainage would be required. The remaining four units have very low potential for maize agriculture, and are also relatively low in native resources that would sustain foragers. Occasionally, a given location might experience high productivity of a certain wild fruit or nut, but because different natural resources are located across elevational gradients, foragers would have to move frequently to gather sufficient food.

Table 2-7. Summary of Ranked Potentials for Foragers and Agriculturalists by Drainage Unit.

Drainage Unit No./Name	Foraging	Agriculture
1. Monument/McElmo	High	High
2. Dolores	Low	Very Low
3. Ute	High	High
4. Mesa Verde/Mancos	High	High. Includes Mesa Verde, above 2134 m
5. La Plata	Low	Very low
6. Animas	Low	Very low
7. Upper San Juan/Piedra	Low	Very low

PALEOENVIRONMENTAL RECONSTRUCTION:
THE LAST 40,000 YEARS IN THE NORTHERN SAN JUAN RIVER DRAINAGE BASIN

Introduction

Precipitation during the summer months in the southern Colorado Plateau, critical for the dry farming of certain crops, results primarily from moisture sweeping in from the south and southwest (Figure 2-2). Climate in the western United States is complex, and general patterns are linked to much larger global weather systems and to a deep geologic history. For the interested reader, Petersen (1994a) provides a brief review that contains an extended bibliography of more detailed modern climate studies, and Adams and Comrie (1997) and Woodhouse (1997) provide additional coverage and references. Petersen (1988, 1994b) and Davis (1994, 1996) provide evidence that the boundary for the summer monsoon has shifted both north and south in the past, affecting the ability of some prehistoric peoples to dry-farm maize and other crops. The following section discusses these findings in the context of other climatic studies from the region. Although this document is primarily focused on southwest Colorado, discussion of climatic systems both present and past requires a much broader treatment.

For periods prior to weather instrumentation (introduced in the late 1800s in the Southwest), climatic reconstruction for human-climate interactions can only be accomplished by proxy. Researchers have access to climatic reconstructions based on studies of tree rings, sedimentary sequences, faunal remains, plant macrofossils, and both archaeological and alluvial pollen records. Except for tree rings, most of these records do not provide continuous sequences from before Pueblo occupation to the present, and each type of proxy record has limitations (e.g., Berglund 1986, Betancourt et al. 1990; Cooke and Reeves 1976; Davis 1995; Dean 1996; Fritts 1976, 1991; Hevly 1981; Huckleberry and Billman 1998). Because Bryant and Holloway (1983) and Hall (1985a, 1985b) list many of the pollen studies done in the Southwest, most will not be repeated here. However, selected examples of the use of proxy climatic records in conjunction with explanations for local and regional abandonment and reoccupation during the prehistoric era in the northern Southwest include Ahlstrom et al. (1995), Betancourt (1984), Betancourt and Davis (1984), Betancourt et al. (1986), Betancourt et al. (1990), Bryant and Holloway (1983), Burns (1983), Cordell (1975), D'Arrigo and Jacoby (1991), Dean (1996), Dean et al. (1985), Eddy (1974), Eddy et al. (1984), Euler et al. (1979), Fall et al. (1981), Force and Howell (1997), Gumerman (1988), Hall (1977, 1985a, 1985b), Hevly (1981), Huckleberry and Billman (1998), Jacobs et al. (1985), Kohler and Matthews (1988), Kohler and Van West (1996), Larson et al. (1996), Lipe (1995), Mackey and Holbrook (1978), Martin and Byers (1965), Matson et al. (1988), Nickens (1981), Pippin (1987), Samuels and Betancourt (1982), Schlanger (1988), Schlanger and Wilshusen (1993), Schoenwetter (1970, 1987), Schoenwetter and Eddy (1964), Van West (1994a, 1996b), Wyckoff (1977).

Tree-ring Climate Reconstruction and Berry's Theory

Since the creation of continuous tree-ring chronologies in the Southwest beginning in 1929 (Douglas 1929, 1935), archaeologists have attempted to correlate the movements of peoples with critical changes in climate. One theory that most clearly relies on the impact of climate on culture to explain relocations and abandonments is that of Berry (1982), who sees the stages of the Pecos Classification as real time-and-space entities that are separated from one another by abrupt transition events. Berry (1982) maintains that these discontinuities were initiated by periodic, Colorado Plateau-wide droughts that left their mark in the numerous tree-ring records available

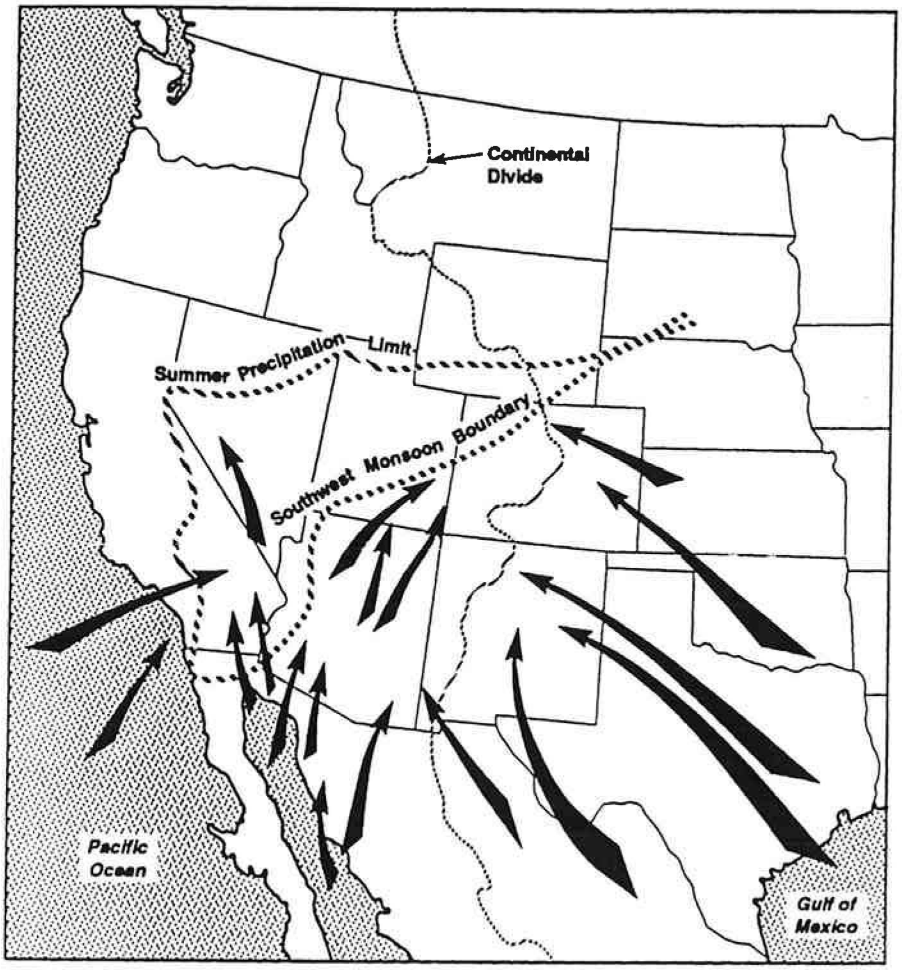

Figure 2-2. Climatic boundaries for the Southwest monsoon (after Petersen 1994b). Precipitation is greatest east and south of the southwest monsoon boundary of Mitchell (1976), where more than half of the annual precipitation occurs during the warm season (Dorrah 1946). North of that boundary the amount of warm-season precipitation decreases until it reaches the summer precipitation limit of Pyke (1972). Arrows show the main paths of moisture in the southwest United States during the summer (adapted from Miller et al. 1973).

from the Southwest. These extensive droughts caused widespread abandonments of low-elevation Puebloan sites and consequent migration to high-elevation refuge sites. The forced coexistence and coalescence of immigrant groups in these various refugia produce the syntheses of material culture traits that have been identified as the hallmarks of the ensuing stage(s). Berry's (1982) model sees the simple link between severe droughts as reconstructed from tree rings and large-scale population movement as the primary explanation of rapid cultural change. Berry's (1982) treatment of demographic movement is from a much larger geographic perspective than many previous studies but it has come under some methodological criticism (for example, see Dean 1985).

However, apparent support for some parts of Berry's (1982) model comes from Wilshusen and Ortman's (1999) survey of the Pueblo I period (A.D. 750-900) in the southern Colorado Plateau region. They indicate that by A.D. 860 there may have been more than 10,000 people settled in the higher elevation villages north of the San Juan River in southwest Colorado and southeast Utah, and that the population of these large villages appear to have moved into the area from at least two areas with distinctly different cultural backgrounds. However, by A.D. 890 the population for the entire San Juan River drainage region had declined by at least two-thirds, suggesting a substantial migration to the south and east. This regional abandonment was likely followed by an ensuing Pueblo II expansion back into the region.

Pollen Records and Black Mesa Climatic Reconstructions

During the late 1950s and early 1960s, Paul S. Martin and his students and associates at the University of Arizona undertook investigation of pollen preserved in alluvial, lacustrine and archaeological sediments in the Southwest—a region noted for its lack of more traditional basins of pollen deposition such as lakes and bogs (Martin 1963; Martin and Byers 1965). One of Martin's associates, James Schoenwetter (1966, 1967, 1970, 1987; Schoenwetter and Eddy 1964) compared modern pollen ratios and pollen spectra with those from dated alluvial and archaeological sites in the Colorado Plateau. From these, Schoenwetter was able to reconstruct an effective moisture curve for the Navajo Reservoir and Chuska Valley areas of northwest New Mexico (Figure 2-3, bottom curve). Higher arboreal (tree) pollen values are interpreted by Schoenwetter as indicating greater effective moisture at his research localities, likely due to greater winter-dominant precipitation. Schoenwetter (1966) was the first to propose such a chronology of winter precipitation fluctuation for the Four Corners region. Schoenwetter (1966) also suggested that the times of low winter precipitation were likely offset by increased summer precipitation although he had no direct pollen evidence to show it.

Another of Martin's students, Richard H. Hevly, became involved in the study of the paleoenvironments of Black Mesa in northeast Arizona (Euler et al. 1979). By far, this long-term, integrated effort has been one of the most productive and most fruitful of all Southwestern studies examining Puebloan and climate interactions. Dean (1988, 1996) presents the preliminary model for behavioral adaption for Puebloans in the northern Southwest by looking at the interaction of behavior with two other major classes of variables: environment and demography. The environmental variables are divided into two types: those termed "low frequency" with base periodicities greater than or equal to 25 years, and those with shorter periodicities termed "high frequency" variation. One of the reasons that such a distinction is made is that each record type can provide information that is unobtainable from the other. For instance, short-term drought may be reflected in tree rings, but it takes a very long-term drying trend to shift a vegetational boundary. High frequency climatic change includes proxies for precipitation and temperature

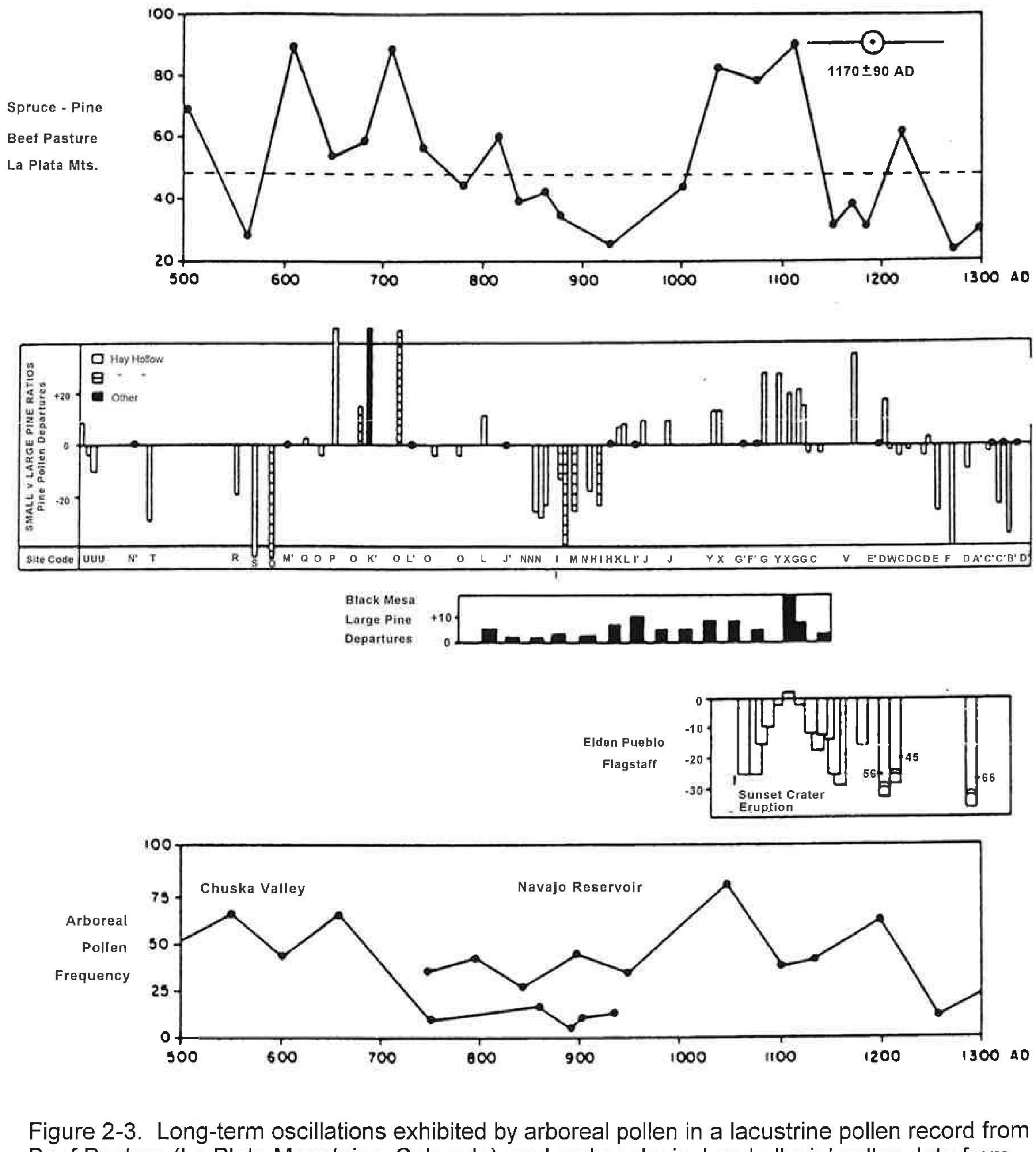

Figure 2-3. Long-term oscillations exhibited by arboreal pollen in a lacustrine pollen record from Beef Pasture (La Plata Mountains, Colorado), and archaeological and alluvial pollen data from Arizona (Flagstaff-Elden Pueblo, Black Mesa, and Hay Hollow Valley), and New Mexico (Chuska Valley and Navajo Reservoir). Data from Hevly 1981; Hevly et al. 1979; Petersen 1985a; Schoenwetter 1966, 1967; Schoenwetter and Eddy 1964. Note that different pollen types have been used at different localities to illustrate these long-term trends, which appear to be generally parallel over a wide geographic area. (Reprinted with the permission of Cambridge University Press.)

derived from tree-ring studies on scales ranging from days to decades. The low frequencies variables include the deposition and erosion of flood plain sediments along drainage and the rise and fall of alluvial ground water levels (Karlstrom 1988). Because Force and Howell (1997) and Huckleberry and Billman (1998) have reviewed this and other alluvial studies in the Colorado Plateau, such studies are not discussed in depth here other than to indicate that, by nature, such paleoenvironmental records are discontinuous and correlation between areas must be demonstrated rather than taken as a given.

Other low-frequency environmental variables used at Black Mesa are the changes in effective moisture and the composition and elevational boundaries of plant communities (Hevly 1988). Hevly (1988) also presents a thorough review of prehistoric vegetation and paleoclimate for other portions of the Colorado Plateau and indicates that although pollen records have been obtained from numerous lacustrine environments, only a few have yielded data which are radiometrically or archaeologically dated within the last 2,000 years. He presents a selection of these in the three center panels of Figure 2-3, including data from Hay Hollow near the headwaters of the Little Colorado in east-central Arizona, Black Mesa, and Elden Pueblo near Flagstaff, north-central Arizona. Each of the samples has been plotted in such a way that "up" indicates greater effective moisture.

Before discussing this figure, some background information needs to be presented. Much of the pollen sampling in the Southwest has been done directly in archaeological sites or nearby sedimentary alluvial sequences. Samples from archaeological room floors and features, potentially datable within 25 years of the occupation of the room, are desirable. However, pollen spectra from archaeological sites may have been affected by such activities as tree clearance (e.g., Wyckoff 1977), local disturbance and subsequent invasion by weedy plant species, and intentional or incidental introduction of pollen into the sites from plants gathered elsewhere. Thus, these pollen spectra from archaeological sites may not represent an unbiased picture of the natural pollen rain. In addition, records constructed from archaeological pollen samples are, by their nature, discontinuous.

To overcome the possible biases that may be associated with pollen samples recovered from archaeological sites, researchers have used standard and adjusted pollen sums, ratios of arboreal to nonarboreal pollen, pine to juniper pollen, and large to small pine pollen to filter out the human effects and to reconstruct the natural vegetation surrounding the archaeological sites (e.g., Hevly 1981, 1988; Schoenwetter 1970). Climatic reconstruction is accomplished by comparing and contrasting the prehistoric pollen spectra or ratios to modern pollen spectra or ratios from an elevational transect through different vegetation types and their associated climates (Davis 1995).

Hevly (1988) also plots the spruce/pine pollen ratio from a continuous, radiocarbon-dated pollen record from Beef Pasture, La Plata Mountains, southwest Colorado (Beef Pasture is located in the La Plata drainage unit 5). Beef Pasture (3060 m elevation) is currently located within the spruce forest but near its lower elevational limit (top panel Figure 2-3). Modern surface pollen transects indicate that as one goes down the mountain, the ratio becomes smaller (Petersen 1988). Or, if conditions were to become drier, and the ponderosa pine forest followed the spruce forest retreat upslope, the ratio would also become smaller. In this figure, any value lower than a ratio of 0.60 indicates a drier condition than that of the present (Petersen 1988). The dotted line in the top panel of Figure 2-3 is the mean ratio for the last 2,800 years.

After developing this figure, Hevly (1988) concludes that despite the different pollen types that have been used at different localities, the long-term trend for the Colorado Plateau is amazingly similar over a large geographic area (see Figure 2-3). Because they were derived and dated independently suggests that they are truly reflecting a robust vegetational signal that is responding to long-term changes in climate.

As part of the Black Mesa work, the paleoenvironmental reconstruction from the high- and low-frequency records are then coupled with regional population trends for specific periods to specify periods of regional population-resource stress that should have elicited a behavioral response (Dean 1996; Dean et al. 1985; Plog et al. 1988). These researchers then use their high-resolution paleoenvironmental and archaeological data obtained from the Black Mesa region to provide the analytical control necessary for a specific local-level test of their model. Then the model is applied to a much larger area. They found that to provide adequate explanation for cultural change, equal consideration had to be given to the relationships among various high- and low-frequency environmental processes. Additional factors to be considered include the physiographic setting, the regional demographic situation, and the degree to which populations were approaching the carrying capacity. When the permutations are considered, the Puebloans probably had a complex suite of adaptive strategies that they employed differentially in response to a wide variety of discreet environmental and demographic situations. In contrast to Berry (1982), Dean et al. (1985) conclude that because of the complex interrelationships, it is not surprising that specific adaptive situations only rarely recurred throughout Puebloan prehistory (see also Dean 1996; Plog et al. 1988).

DAP Environmental Archaeology

Like the Black Mesa work, another thoroughly integrated archaeological project was undertaken by the DAP on the Dolores River in southwest Colorado in the late 1970s and early 1980s (Robinson et al. 1986). However, the scale of the DAP was much more massive than that of the Black Mesa (the DAP was one of the largest archeological mitigation projects ever carried out in the U.S.) and the many volumes of research results could fill a large shelf.

To facilitate interpretation of the DAP findings, a number of researchers in the DAP Environmental Archaeology Group developed a model of past climatic change and related it to physiographic and agricultural conditions in the DAP reservoir area (Petersen 1985a, 1985c, 1986, 1987a, 1987b, 1987c, 1987d, 1988, 1994b; Petersen and Clay 1987). The climatic model was based on non-DAP-supported studies begun by another student of Paul S. Martin, Peter J. Mehringer, Jr., in the early 1970s. These studies were subsequently taken over by Kenneth L. Petersen, one of Mehringer's students (Petersen 1981; Petersen and Mehringer 1976). Earlier, work by Mehringer et al. (1967) had demonstrated that pollen analysis of discontinuous alluvial sediments could be used to document an increase in summer precipitation even when other geologic evidence might suggest otherwise. The pollen analysis that was undertaken in the La Plata Mountains was an attempt to obtain a continuous and well-dated pollen record of climatic change that could be applied to archaeological questions in the Four Corners region.

The model developed for the DAP by Petersen and colleagues (Petersen 1985a, 1985c, 1986, 1987a, 1987b, 1987c, 1987d, 1988, 1994b; Petersen and Clay 1987) included palynological data from two bogs (Beef Pasture and Twin Lakes—located in the La Plata drainage unit) at different elevations within the spruce forest of the La Plata Mountains (which falls within the Dolores, La Plata, and Animas drainage units) and tree-ring data from several areas of the Four

Corners region, plus Almagre Mountain in the Colorado Front Range (for a high-elevation bristlecone pine tree-ring sequences indicative of summer temperature variations). Additional palynological data were obtained in the DAP area from a dated but discontinuous record from Sagehen Marsh (located in the Dolores drainage unit), which allowed a local calibration of the findings obtained from the La Plata Mountains. Using these data, Petersen and colleagues reconstructed relative measures for annual precipitation (primarily jet-stream derived), summer precipitation (primarily monsoon derived), and summer warmth, as well as the effects of physiography on cold-air pooling. Based on these, and taking into account elevation, aspect, exposure, and cold-air drainage, Petersen (1987a, 1988, 1994b) proposed that for the period from late A.D. 500 through 1300, there were episodic changes in the width and elevation of the "dry-farming belt" (today, located between 2000 m and 2300 m elevation in the DAP area). Using the data on the frequency of droughts and short summers enabled measures of agricultural costs and stresses to be derived (Orcutt 1986, 1987; Kohler et al. 1986)

The DAP model of environmental and subsistence potential showed generally good agreement with estimates of project area populations and settlements (Schlanger 1986, 1988). The eighth and ninth centuries in particular showed declines in annual precipitation that would have made the high elevation environment of the Dolores Valley (in the Dolores drainage unit) attractive for farmers who would have had less favorable results from farming at lower elevation in other parts of southwest Colorado in the very late A.D. 800s and early 900s. This narrowed farm belt, coupled with the probably short growing seasons in the early 900s, may have contributed to a "push" for abandonment or near-abandonment of the McPhee Reservoir area at that time (Petersen 1988, 1994b) as well as to the regional abandonment described above (Wilshusen and Ortman 1999).

Push and Pull Factors

In any given case, it is almost certain that a combination of factors was involved in population settlements and abandonments. There must almost certainly be a reason to leave one area as well as a reason to go somewhere else, called informally "push-pull" motivation, and exemplified in this presentation as unfavorable and favorable climatic conditions affecting the ability to farm maize. Even then, cultural and political (or other environmental factors) may have further influence. Schlanger (1988) examined population movements along the great slope between the DAP (high elevation and to the east) through Woods Canyon to Mockingbird Mesa (low and to the west) (Woods Canyon and Mockingbird Mesa are located in the Monument-McElmo drainage unit). Schlanger (1988) found that Petersen's (1988) changing dry-farm belt model was adequate to explain population movements for certain periods but not others. For example, in Schlanger's (1988:756) period 7.4 (A.D. 1175 - 1250; Pueblo III), the extended drought evidenced in the tree-ring record from the Mesa Verde and the DAP (Petersen 1986:Figure 4.19) rendered her entire area unsuitable for rainfall farming except on the highest eastern mesas where cold temperatures would then limit growing season length. Yet Mockingbird Mesa and Woods Canyon showed their highest population levels at this time (Schlanger 1988:786), though the higher DAP area had been abandoned. Woods Canyon and Mockingbird Mesa are low-elevation uplands that adjoin headwater segments of large flood plains. Schlanger (1988) suggests that the agriculture intensification strategies described by Winter (1976, 1977) for the Hovenweep area were likely utilized at Woods Canyon and Mockingbird Mesa at this time. This entailed a shifted from rainfall-dependent upland farming to farming the adjoining flood water drainages. Force and Howell (1997) draw the very same conclusion of a likely shift in farming strategy during Pueblo III times based on their work in McElmo Canyon.

As discussed, although unfavorable climatic factors may provide a "push" for population settlements and abandonments, even larger "pull" factors may have been involved in population dislocation at various times (Lipe 1986, 1995; E. Adams 1991). For instance, Van West (1994a) does a marvelous job of converting tree-ring indices into a paleoproduction model encompassing a 1,816 km^2 area of southwestern Colorado within the Monument-McElmo drainage unit to examine the potential effects of past climatic variation on dry-land maize agriculture and sustainable population during the period A.D. 901-1300. Based on her results, Van West (1994a) concludes that after A.D. 900 climatic variability was never severe enough to totally disrupt agriculture and hasten abandonment of the area. Because all of her area was abandoned by A.D. 1300, it can be surmised that attractive "pull" factors from other areas may have contributed to abandonment and should be examined further (e.g., Ahlstrom et al. 1995; Lipe 1995).

Medieval Warm Period and Little Ice Age

As mentioned, Petersen (1988, 1994b) interprets an integrated record of tree-ring and pollen analyses from a number of sites in the La Plata Mountains, the DAP area, and elsewhere as showing changes in summer temperature and the monsoonal-wind systems strength in the Colorado Plateau during the last 2,000 years. However, he also interprets his record as showing that the fluorescence of Puebloan occupation coincides with the Medieval Warm period (approximately A.D. 800-1200; Hughes and Diaz 1994) and that final regional abandonment coincides with the onset of the Little Ice Age (approximately A.D. 1250-1850; Porter 1986). A discussion of these findings follows.

Petersen (1988, 1994b) reconstructs the strength of the summer monsoon in southwest Colorado from the inferred changes in the areal distribution of pinyon pine as reflected by the annual numbers of pinyon pine pollen grains wafted up to the Beef Pasture pollen site and deposited on a 1 cm square area. Using modern analogies and calibration, Petersen (1985c, 1988, 1994b) argues that pinyon seedling establishment is a good proxy of monsoon strength. Davis (1994, 1996) concludes from pollen analysis of other sites within the monsoon boundary (see Figure 2-2), such as Peck Lake, in central Arizona (see Figure 2-4), that there was an increase in lake levels from A.D. 700 to 1350, thereby suggesting supporting Petersen's (1988, 1994b) contention that summer precipitation during the Medieval Warm period was much higher than that of the subsequent Little Ice Age.

As presented here, the Little Ice Age is a period characterized by lower summer temperatures and reduced summer monsoon strength than the preceding Medieval Warm period. Based on the pollen evidence shown in Figure 2-4, during the Little Ice Age monsoon rains arrived later in the early summer, did not penetrate as far north, and left earlier in the fall than those of today. Using annually dated ice cores from the Antarctic and also central Greenland, Kreutz et al. (1997) also found that a major difference between the Medieval Warm period and the subsequent Little Ice Age was a fundamental difference in global atmospheric circulation patterns—the Little Ice Age was characterized by increased meridional circulation intensity variability. For an expanded discussion of the characteristics and timing of the Medieval Warm period and Little Ice Age in the western U.S., see Porter (1986), Petersen (1988, 1994b), and Grove and Switsur (1994). It was not until the close of the Little Ice Age (after 1850 in the western U.S.) that continental heating again increased, the monsoon system could again take on its modern character of warmer and wetter summers in the Colorado Plateau (see Figure 2-4), and farmers (this time modern Anglos) could again farm the DAP area.

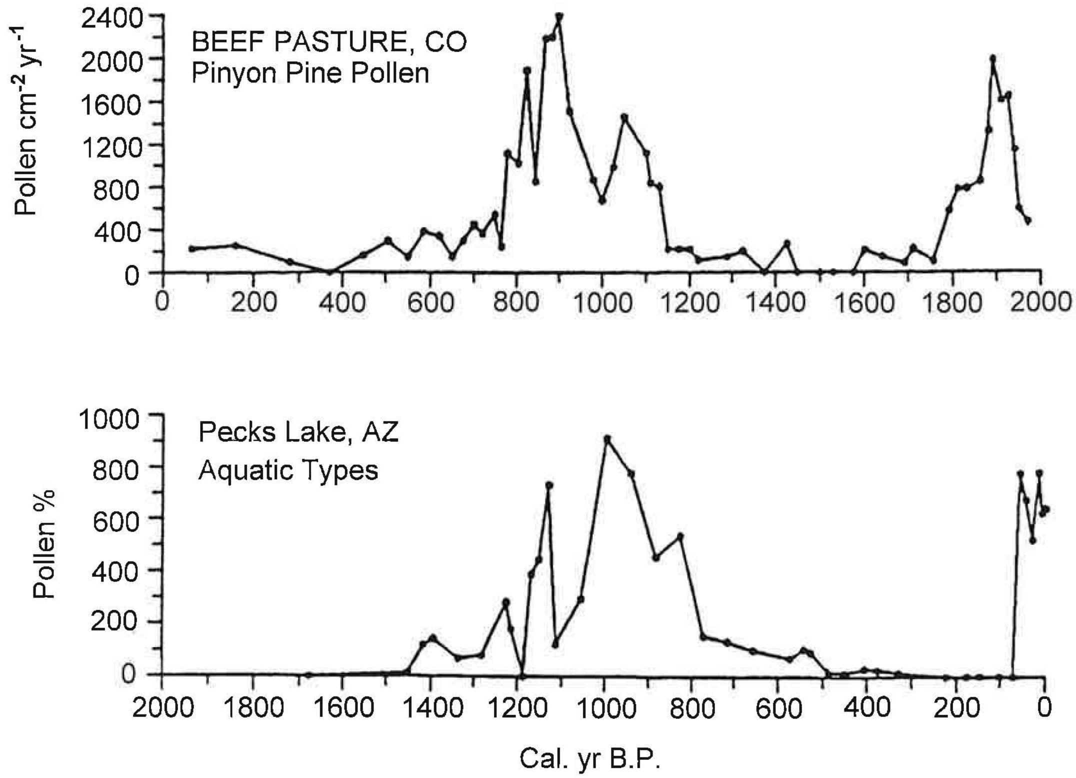

Figure 2-4. Climatic reconstruction of the southwest U.S. for the Medieval Warm period (after Davis 1996:Figure 12-5). Beef Pasture and Pecks Lake indicate greater summer precipitation and higher lake levels during the Medieval Warm period, suggesting strengthened monsoonal precipitation.

Paleoenvironmental Studies at Chaco Canyon

Besides Black Mesa and the DAP, another region that has had many paleoenvironmental studies undertaken is that of Chaco Canyon, northwest New Mexico (Betancourt 1984; Betancourt and Van Devender 1981; Betancourt et al. 1983; Betancourt et al. 1986; D'Arrigo and Jacoby 1991; Fredlund 1984; Fredlund and Johnson 1984; S. A. Hall 1977, 1980, 1983, 1985b; Mathein 1985; Samuels and Betancourt 1982; Schoenwetter 1967; Wright et al. 1973). As shown in Figure 2-3, the pollen record for the Chuska Valley (Schoenwetter 1967) seems to reflect what has been found in other regions. However, a number of other climatic studies do not seem to match that presented here. For instance, Hall (1977, 1985b) uses changes in pine pollen frequencies and taxa in the discontinuous alluvial record of Chaco Canyon to reconstruct climatic change in an area that is now modern pinyon and juniper woodland. Hall (1977) concludes that conditions during Pueblo occupation in the canyon were more arid than that of today and that the pinyon woodland on Chacra Mesa may have been less than one-half as extensive as that of today. After this arid period during the Puebloan occupation, there was a large expansion of pinyon cover to almost that of the modern range between 860 and 600 years ago. Hall's period of pinyon expansion falls within the Little Ice Age. Using the dating scale for Pecks Lake in Figure 2-4, the interpretation by Hall (1977, 1985b) is exactly 180 degrees out of phase with that of Petersen (1988, 1994b), who reconstruct a reduction of pinyon cover in the Four Corners region during the Little Ice Age. Elsewhere, Petersen (1981:157-161) attempts to reconcile the differences between the discontinuous Chaco Canyon alluvial record of pinyon and the continuous pollen record from the La Plata Mountains by suggesting that Hall's (1977:Figure 9) Post Bonito Fill unit from Gallo Wash I (with its relatively high pine content and high concentrations of *Zea* pollen) may have been incorrectly dated. The deposition of maize pollen into sediments for hundreds of years after regional abandonment does not seem very likely, while deposition of maize pollen during Puebloan occupation does seem much more likely.

Betancourt and Van Devender (1981) use plant macro-fossils in a well-dated series of fossil packrat (*Neotoma*) middens to reconstruct past vegetation below 1950 m on the north, xeric side of Chaco Canyon. The midden record is, by its very nature, a periodic sampling of local vegetation at discrete periods of time. The composition of the local vegetation between the dated midden samples is then extrapolated. Using these samples, Betancourt and Van Devender (1981) conclude that there had been a persistence of pinyon-juniper woodland for at least 5,500 years prior to their last midden containing pinyon (dated at about A.D. 720). The next midden is dated at about A.D. 1490 and contains no pinyon remains. They suggest that the lack of pinyon in their youngest midden is best explained by the fuel needs of the resident population, which overtaxed the local stands of pinyon and juniper to the point that they were never able to recover. Samuels and Betancourt (1982) use computer simulation to show that such a scenario is possible. However, examination of Figure 2-4 suggests that the midden sample intervals at A.D. 720 and again at A.D. 1490 likely missed the expansion of pinyon during the Medieval Warm period caused by the increase in monsoonal rain. The lack of pinyon in the youngest packrat midden is more congruent with Petersen's characterization of the Little Ice Age as a time of reduced pinyon cover owing to reduced summer monsoons. Also, the lack of pinyon in the A.D. 1490 sample may not support Hall's reconstruction of a pinyon cover in the region during the Little Ice Age as equivalent to that of modern times.

Late Pleistocene and Holocene Climate of the Four Corners Region

Figure 2-5 depicts a present-day elevational distribution of vegetation, temperature, and precipitation in the Four Corners region (Waugh and Petersen 1995). Assuming some consistency of vegetational and climatic interactions, evidence of past changes in the distribution of plants preserved along the elevational gradient is the basis for reconstructing past climates. Temperature and precipitation curves were derived from meteorological data compiled by Petersen (1987f) for 12 sites located between 1300 m and 2700 m elevation in southwestern Colorado and southeastern Utah. The generalized plant species distribution curves are based on numerous sources (Arno and Hammerly 1984; Betancourt et al. 1990; Hevly 1988; Maher 1961; Petersen 1987f, 1988). Lower limits of plants are generally considered to be set by moisture deficiencies and upper limits by low temperature. Table 2-8 presents the types of proxy data, dates, and references for the paleoclimatic data of sites presented here. Figure 2-6 is a map that includes the locations shown in Table 2-8.

The records in Table 2-8 indicate that plant distribution in the Four Corners region shifted hundreds of meters in elevation since the Late Pleistocene (nominally considered here as the period from 40,000 to 13,000 years before present [B.P.]) up through the present in response to fluctuations from subhumid to arid climates (Figure 2-7). Presented here is a brief discussion of the reconstruction of vegetation and climate for the Four Corners region beginning in the Late Pleistocene (see also Petersen 1994a), through the post-glaciation period (13,000 to 10,500 years ago), and the Holocene (the last 10,500 years). For a more comprehensive discussion of climatic change during the last 15,000 years or so, see Fall (1997).

The records from 18,000 B.P. to the present are well constrained by radiocarbon dates. These paleorecords reflect long-term shifts in vegetation and not the high variability that exists in meteorological (Nielsen 1986) and tree-ring records (Dean 1988). Records of past climatic change in the Four Corners region provide working limits for ranges of temperature and precipitation. For example, the modern vegetation at Monticello, Utah, (2135 m elevation; see Figure 2-6) is scrub oak with pinyon-juniper on southern exposures and ponderosa pine on northern exposures (see Figure 2-5). Present mean annual temperature and precipitation are 8 °C and 38 cm (46 °F and 15 in.) respectively (see Figure 2-5). During the Late Pleistocene, subalpine forests dominated vast areas now occupied by the pinyon-juniper woodland (see Figure 2-7). This predominance of cold-tolerant species, downward expansion of subalpine trees, and the apparent absence of warm-season species reflect a much wetter and colder climate than that of today (Lao and Benson 1988; Thompson 1990). The Laurentide ice sheet, thrust up into the lower atmosphere, may have split the jet stream into two branches with the southern branch forced south across northern California, Nevada, Utah, and Colorado (Cooperative Holocene Mapping Project [COHMAP] Members 1988), resulting in long wet winters, cool summers, and an essentially nonexistent summer monsoon in the Four Corners region. On the basis of a synthesis of Late Pleistocene paleorecords, Waugh and Petersen (1995) set working-level values of mean annual temperature at 2 °C (36 °F) and precipitation at 80 cm (32 in.) for Monticello.

Paleoclimatic data from Table 2-8 sources record a post-glaciation climate (13,000 to 10,500 B.P.) that continued wetter but warmer, with the upper plant limit moving upslope, but little change in lower plant limits (see Figure 2-7). Conditions of global warming increased the moisture holding capacity of Pacific air masses; however, the jet stream continued tracking south of the slowly retreating continental ice (Ruddiman and Wright 1987), sustaining wet winters in the Great Basin and Colorado Plateau. By the early Holocene (approximately 10,000 B.P.), the Four Corners climate was significantly warmer and drier than previously, although seasonal patterns of wet winters and dry summers persisted. A shift toward a more modern summer monsoonal climate was delayed until the ice sheet retreated into northeast Canada.

Table 2-8. Proxy data sources, dates, and references for paleoclimatic sites used to reconstruct climate of the Four Corners region.

Paleoclimate Site	Proxy Data	Dates	Reference
Deadman Lake	Pollen	Late Pleistocene to Present	Wright et al. 1973
Fishmouth Cave	Packrat middens	13,800 B.P. to present	Betancourt et al. 1990
Cowboy Cave	Packrat middens, pollen, and plant macrofossils	13,000 B.P. to present	Jennings 1980
Chaco Canyon	Packrat middens	10,600 B.P. to present	Betancourt et al. 1984
Allen Canyon Cave	Packrat middens	11,300 B.P. to present	Betancourt 1984
Duck Lake	Pollen	Late Pleistocene	Betancourt and Biggard 1985
Bridger Jack Mesa	*Pinus edulis* dendro-chronology	500-yr record	Van Pelt 1978
Beef Pasture	Pollen	6,000 B.P. to present	Petersen 1988
Twin Lakes	Pollen	10,000 B.P. to present	Petersen 1988
Molas Lake, San Juan Mountains	Pollen	16,000 B.P. to present	Maher 1961
San Juan Mountains Timberline	Macrofossils and pollen in timberline bogs	10,000 B.P. to present	Carrara et al. 1991
Sagehen Marsh	Pollen	5,000 B.P. to present	Petersen 1985b
Navajo Reservoir	Pollen	2,000 B.P. to present	Schoenwetter 1966
Chuska Valley	Pollen	2,000 B.P. to present	Schoenwetter 1967
Pecks Lake	Pollen	1,800 B.P. to present	Davis 1996
Hay Hollow	Pollen	2,000 B.P. to present	Hevly 1988
Black Mesa	Pollen	2,000 B.P. to present	Hevly 1988

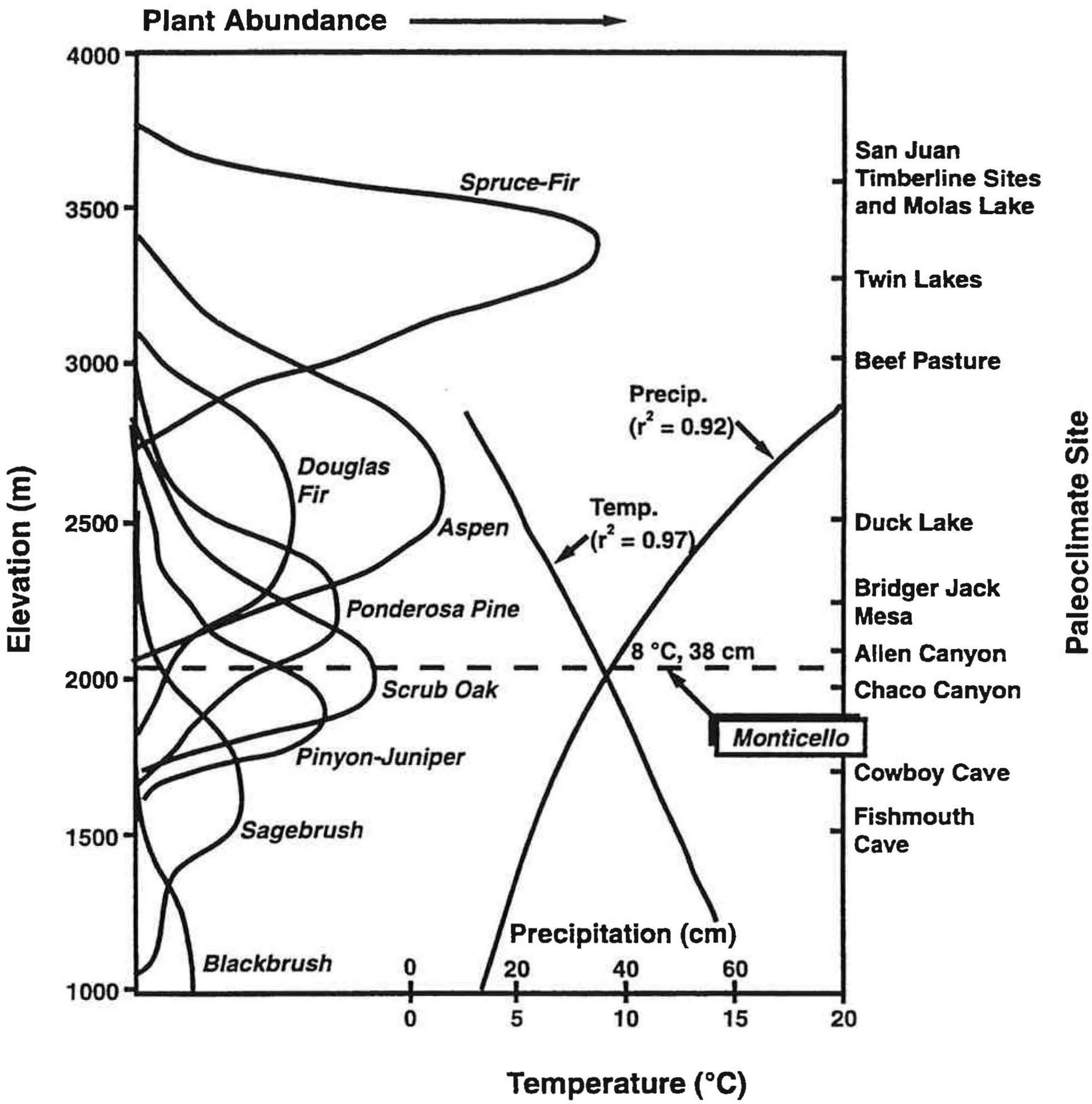

Figure 2-5. Elevational distribution of present-day vegetation, mean annual temperature, mean annual precipitation, and paleoclimate sites in the Four Corners region. Monticello, Utah is shown as an example (after Waugh and Petersen 1995:Figure 5).

Figure 2-6. Map of sites with paleoclimatic data in the Four Corners region (after Waugh and Petersen 1995:Figure 6).

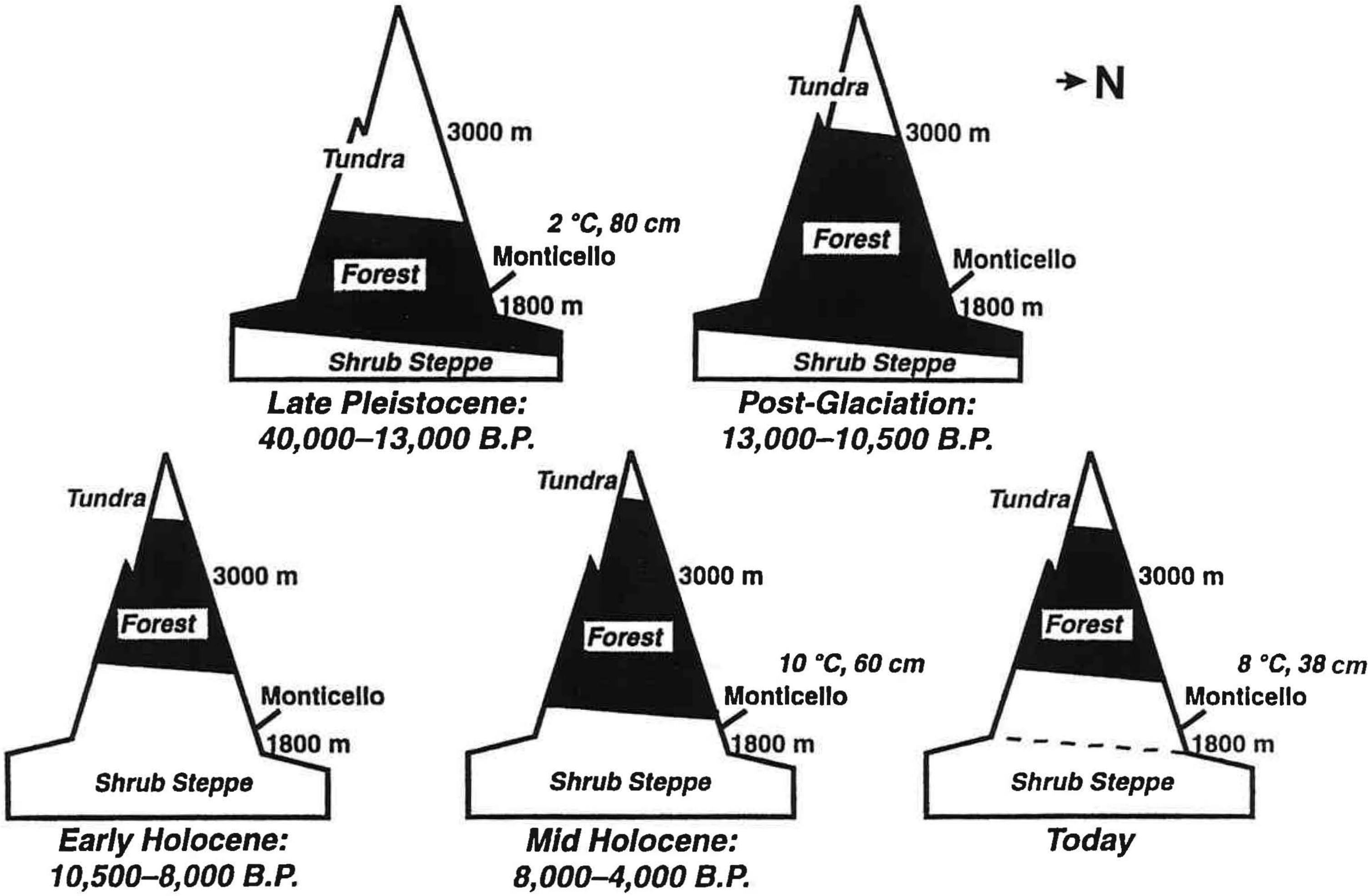

Figure 2-7. Generalized late Pleistocene and Holocene shifts in forest boundaries in the Four Corners region (north is to the right). The present lower extent of pinyon pine, a late Holocene newcomer, is marked with a dashed line (after Waugh and Petersen 1995:Figure 7).

The middle Holocene (8000 to 4000 B.P.) was warmer and wetter than today—approximately 10°C (50°F) and 60 cm (24 in.) precipitation at Monticello (see Figure 2-7). The packrat midden record of vegetative change reflects cold and relatively dry winters, an increase in both summer and annual temperatures, a shift to monsoon-dominated summers, and greater effective moisture than at present (Betancourt 1984; Betancourt and Biggard 1985). Upper treeline was at least 80 m to as much as 140 m higher than at present (Carrara et al. 1991).

The middle Holocene period, also known as the Altithermal, has most often been characterized as being warmer and drier than the present. For instance, Hall (1985b) concludes from his survey of the literature and his pollen work in Chaco Canyon that it was very hot and dry in the western U.S. during this period and that Martin (1963) and Mehringer et al. (1967) were in error in proposing that there was increased monsoonal activity in the western U.S. during mid-Holocene times. Hall's conclusion is counter to that presented here (and shown in Figure 2-7) and that presented by Fall (1997). The North American monsoon is essentially a giant sea breeze laden with moisture and drawn inland by the heating and rise of air above the highlands of western North America including Mexico (Adams and Comrie 1997). Thus, the greater the heating of the western continental highlands (such as during the middle Holocene), the stronger the monsoon in the Southwest. As discussed above, one possible reason for the discrepancy is that discontinuous pollen records such as those based on archaeological or alluvial sequences may be hampered by missing portions of the record and dating problems.

After 4000 B.P., the paleoclimatic record for the Four Corners region become a little more complicated. By about 3500 B.P., tree line had dropped to near its present elevation and by 2800 B.P., the lower limit of the spruce forest had retreated upslope to its present elevation. All forest boundary changes after these times are minor compared to those of the earlier periods but were enough to be interpreted as indicating critical differences in the extent of the dry-farming belt in the Four Corners region as discussed above.

Finally, it should be noted that pinyon is a relative newcomer in the Four Corners region. Betancourt and Van Devender (1984) and Van Devender et al. (1984) indicate that at 11,000 B.P. pinyon began its northward expansion from its late Pleistocene refugia in the northern Chihuahuan Desert and arrived in Chaco Canyon between 10,000 and 8,000 B.P. However, it does not seem to have expanded north into eastern Utah and western Colorado until mostly after 4500 B.P., although it may have arrived in central Nevada as early as 6200 B.P. (see Petersen 1985c, 1988 for reviews). As discussed, once pinyon arrived it seems to provide a good proxy for the strength of the summer monsoon in the Four Corners region with major expansions during Pueblo occupation and during the last 150 years (see Figure 2-4).

Conclusion

Climate in the Four Corners region is complex, and general patterns are linked to much larger global weather systems and even a longer geologic history. A brief look at climatic conditions from the late Pleistocene (Petersen 1994a) through the present (Waugh and Petersen 1995) suggests that the Four Corners region has been subject to significant climatic changes. Such changes would have affected resources available to prehistoric peoples (for instance the availability of pinyon nuts). With the arrival of maize horticulture in the region, a different suite of climatic parameters became important to the inhabitants. Currently (and during Puebloan occupation) the region is near the northern and upper elevational limits of where rainfall farming of maize can take place.

Proxy record suggest that ideal growing conditions have fluctuated in the past and these fluctuations undoubtedly affected where farming could be practiced and, ultimately, if it could be undertaken at all. As more proxy climate data become available, the interpretations presented here may have to be revised (for instance, Matt Salzer of the University of Arizona Tree-Ring Laboratory has been analyzing a 2,000-year, high-elevation bristlecone pine chronology from the San Francisco Peaks near Flagstaff, Arizona, that will soon be available). At present however, it appears that the Medieval Warm period and the Little Ice Age were key elements in the Puebloan ability to dry-farm maize in the Four Corners region and the inherent climatic characteristics of each period may have produced environmental gradients of the proper proportions to contribute to population movements within the region and ultimately to the complete abandonment of the northern San Juan River drainage (units 1-5) in the thirteenth and fourteenth centuries (Petersen 1996).