

**Brigham Young University
Science Bulletin**

**PINYON-JUNIPER SUCCESSION
AFTER NATURAL FIRES ON RESIDUAL SOILS OF
MESA VERDE, COLORADO**

by

James A. Erdman



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Frontispiece. The Morfield Burn of 1959 several days after the natural fire was suppressed. Ash and mud were temporarily impounded behind this road across East Canyon.

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PINYON-JUNIPER SUCCESSION AFTER NATURAL FIRES ON RESIDUAL SOILS OF MESA VERDE, COLORADO

by

James A. Erdman*

ABSTRACT

A mountain brush vegetation typified by Gambel oak (*Quercus gambelii*) and serviceberry (*Amelanchier utahensis*) dominates the uplands of Mesa Verde National Park. There is evidence that this brush element is a successional stage that has been maintained by repeated natural fires in a large part of the Mesa Verde landscape. This study was conducted to determine the role of fire in the region's ecology, the nature of the climax pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) vegetation, and the major successional stages that lead to the climax condition.

Three postburn plant communities and two climax stands overlying residual soils at elevations of about 7,500 feet were studied. The successional stands had been burned through natural causes in 1873, 1934, and 1959. The earliest date was determined by cross-dating trees affected by the fire with the Mesa Verde master chronology, since the fire antedated any written records of the region. Pith dates from pinyon pines in the climax forest stands indicated an age of about four centuries.

Permanent sample plots representative of each stand were established, and the vegetation was analyzed using a modification of the line intercept and macroplot methods. The vascular species that occurred in each sample were noted, and their cover value and frequency were summarized.

Plant succession proceeds rapidly from a pioneer stage of the shade and competition intolerant weeds,

Helianthus annuus and *Chenopodium pratericola*, to a meadow stage dominated by the native grasses, *Oryzopsis hymenoides*, *Sitanion hystrix*, and *Poa fendleriana*. In the most recent burn, several species of perennial exotic grasses have been introduced to check erosion.

After about 25 years, a crown-sprouting brush element, consisting primarily of *Quercus gambelii*, *Amelanchier utahensis*, *Cercocarpus montanus*, and *Purshia tridentata* becomes the dominant vegetation. At this time, seedlings of *Pinus edulis* and *Juniperus osteosperma* are also established. This open shrub stage gradually becomes more dense, and in about 100 years forms a thicket stage. Young trees come up through the shrubs, eventually overtopping them. As the fire sere proceeds toward a climax condition, the brush species are gradually suppressed by the maturing forest. After several centuries, the understory is composed mainly of a sparse shrub component, a grass (*Poa fendleriana*), prickly-pear (*Opuntia polyacantha*), and several forbs.

The data tend to support the theory that recurrent fires throughout previous centuries have permitted a chaparral-like, floristically rich shrub vegetation to persist as a fire climax along the uplands of Mesa Verde National Park. Under the present management policies of fire suppression, however, a pinyon-juniper forest is slowly replacing the former extensive shrub vegetation.

INTRODUCTION

Mesa Verde, a highly eroded plateau in southwestern Colorado (Fig. 1), is on the eastern edge of the Colorado Plateau physiographic province. A pinyon-juniper forest dominates most of the mesa, but dense brush vegetation is common at higher elevations, especially within the boundaries of Mesa Verde National Park. The ecological status of the brush has been a puzzle because, while it appears relatively stable, other sites on the mesa with an apparently similar environment are occupied by stands of pinyon-juniper. Moreover, evidences of fire predating the recent human occupation of the area suggest that

the brush may be a product of fire (Anderson, 1961).

As a member of the staff of the park's Wetherill Mesa Project (Osborne, 1964), I was charged with helping to determine the environmental conditions that existed during the prehistoric Indian occupation of the area, which extended up to the close of the thirteenth century. It was apparent that an understanding of succession following fires would be helpful in the paleoenvironment researches. A fire in Morfield Canyon, in July 1959, provided me with an opportunity to study early stages in the sere, and shortly thereafter I began an intensive investigation of

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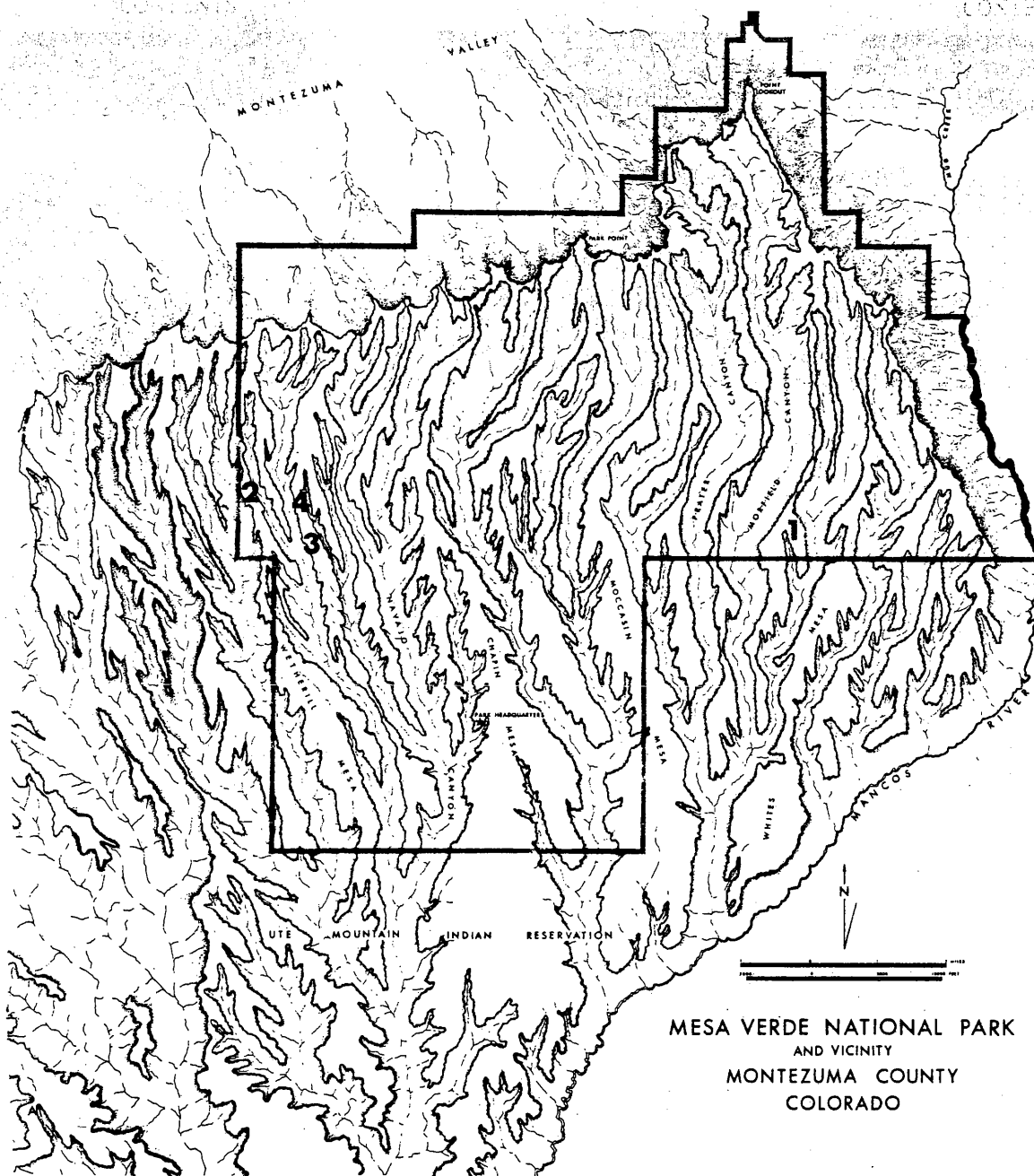


Fig. 1. Map of the eastern part of Mesa Verde. Residual soils cover the upper third of the mesa, at elevations generally above 7,500 feet. The study sites are as follows: 1) Morfield Burn, 2) Wetherill Burn, 3) Long Mesa Burn, and 4) the Long Mesa Climax. An additional climax site that was studied is located on the Ute Mountain Indian Reservation about 2 miles west of the Wetherill Burn.

the mountain brush, or chaparral (Bader, MS.; Anderson, 1961).

The Mesa Verde sandstones and shales of Upper Cretaceous age (Wanek, 1959) rise 1,500 feet above the valleys to the north which reach a maximum elevation of 8,500 feet. These beds dip southward towards the Mancos River. Here the canyons attain depths of 1,000 feet. Travel across the mesa, therefore, is generally along the upper reaches, where the relief consists of rolling swales and ridges.

Residual soils are developed from the underlying sandstone on the narrow, more easily eroded ridges of the higher parts of Mesa Verde—the area under consideration. Most of the soils on the remainder of the plateau, however, appear to be eolian in origin (Arrhenius and Bonatti, 1965), with accumulation continuing even today though at a minimal rate. The calcium carbonate content is highly variable; in some places it forms a thick caliche layer, while in others free lime is absent.

The climate of Mesa Verde is mild, for in this semi-arid region fair weather prevails throughout the year.

Temperatures on the mesa (Table 1) are surprisingly moderate, considering the altitude. This is a result of both generally continuous winds from the southwest and lack of cold-air drainage. Extreme temperature fluctuations, rare on the mesa tops, are pronounced along the canyon floors, however (Erdman, Douglas, and Marr, 1969).

TABLE 1
SUMMARY OF MESA VERDE CLIMATE,
U.S. WEATHER BUREAU STATION
AT HEADQUARTERS, CHAPIN MESA.
ELEVATION 7,070 FEET.
RECORD PERIOD, 1923-1963*

Month	Air Temperature, °F			Precipitation in inches
	Maximum	Minimum	Mean	
January	62	-20	29.8	1.93
February	68	-15	33.0	1.95
March	72	4	38.6	1.76
April	84	9	48.1	1.32
May	90	23	57.0	1.05
June	101	32	67.4	.70
July	102	43	72.9	1.68
August	101	41	70.8	2.01
September	94	28	64.4	1.53
October	85	13	52.7	1.66
November	75	-3	39.5	.98
December	67	-6	32.1	1.71
Annual	102	-20	50.5	18.28

*U.S. Weather Bureau, 1964, and Mesa Verde National Park weather records.

Precipitation is irregular. A proportionately large amount comes as snow during the late winter months. Normal snowfall is 78 inches. The typically dry months of May and June are followed by a period of intense and often highly localized thunderstorms. Rainfall during the late summer and early autumn may be heavy, but because of rapid runoff and high evaporation it is much less effective than winter moisture in recharging ground water supplies. Except for the Mancos River, which skirts the mesa on the south, the only natural water supplies available to wildlife are occasional springs, seeps, and potholes that have been filled by rains or melted snow.

Pollen studies by Martin and Byers (1965) and simultaneous dendroclimatic investigations by Fritts, Smith, and Stokes (1965) indicate that the climate has been relatively stable in the Mesa Verde region during the past millennium. This period would seem to be adequate for plant species adapted to the climatic conditions here to establish themselves and achieve stable communities.

Mesa Verde lies within the pinyon-juniper climax region, an area of 60 million acres lying mostly in Nevada, Utah, Colorado, Arizona, New Mexico, and western Texas (Arnold, Jameson, and Reid, 1964). These forests have been described by Howell (1941), Woodbury (1947), Merkle (1952), and Woodin and Lindsey (1954).

I have not used Merriam's terms, Upper Sonoran and Transition zones, since I agree with Johnsen (1964) that "The terms Upper and Lower Sonoran are occasionally used in generalized, limited area studies by nonbotanists to avoid detailed descriptions of flora and fauna; and, as such, the terms have a general but limited descriptive value."

Most of the plateau is mantled with stands of pinyon pine (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* (Torr.) Little). The areas underlain by loess have an understory dominated by muttongrass (*Poa fendleriana* (Steud.) Vasey), and those underlain by residual soils have an understory dominated by shrubs. *Dominance*, as used here, is based upon "an approximation of the area over which a plant exerts its influence upon other components of the ecosystem" (Daubenmire, 1959).

Elements of the montane flora are common at the more mesic sites in the Mesa Verde area. These sites are dominated by aspen (*Populus tremuloides* Michx.), ponderosa pine (*Pinus ponderosa* Dougl.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), or a combination of all three. As an extension of the Great Basin flora to the west, big sagebrush (*Artemisia tridentata* Nutt.) assumes a climax status on the deep, friable, alluvial terraces in the canyons.

The flora of Mesa Verde is characterized by Madro-Tertiary species (Weber, 1965). In addition to the pinyon-juniper element, the mountain-brush thickets so extensive along the North Rim contain several species belonging to this assemblage, the principal one of which is Gambel oak (*Quercus gambelii* Nutt.). Some of the Madro-Tertiary representatives, however, are exceedingly rare relicts in the Mesa Verde. Among these are single-leaf ash (*Fraxinus anomala* Torr. ex S. Wats.), big-toothed maple (*Acer grandidentatum* Nutt. ex T. & G.), and Ajo oak (*Quercus ajoensis* Muller), a recent addition to the Colorado flora (Erdman, Weber, and Tucker, 1962).

This study is concerned with the mountain-brush element associated with the pinyon-juniper forest on residual soils.

METHODS

I have modeled this study on Viereck's research (1966), which followed the methods of Jenny (1941), Major (1951), and Crocker (1952). Jenny proposed that soil is the result of five independent variables—climate, organisms, topography, parent

material, and time—all acting together to produce a characteristic type of soil. He emphasized the value of finding examples in nature where all the variables but one are relatively constant. In his terminology, for example, a chronosequence develops with all factors except time held constant.

Major (1951) pointed out that these variables are just as valuable in vegetational studies, and illustrated a series of vegetation sequences in which all variables except one were kept constant.

Crocker (1952) suggested that the ecosystem would be a more logical unit to use than either soil or vegetation, for it is the ecosystem that is the function of the five independent variables. The present study is based on this concept. In addition, I have employed the principle of succession, which states that given an adequate period of time and barring disturbance, unstable ecosystems with the same climate, potential organisms, relief, and parent material will converge towards a single climax type.

Through reconnaissance studies and inspection of aerial photos, a selection was made of several young postburn stands (i.e., concrete ecosystems of Marr, 1961) of different ages and of two much older, relatively stable ecosystems. A permanent sample area, visually determined to be representative of each stand, was established, and a species list for it was compiled. The line intercept method (Canfield, 1941) and the macroplot method (Poulton and Tisdale, 1961) were used. Both methods are based on the line transect, although the latter adds small rectangular quadrats, called observation plots, for estimating herbaceous cover.

Ten parallel, 50-foot lines, each subdivided into 10-foot units, were laid out in each sample area at 25-foot intervals along a base line. Tree and shrub canopies projected onto these lines provided a measure of the relative importance or dominance of each species in the sample. According to Lindsey (1956), this canopy coverage is "the most important single parameter of a species in its community relations." Earlier studies of the pinyon-juniper type have also used the intercept technique (Cable, 1957; Jameson, Williams, and Wilton, 1962; and Arnold, Jameson, and Reid, 1964). Frequency, expressed as the percentage of subsamples in which a species occurs, was used to measure the relative distribution throughout the stand.

Understory was studied within 1x2-foot observation plots placed at 10-foot intervals along each line. Cover within these quadrats was estimated by using the Domin scale (Cain and Castro, 1959).

The abundance and reproduction of pinyon pine and juniper were compared by counting those individuals found within ten 4x50-foot belt transects adjacent to each line. The following size categories were used: seedlings, less than 1 foot in height; saplings,

stem diameters less than 2 inches; and trees, greater than 2 inches in diameter.

In the climax-forest samples, trees were selected for importance values and associated data, using the point quarter method of Cottam and Curtis (1956). Ten points were located at 50-foot intervals.

Tree-ring samples were dated according to the Douglass system (Glock, 1937). Increment cores provided ages of the recovering forest, while cross sections from charred snags were collected from the Long Mesa Burn to establish the date of that fire. Robert F. Nichols, archeologist and dendrochronologist with the Wetherill Mesa Project, helped collect samples from both the Long Mesa Burn and the Ute area climax forest. David G. Smith, dendrochronologist-climatologist formerly with the Laboratory of Tree-Ring Research, provided most of the dates.

Dating mature junipers was not attempted because this species often has an extremely erratic growth and lobing habit, and shows frequent doubling of rings.

Up-to-date discussions of the principles and applications of dendrochronology have been published by Bannister (1963), McGinnies (1963), and Fritts (1965a). A good treatment of "signature groups" and key years that occur in the Mesa Verde chronology is to be found in an article by Spencer (1964).

Soil profiles were described and additional information was provided by Orville Parsons, of the Soil Conservation Service. Where possible, photographs of these profiles were made by Fred Mang, Jr.

RESULTS

The Morfield Burn of 1959: Pioneer Weeds and Meadow Seral Stages

Between July 15 and August 7, 1959, a lightning-sparked fire burned 2,043 acres extending over sections of both Mesa Verde National Park and Ute Reservation lands of the east end of Mesa Verde. The flanks of the burn generally paralleled Morfield Canyon on the west and Whites Mesa to the east (Fig. 1).

Razing of the vegetation was complete (see frontispiece). After spending several days on a fire line at Whites Mesa, the fire crew was relieved from duty, and as we drove through the moonlit pall of ash and smoke in Waters Canyon the tree snags glowed like a myriad of campfires.

Some of the burned area had not been completely forested prior to the fire. Much of the eastern part of the park is covered with dense brush and scattered young pinyon and juniper trees. This vegetation has developed since the mid-1800's, when a large fire swept over the terrain. The western part of the Morfield Burn had been a pinyon-juniper forest with trees up to 30 feet in height. On an isolated ridge of this portion of the burn (Fig. 1) a permanent study

plot was established to monitor the vegetation change.

Vegetation.

According to park files, a mixture of commercial seed was air-dropped over most of the burned area in early October 1959, to check erosion. Equal amounts of intermediate wheatgrass (*Agropyron intermedium*), crested wheatgrass (*A. desertorum*), and smooth brome (*Bromus inermis*) were applied at the rate of 6 pounds per acre. The small ridge in Figure 1 was not seeded intentionally so that natural succession could be studied. But, because of seed drift, the exotic grasses soon became well established in the sample plot also. In order to promote tree recovery, 30 pounds of pinyon seeds were planted in a 1-acre plot on Whites Mesa. However, germination and growth have been poor.

The vegetation was leveled by the fire except for the snags of the mature trees. A layer of ash was evident over most of the landscape. But by autumn, many of the fire-adapted shrubs were sprouting from root crowns, and these were developing vigorously the following year. Gambel oak had crown-sprouted and was in leaf within a few months after the fire—impressive evidence of its adaptability to fire.

The pioneer vegetation during the first two years of recovery was dominated by two annuals, sunflower (*Helianthus annuus*) and pigweed (*Chenopodium pratericola*). Other adventives found at the site in 1960 were wheat (*Triticum aestivum*) and the brome grasses, *Bromus carinatus* and *B. japonicus*.

Further evidence suggests that the *Helianthus-Chenopodium* community-type constitutes an early seral stage throughout Mesa Verde. In the summer of 1960, a small plot on Chapin Mesa was intentionally burned in a fire-school demonstration. Sunflower and pigweed appeared the following year.

By 1962, the third year after the Morfield burn, the introduced and native grasses began supplanting the pioneer annuals. In August 1963 the grass community in the study plot was analyzed for cover and frequency, using the modified line intercept-macroplot method (Table 2). The grasses by then were well established, with scattered clumps of resprouted shrubs assuming a minor role (Fig. 2). The composite, *Machaeranthera bigelovii*, and Russian thistle (*Salsola kali*) were the most abundant forbs, but the original pioneer annuals were evident only as litter. Of the herbs listed in Table 2, only lupine (*Lupinus caudatus*) and *Penstemon linarioides* are components of the climax forest. The following perennial herbs, also common in the climax forest, were observed in the study area by 1963 but did not occur in the sample plot: *Poa fendleriana*, *Sitanion hystrix*, *Yucca baccata*, *Petradoria pumila*, *Opuntia polyacantha*, *Comandra umbellata*, *Arabis selbyi*, and *Eriogonum racemosum*. A summary of all the species occurring in the stands sampled is given in Table 13.

TABLE 2
COVER AND FREQUENCY OF THE
VEGETATION IN THE MORFIELD
BURN SAMPLE

ELEVATION 7,550 FEET. AUGUST, 1963

Species	% Cover	% Frequency*
Shrubs		
<i>Amelanchier utahensis</i> **	+***	2
<i>Fendlera rupicola</i>	+	2
<i>Quercus gambelii</i>	+	2
Herbs		
<i>Machaeranthera bigelovii</i>	<4	74
<i>Agropyron desertorum</i>	<4	60
<i>Salsola kali</i>	<4	46
<i>Bromus tectorum</i>	<4	42
<i>Agropyron intermedium</i>	<4	34
<i>Viguiera multiflora</i>	<4	18
<i>Bromus inermis</i>	<4	10
<i>Oryzopsis hymenoides</i>	<4	6
<i>Descurainia pinnata</i>	+	44
<i>Lactuca scariola</i>	+	14
<i>Lappula redowskii</i>	+	8
<i>Lupinus caudatus</i>	+	8
<i>Chenopodium fremontii</i>	+	6
<i>Penstemon linarioides</i>	+	6
<i>Sphaeralcea coccinea</i>	+	6
<i>Camelina microcarpa</i>	+	4
<i>Moldavica parviflora</i>	+	2
Ground		
soil	25-33	92
litter	4-10	100
rock	<4	46

*Based on 50 subplots.

**Species authorities are given in the synoptical list of Table 13.

***Indicates presence but no significant cover value.

Soils.

The soils on the study ridge are highly variable. Parsons considered the soil just north of the sample plot to be Witt loam developing on a thin mantle of loess sediments over Cliffhouse sandstone. This pocket of relatively deep soil (one auger hole reached 60 inches to bedrock) is more like the eolian soils common at lower elevations to the south, where the mesa tops are broad and subject to less erosion.

The shallower soil south of the plot is Montvale stony fine sandy loam. No description was made of the profile, but the following data were obtained from auger holes at the corners of the macroplot: southeast corner 16 inches to bedrock, B₂ at 6 inches, + test for CaCO₃ at 12 inches depth; southwest corner 12 inches to bedrock, rock slabs at 8 inches, CaCO₃ test -; northwest corner 17 inches to bedrock, slight + CaCO₃ test at bottom, B₂ among

rock fragments, northeast corner 12 inches to bedrock. CaCO_3 test + at bottom. Rock outcrops occur along the edges of the ridge and in parts of the sample plot.

In general, the soil within the macroplot is probably less than two feet in depth. Some CaCO_3 occurs at the bedrock-soil interface.

The Wetherill Burn of 1934: the Mountain
Brush Seral Stage

Biesen (1931) prefaced his description of the con-

fers of Mesa Verde with these observations:

While the trees of the park completely cover the mesa areas, they do not grow densely together. . . For this reason as well as for the fact that usually heavy downpours accompany each severe electrical storm, the fire hazard of the park is not considered to be very great. It is interesting to note that Mesa Verde has not been troubled with severe fires in recent years. During the present season



Fig. 2. Aspect of the Morfield Burn in July 1963. The vegetation at this stage consists of exotic and native grasses, some forbs, and scattered fire-adapted shrubs, such as this small clone of Gambel oak in the foreground. Soils on this ridge are variable. Elevation, 7,500 feet.

only two small fires have been reported, and they were quickly extinguished by the Park's efficient protective organization.

This was the feeling that prevailed in the park prior to 1934. Fire was never considered a serious threat to the mantle of pinyon-juniper, often referred to as "the asbestos forest."

That view soon changed when the largest fire in park history taxed the efforts of over 1,000 men attempting to control it. Don Watson (1934), then ranger-historian of the park, gave this account of the event:

On the ninth of July a small cloud, wandering across the Mesa Verde, caused an electrical storm that sent a few streaks of lightning down into our forests. One of these lightning streaks, striking a tree, started a fire that was to prove the most disastrous Mesa Verde has ever known. For two weeks it raged, ultimately consuming 4,540 acres of timber and brush lands.

The Wetherill Burn was in reality the result of two fires that flared up consecutively, one on the Ute Mountain Indian Reservation on July 9, and the other in the park on July 11, 1934. During a flare-up on July 14, they merged into a fire that was not declared out until July 26. This burn, too, left a desolate landscape in its wake.

The following incident provides further evidence of the fire potential of lightning. An extremely abbreviated electrical storm that resulted in a "smoke" occurred one summer afternoon in 1964 while I was visiting Long House, a cliff dwelling on Wetherill Mesa. The weather was fair with no sign of shower activity. Yet while I was in the recesses of the large rock shelter I heard what later proved to have been a lightning bolt strike a large juniper tree about 1 mile up the mesa. The fire was quickly suppressed before it spread, but this event underscores the major role of fire in the dynamics of the regional vegetation prior to modern fire-fighting technology.

Contrary to the statement of Biesen (1931), electrical storms are a consequential factor in determining the nature of the Mesa Verde vegetation. The Wetherill Burn, and, more recently, the Morfield fire were lightning-caused.

Vegetation.

As with the Morfield Burn, attempts to reforest the area artificially have met with but limited success. There were 42,000 trees planted on Wetherill Mesa in 1942 (unpublished park records). Several years earlier, the Civilian Conservation Corps planted 200,000 seedlings. Only a few isolated stands of these pinyon

and Rocky Mountain junipers (*Juniperus scopulorum* Sarg.) persist today, in most cases as rows across shallow washes off the main ridges.

The present open brush vegetation was sampled in 1963 in an area heavily forested before the 1934 fire (Fig. 3). A macroplot was established on the main ridge of Wetherill Mesa at an elevation of 7,650 feet (Fig. 1). The data given in Table 3 are for only those plants intercepted by the sample lines or included in

TABLE 3
COVER AND FREQUENCY OF THE
VEGETATION IN THE WETHERILL
BURN SAMPLE
ELEVATION 7,650 FEET. AUGUST, 1963

Species	% Cover	% Frequency*
Trees		
<i>Pinus edulis</i>	***	2
Shrubs		
<i>Amelanchier utahensis</i>	10	20
<i>Yucca baccata</i>	6	16
<i>Chrysothamnus nauseosus</i>	2	10
<i>Cercocarpus montanus</i>	1	6
<i>Fendlera rupicola</i>	1	6
<i>Symphoricarpos oreophilus</i>	+	4
Herbs		
<i>Poa fendleriana</i>	4-10	88
<i>Sitanion hystrix</i>	<4	24
<i>Sphaeralcea coccinea</i>	<4	22
<i>Heterotheca villosa</i>	<4	18
<i>Bromus tectorum</i>	+	22
<i>Penstemon linarioides</i>	+	16
<i>Schoenocrambe linifolium</i>	+	16
<i>Lappula redowskii</i>	+	10
<i>Viguiera multiflora</i>	+	8
<i>Polygonum racemosum</i>	+	6
<i>Zygadenus elegans</i>	+	6
<i>Petradoria pumila</i>	+	6
<i>Oryzopsis hymenoides</i>	+	6
<i>Moldavica parviflora</i>	+	4
<i>Comandra umbellata</i>	+	4
<i>Machaeranthera bigelovii</i>	+	4
<i>Stipa comata</i>	+	2
<i>Lupinus caudatus</i>	+	2
<i>Calochortus nuttallii</i>	+	2
<i>Achillea lanulosa</i>	+	2
<i>Arabis selbyi</i>	+	2
Ground		
soil	25-33	88
litter	4-10	96
rock	<4	20

*Based on 50 subplots.

**Indicates presence but no significant cover value.



Fig. 3. Aspect of the Wetherill Burn in July 1963. Dead snags of the former pinyon-juniper forest show little weathering. The mountain-brush species, released from competition with the trees, are becoming more dominant. Elevation, 7,650 feet.

the observation plots. Gambel oak, for example, was not sampled but was abundant along the edges of the ridge. Bitterbrush (*Purshia tridentata*), too, was common in the burn but not in the immediate area. A listing of those species occurring in the macroplot area, however, is given in Table 13.

The stand was characterized by serviceberry (*Amelanchier utahensis*), *Yucca baccata*, *Poa fendleriana*, and *Heterotheca villosa*. One pinyon pine sapling occurred in the macroplot and was included in the line intercept. Since the pith date by ring count was 1953, this tree was not part of the earlier planting program. Such a delay in natural establishment of the tree component is consistent with the postfire recovery on Mesa Verde. Regardless of the extent of the area burned, 20 to 30 years usually lapse before the pinyon-juniper element begins to return.

The few nonvascular plants encountered are, for the most part, the moss *Grimmia*, found on rocks scattered over the ridge. A small complex of lichens,

principally *Collema tenax*, covers parts of the soil surface.

Soil.

The soil profile (Fig. 4 and Table 4) was studied at a pit located a short distance down the ridge from the macroplot. According to Parsons (personal communication), the soil representative of this site is tentatively identified as Roubideau very fine sandy loam. It has developed primarily from weathered products of the underlying sandstone, although eolian soils have modified it to some extent. Soil depth around the macroplot, however, is shallower. Holes augered at the corners of the sample revealed the following depths to bedrock: southeast corner, 14 inches; southwest corner, 10 inches; northwest corner, 6 inches; and northeast corner, 6 inches. Tests for CaCO_3 were negative. Several additional test holes inside the macroplot ranged from 20 to 43 inches in depth. One of these had 10 inches of caliche (CaCO_3) in the lower part of the profile.

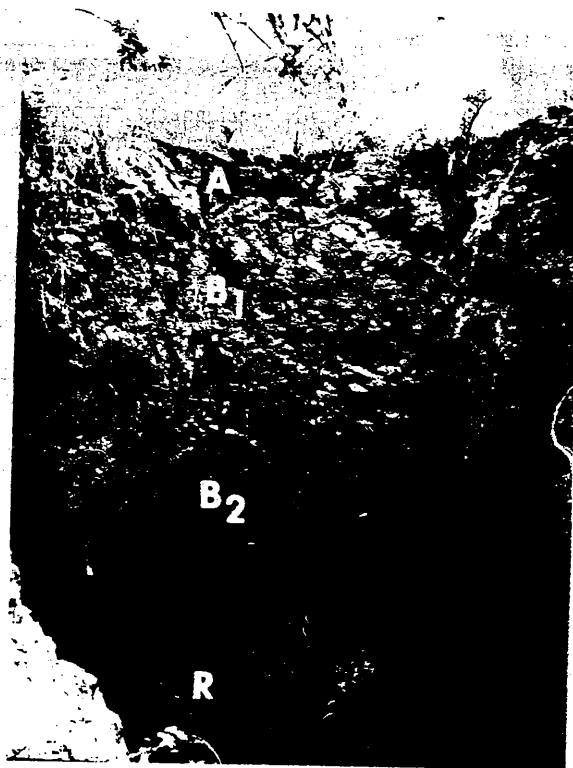


Fig. 4. Soil profile underlying the Wetherill Burn near the macroplot sample. The soil in this pit typifies the Roubideau very fine sandy loam. Note the deep, highly structured B₂ horizon and the absence of CaCO₃.

TABLE 4
DESCRIPTION OF THE SOIL PROFILE
UNDERLYING THE WETHERILL BURN
NEAR THE MACROPLOT SAMPLE

Horizon	Depth (inches)	Description
A ₁₁	0-4	Brown (7.5YR 5/2, dry) to dark brown (7.5YR 3/2, moist) very fine sandy loam; moderate to strong very fine granular structure; consistence soft dry, very friable moist; noncalcareous; weakly platy structure in the upper inch or two; lower boundary clear and smooth.
A ₁₂	4-7	Reddish-brown (5.0YR 5/3, dry) to reddish-brown (5.0YR 4/3, moist) very fine sandy loam; weak medium structure breaking to weak to
B ₁	7-12	moderate medium subangular blocks; consistence slightly hard dry, and very friable moist; many fine pores, numerous fine worm casts; noncalcareous; lower boundary clear and smooth.
B ₁	7-12	Reddish-brown (5.0YR 5/4, dry) to dark reddish-brown (5.0YR 3/4, moist) heavy loam; moderate medium prismatic structure breaking to moderate medium subangular blocks; consistence hard dry, and very friable moist; a few very thin and patchy clay skins on soil peds, noncalcareous; lower boundary clear and smooth
B ₂₁	12-19	Reddish-brown (5.0YR 5/4, dry) to dark reddish-brown (5.0YR 3/4, moist) clay loam; moderate medium prismatic structure breaking to moderate to strong medium angular blocks; consistence very hard dry to firm moist; many thin patchy clay skins on ped surfaces with some slickenside surfaces; a few weathered sandstone fragments; noncalcareous; lower boundary clear and smooth.
B ₂₂	19-32	Reddish-brown (slightly redder than 5.0YR 5/4, dry, and 5.0YR 4/4, moist) heavy clay loam; strong medium prismatic structure breaking to strong medium angular blocks; consistence very hard dry, and firm moist; thin almost continuous clay skins on soil peds; slickenside numerous; noncalcareous; lower boundary clear and smooth.
R	32	Relatively unweathered sandstone with extensions of B ₂₂ into cracks.

The Long Mesa Burn of 1873: the Mountain
Brush-Incipient Forest Seral Stage

Long Mesa lies due east of Wetherill Mesa (Fig. 1). Its northern ridges are within the area of the 1934 Wetherill Burn. Much of the northern part of Long Mesa and a large segment of Long Canyon show evidence of a fire that occurred before the park was established. To my knowledge, this burn antedates the settling of the region by early ranchers.

A site was selected on a narrow ridge where the fire, originating in Long Canyon, had spread over part of the mesa top (Fig. 1). This small section of the Long Mesa Burn was bordered on the north and south by pinyon-juniper forest.

Dating the Burn.

Cross sections were cut from pinyon pines that had been killed by the fire. The results given in Table 5 indicate that the event must have occurred *after* 1870. This was not a bark date since the terminal rings had weathered away, and the date presumably represents the latest date of the outermost persisting rings.

TABLE 5

OUTSIDE RING DATES OF PINYON PINES
KILLED IN THE LONG MESA BURN OF 1873

Mesa Verde Specimen No.	Outside Ring Date
3002	1870
3003	1810±
3004	c.1846
3005	no date
3009	1868
3011	no date
3015	no date
3016	no date
3019	1869
3020	c.1860

The most recent year in which the fire might have occurred is 1896. This is the pith date of the oldest living tree within the burn. This second line of evidence—increment cores from trees that have come in subsequent to the fire (Table 6)—provided the latest dates possible for the burn.

More precision was made possible by studying two Douglas-fir trees that were caught in the upward

TABLE 6

DATES FOR PINYON-JUNIPER ESTABLISHMENT
FOLLOWING THE LONG MESA BURN OF 1873

Mesa Verde Specimen No.	Species	Inside Ring Date ¹
3047	Utah juniper	1896±nc ²
3048	Utah juniper	1908 nc
3055	pinyon pine	1927 p ³
3056	pinyon pine	1901 p
3057	pinyon pine	1912 nc
3058	pinyon pine	1907 nc
3059	pinyon pine	1907 nc
3060	pinyon pine	1900 p
3063	pinyon pine	1905 p
3064	pinyon pine	1900±nc
3065	pinyon pine	1912 nc

¹Based on increment cores

²nc indicates "near center"

³p indicates "pith"

sweep of the fire as it moved out of Long Canyon. A wedge (Mesa Verde specimen No. 3066) was cut from one of the trees destroyed by the fire. The ring series from this section was plotted and matched with the master chronology developed for Mesa Verde by dendrochronologists of the Laboratory of Tree-Ring Research (Fig. 5). The pith date was 1663; the extremely eroded outermost ring was 1871 (Fig. 6), a date that was in accord with those from the mesa-top samples.

At the same time the wedge was collected, an increment core (Mesa Verde specimen No. 3067) was taken from a Douglas-fir tree that was living but had probably been affected by the fire. David Smith studied the core and arrived at a probable fire date of 1874 based on a suppression wood sequence from 1874 through 1889 (Fig. 7). Apparently no xylem increment occurred in the position from which the increment core was taken during the initial years, for only ten rings are evident in the suppression series.

In light of radial growth studies reported by Douglas and Erdman (1967) and a closer analysis of the increment core in Figure 7, the year 1873 may be a more accurate date of the Long Mesa fire. Radial growth in Douglas-fir terminates by late spring, certainly by early June. Therefore, the increment laid down the year of the fire should be normal, not locally absent or suppressed; 1873 is the last normal ring before the sequence, 1874 through 1889.

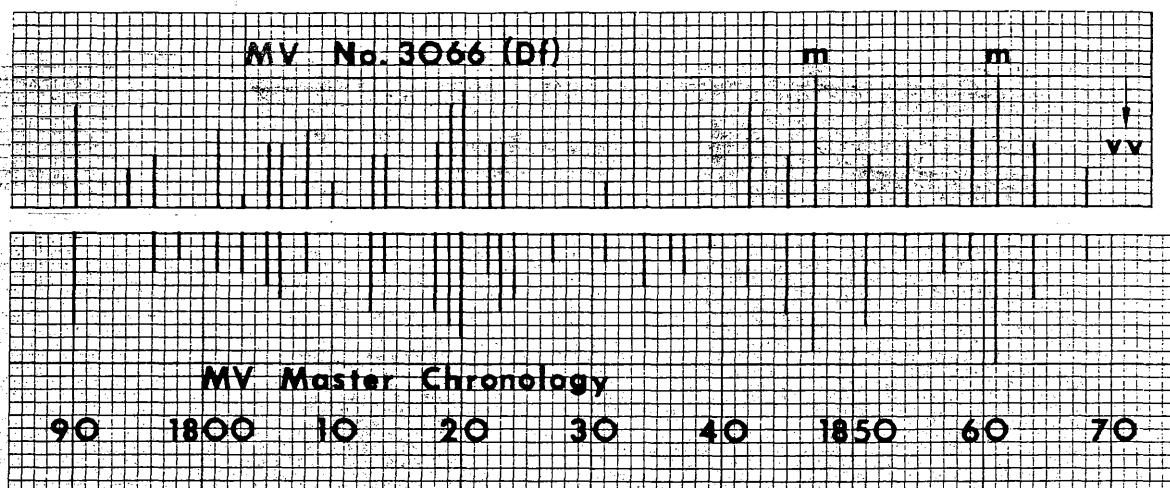


Fig. 5. Dating the Long Mesa Burn: Cross-dating the skeleton plot derived from the wedge of a burned Douglas-fir with the Mesa Verde master chronology. A diagnostic grouping, or "signature" occurs in the 1818-24 sequence. Other key years are 1847, 1851, and 1861. The annual increments for 1847 and 1861 are missing from the specimen (indicated by the letter m). The extremely eroded outermost ring of 1871 is indicated by the symbol vv.

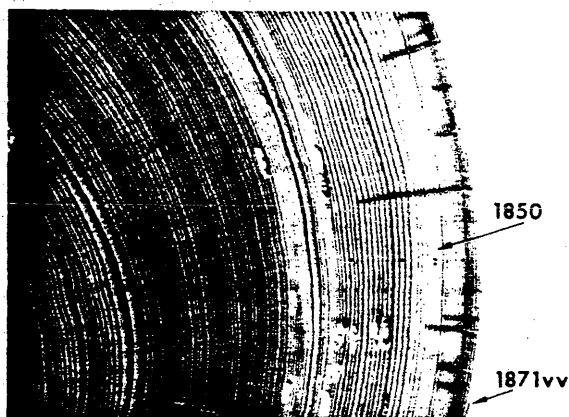


Fig. 6. Dating the Long Mesa Burn: Part of the wedge of a burned Douglas-fir (Mesa Verde specimen No. 3066) from which the skeleton plot shown in Figure 5 was made. The cross-dating provided an outermost ring date of 1871. The single pinholes indicate decades; the double pinhole, the 1850 increment.

Vegetation.

The present vegetation in the Long Mesa Burn is a dense entanglement of shrubs and young trees (Fig. 8). The dead, charred snags of the former forest are generally screened by this new vegetation.

The pinyon-juniper component of the stand has been increasing since the turn of the century, when the first seedlings were established (Table 6). Although the older trees are 15 to 20 feet in height, the mountain brush species continue to characterize the stand (Table 7). The shrubs with the maximum cover and greatest frequency were bitterbrush (*Purshia tridentata*) and *Fendlera rupicola*, both almost tree-like in their growth habits here, in contrast to their small size in the climax forest.

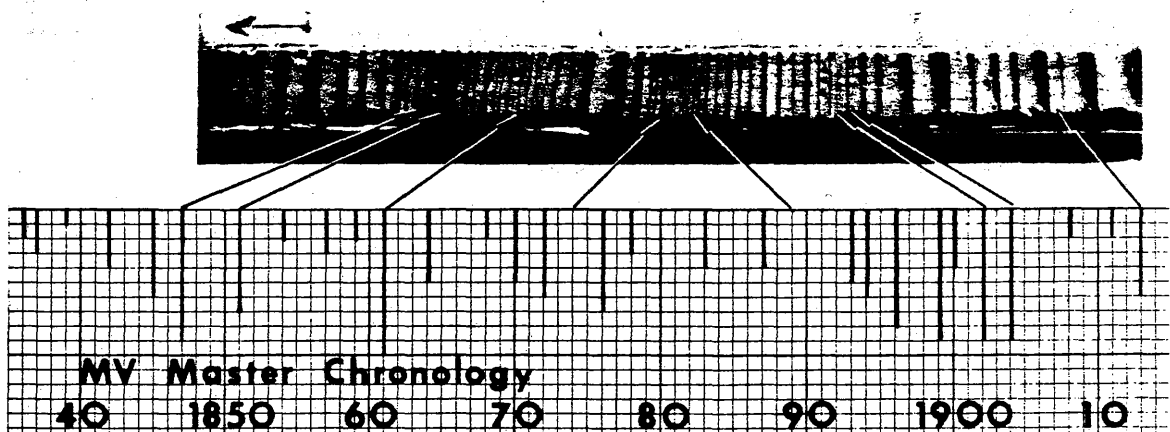


Fig. 7. Dating the Long Mesa Burn: Increment core of Douglas-fir cross-dated with the Mesa Verde master chronology. The length of each vertical bar on the graph is inversely proportional to the relative width of the ring; average width rings are not recorded. The suppression wood between the years 1874 and 1889 is atypical and reflects the effect of the fire. Micro-rings occurred in 1847, 1851, 1861, 1902, and 1904.



Fig. 8. Aspect of the Long Mesa Burn in July 1963. The mountain brush species dominate the stand although the cone-bearing pinyon-juniper canopy is overtopping them. The charred snag in the center was a mature Utah juniper. Elevation, 7,400 feet.

Most of the herbs sampled were perennials, the only exceptions being *Polygonum sawatchense*, found in the pinyon-juniper forest throughout Mesa Verde, the widespread cheatgrass (*Bromus tectorum*), and the almost equally common weed, *Lappula redowskii*.

Soil.

The soil underlying the burn is identified as a shal-

low phase of Montvale fine sandy loam. It is very stony and highly calcareous, as is evident in Figure 9. Eolian sediments are possibly a minor influence in this solum, developing residually from weathered Cliffhouse sandstone.

Plant growth may be enhanced by the underlying fractured sandstone, which serves as a reservoir for additional soil moisture, and by some lateral flow along the bedrock surface.

TABLE 7
COVER AND FREQUENCY OF THE VEGETATION
IN THE LONG MESA BURN SAMPLE
ELEVATION 7,400 FEET. SEPTEMBER, 1963

Species	% Cover	% Frequency*
Trees		
<i>Pinus edulis</i>	19	46
<i>Juniperus osteosperma</i>	6	12
Shrubs		
<i>Purshia tridentata</i>	26	82
<i>Fendleria rupicola</i>	14	48
<i>Yucca baccata</i>	13	40
<i>Cercocarpus montanus</i>	2	10
<i>Quercus gambelii</i>	+**	4
<i>Amelanchier utahensis</i>	+	2
Herbs		
<i>Poa fendleriana</i>	<4	56
<i>Lappula redowskii</i>	<4	32
<i>Oryzopsis hymenoides</i>	<4	16
<i>Opuntia polyacantha</i>	<4	6
<i>Eriogonum umbellatum</i>	<4	6
<i>Bromus tectorum</i>	+	22
<i>Penstemon linarioides</i>	+	16
<i>Sitanion hystrix</i>	+	8
<i>Senecio multilobatus</i>	+	6
<i>Bouteloua gracilis</i>	+	4
<i>Cryptantha bakeri</i>	+	4
<i>Polygonum sawatchense</i>	+	4
<i>Artemisia ludoviciana</i>	+	2
<i>Schoenocrambe linifolium</i>	+	2
<i>Gutierrezia sarothrae</i>	+	2
<i>Sphaeralcea coccinea</i>	+	2
<i>Petradoria pumila</i>	+	2
<i>Penstemon strictis</i>	+	2
Ground		
litter	25-33	100
soil	10-25	46
rock	<4	36

*Based on 50 subplots.

**Indicates presence but no significant cover value.

This profile is similar to the profile described in the climax forest nearby (Table 11), although the former is four inches less in total depth and has a slightly coarser-textured B₂ horizon.

The Long Mesa Climax Site: the Pinyon-Juniper/Mountain Brush Stage

One mile north of the Long Mesa Burn lies a small stand of pinyon-juniper that was missed by both the



Fig. 9. Soil profile underlying the Long Mesa Burn. This soil is transitional between Montvale fine sandy loam and shallower series. The highly structured, blocky B₂ is developing between fragments of Cliffhouse sandstone which overly a pronounced C_{ca} horizon.

1873 and 1934 fires (Fig. 1). This stand was studied for two reasons. First, as a remnant of the forest that was destroyed in the 1873 burn, it served as a control. Secondly, and of more significance, it is considered to be representative of the type of vegetation that can develop on relatively shallow soils in the Mesa Verde only after centuries of little disturbance—the climax forest-type under the present climatic regime.

Vegetation.

This 400-year-old stand consists of but a few characteristic species. Those apparent in Figure 10 are *Yucca baccata*, *Poa fendleriana*, the prickly-pear, *Opuntia polyacantha*, and some scraggy examples of the mountain brush element.

On the basis of the macroplot analysis (Table 8), the pinyon pine and Utah juniper are clearly codominants, with similar cover values and frequencies. But from the results given in Table 9, juniper is more dominant than pinyon pine, and is of considerably more importance in the stand. These differences are due to differences in the criterion used to determine dominance. The macroplot method stresses cover from the canopy; the point quarter method summarized in Table 9 emphasizes board feet. Cover was

based on canopy projection irrespective of tree size; the point quarter study excluded trees less than four inches in diameter. Pinyon pine had a relatively small trunk compared with juniper, averaging seven inches in diameter. Trunks of juniper averaged 20 inches. The density transects reported in Table 10 indicate

that pinyon pine was more numerous when seedlings and saplings are considered. Thus, although juniper was the aspect dominant, pinyon pine was more abundant. Both species attained crown heights of 35 feet, about the maximum reported for other parts of the Mesa Verde.

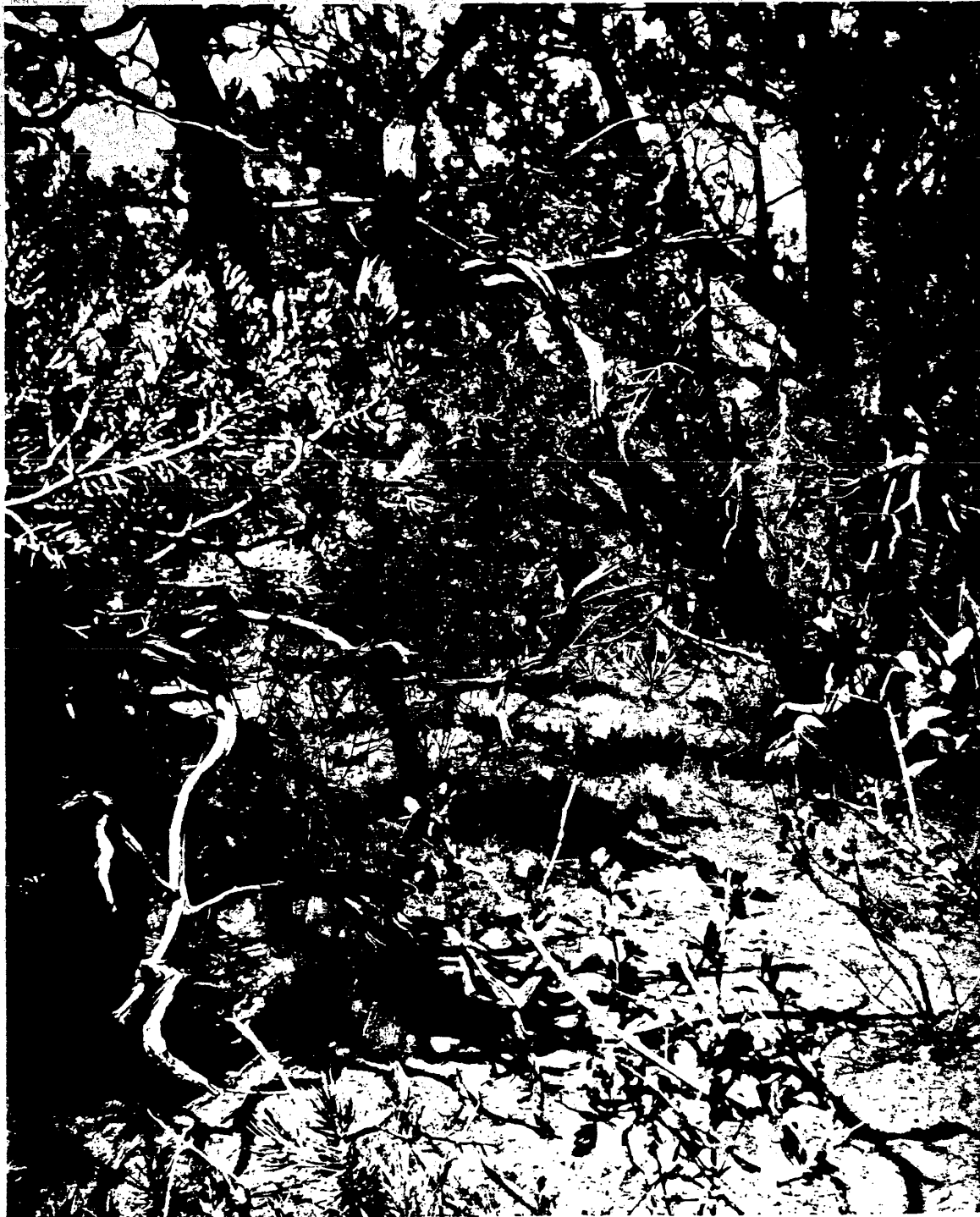


Fig. 10. Aspect of the Long Mesa climax stand in July 1963. The sparse understory consists mostly of *Poa fendleriana*, *Yucca baccata*, and generally suppressed shrub species such as the mountain mahogany in the foreground. Elevation, 7,600 feet.

The age of the stand was based upon increment cores taken from the older trees in the stand. The oldest pith ring date, 1576, came from a 21-inch diameter pinyon. The considerably greater diameters of juniper trunks, however, suggest that this species may be the older of the tree components. Unfortunately, mature juniper trees can rarely be dated.

TABLE 8
COVER AND FREQUENCY OF THE VEGETATION
IN THE LONG MESA CLIMAX FOREST
ELEVATION 7,600 FEET. AUGUST, 1963

Species	% Cover	% Frequency*
Trees		
<i>Juniperus osteosperma</i>	31	50
<i>Pinus edulis</i>	27	48
Shrubs		
<i>Cercocarpus montanus</i>	14	28
<i>Yucca baccata</i>	2	14
<i>Symphoricarpos oreophilus</i>	2	12
<i>Fendlera rupicola</i>	2	8
<i>Amelanchier utahensis</i>	***	2
<i>Purshia tridentata</i>	+	2
Herbs		
<i>Poa fendleriana</i>	4-10	80
<i>Penstemon linarioides</i>	<4	24
<i>Opuntia polyacantha</i>	<4	10
<i>Comandra umbellata</i>	+	14
<i>Eriogonum umbellatum</i>	+	8
<i>Petrorhiza pumila</i>	+	8
<i>Polygonum sawatchense</i>	+	6
<i>Schoenocrambe linifolium</i>	+	6
<i>Lupinus ammophilus</i>	+	4
<i>Oryzopsis hymenoides</i>	+	4
<i>Lappula redowskii</i>	+	4
<i>Bromus tectorum</i>	+	4
<i>Sitanion hystrix</i>	+	2
<i>Pedicularis centranthera</i>	+	2
<i>Cryptantha bakeri</i>	+	2
<i>Chenopodium fremontii</i>	+	2
<i>Balsamorhiza sagittata</i>	+	2
Ground		
litter	33-50	94
soil	4-10	48
rock	<4	20

*Based on 50 subplots.

**Indicates presence but no significant cover value.

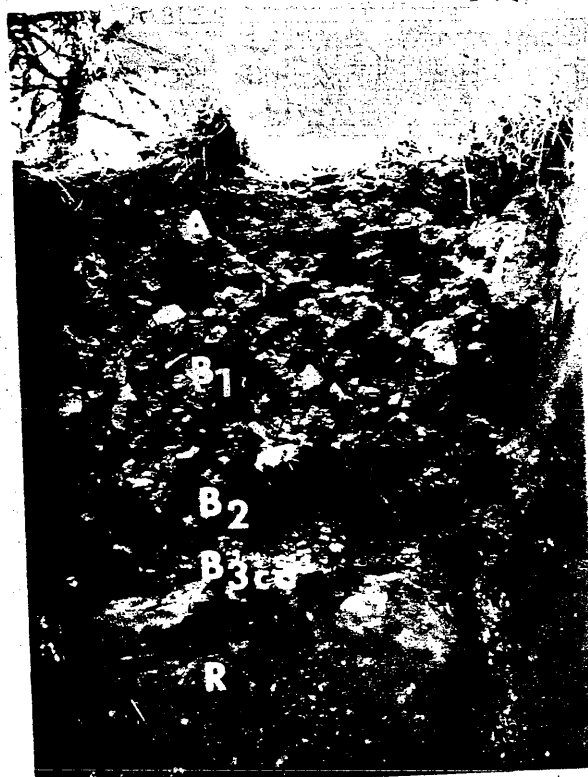


Fig. 11. Soil profile underlying the Long Mesa climax stand. The Montvale fine sandy loam has a finer-textured B horizon than is typical, but otherwise it is representative.

Soil.

This soil, too, has been tentatively identified as Montvale fine sandy loam. It has a finer-textured B horizon than is typical of most of the Montvale soils mapped in the area by Parsons (MS), but it is otherwise representative. The CaCO_3 component is less extensive than that in the burn sample. The profile (Fig. 11) is described in Table 11.

Additional Evidence on Climax: Ute Pinyon-Juniper/Mountain Brush Forest

An answer to the problem of determining climax vegetation is especially difficult in the park proper because prehistoric burns cover the entire northern third of its area. On the other hand, the Ute Indian holdings of the Mesa Verde to the west remain relatively unaffected by fire. For whatever reason, a mature pinyon-juniper forest covers that section of the mesa. The mountain brush or chaparral "zone" so familiar in the park is not evident on the Reservation.

In 1963, a reconnaissance flight over Mesa Verde prompted a brief excursion into the reservation forest. On July 11, 1964, a small field party ascended the North Rim in the vicinity of the Mesa Verde Mine, about four miles west of Wetherill Mesa. A

TABLE 9

POINT QUARTER ANALYSIS OF THE PINYON-JUNIPER ELEMENT IN THE LONG MESA CLIMAX FOREST*

Species	Number of Trees	Mean Distance (feet)	Basal Area (inches ²)	Density No./Acre	Dens. (%)	Relative Freq. (%)	Dom. (%)	Importance Value (D+F+Do)
<i>Juniperus osteosperma</i>	24	-	7,309	155	60	53	92	205
<i>Pinus edulis</i>	16	-	647	103	40	47	8	95
all trees	40	13	7,956	258	100	100	100	300

*Sampling method included only those trees greater than four inches in diameter.

TABLE 10

TREE DENSITY ANALYSIS OF THE LONG MESA CLIMAX FOREST BASED ON TEN 4x50-FOOT BELT TRANSECTS

Species	Seedlings*	Saplings**	Trees***	Total
<i>Pinus edulis</i>	6	10	8	24
<i>Juniperus osteosperma</i>	5	0	9	14

*Individuals less than one foot in height.

**Individuals taller than one foot but with the main stem less than two inches in diameter.

***Individuals with main stems greater than two inches in diameter.

pinon-juniper stand with a mountain-brush understory similar to the one studied on Long Mesa was selected for observation (Fig. 12). The elevation of this ridge-top site was 7,900 feet.

The species composition was generally similar to that in the Long Mesa climax stand, except for some herbs along the North Rim in the park.

The tree stratum was very similar to that on Long Mesa, although the Ute stand tended to be more open (Table 12). Maximum height was 35 feet and the approximate age was 400 years. One of the largest pinyon pines observed in the Mesa Verde was cored at this site; the diameter was 32 inches, and the date of the center ring was 1539. Several other pinyons dated around 1600. A Utah juniper, 20 feet tall and 15 inches in diameter was also cored. The center ring



Fig. 12. Detail of the pinyon-juniper/mountain brush element that characterizes the higher parts of the Mesa Verde in the Ute Mountain Indian Reservation. Elevation at this ridge-top site is 7,900 feet.

date was 1570, nearly as old as the pinyon of twice the size. The largest juniper in the point quarter analysis was 36 inches in diameter. These data, along with similar results obtained elsewhere, suggest that the juniper component in much of the forested sections of the Mesa Verde is considerably older than the pinyon pine codominant.

TABLE 11

Table 11 (Continued)

DESCRIPTION OF THE SOIL PROFILE
UNDERLYING THE LONG MESA CLIMAX FOREST

Horizon	Depth (inches)	Description			
A ₁	0-4	Brown (7.5YR 5/3, dry) to dark brown (7.5YR 3/3, moist) fine sandy loam; moderate to strong very fine granular structure; consistence soft dry, and very friable moist; considerable dark organic flakes and very many fine almost matted roots; non-calcareous; lower boundary clear and smooth.	B ₂₂	10-14	Reddish-brown (5.0YR 5/4; dry) to reddish-brown (5.0YR 3/4, moist) clay loam; moderate medium prismatic structure breaking to strong medium and fine angular blocky structure; consistence very hard dry, and firm to slightly friable moist; almost continuous clay skins with some slickensides; 25 percent weathered sandchips; non-calcareous; lower boundary clear and smooth.
B ₁	4-7	Brown (slightly redder than 7.5YR 5/4, dry) to dark brown (slightly redder than 7.5YR 3/4, moist) loam; weak medium subangular structure; consistence slightly hard dry, and very friable moist; very many fine roots and pores; noncalcareous; lower boundary clear and smooth.	B _{3ca}	14-16	Brown (7.5YR 5/4, dry) to dark brown (7.5YR 4/4, moist) heavy loam or light clay loam; weak medium subangular blocky structure; consistence hard dry, and friable moist; white chalky lime concretions, 25 percent sandstone fragments; very thin patchy clay skins; strongly calcareous; lower boundary clear and smooth with large roots following along underlying sandstone surface.
B ₂₁	7-10	Brown (slightly redder than 7.5YR 5/4, dry) to dark brown (slightly redder than 7.5YR 3/4, moist) heavy loam; weak medium prismatic structure breaking to moderate medium angular blocky structure; consistence very hard dry, and very friable moist; thin patchy clay skins; many fine roots,	R	16	Relatively indurated sandstone.

TABLE 12

POINT QUARTER ANALYSIS OF THE PINYON-JUNIPER ELEMENT IN THE
UTE MOUNTAIN INDIAN RESERVATION CLIMAX*

Species	Number of Trees	Mean Distance (feet)	Basal Area (inches ²)	Density No./Acre	Dens. (%)	Relative Freq. (%)	Dom. (%)	Importance Value (D+F+Do)
<i>Juniperus osteosperma</i>	27	—	9,020	61	68	56	81	205
<i>Pinus edulis</i>	13	—	2,111	29	32	44	19	95
all trees	40	22	11,131	90	100	100	100	300

*Sampling method included only those trees greater than four inches in diameter.

Dendrochronology: A New Application

The counting of rings from actively growing trees has been used for years to determine the age of forest stands and even some geomorphological events. For instance, ring counts have provided some information on the effects of fire and other disturbances on the pinyon-juniper type in Arizona (Arnold, Jameson, and Reid, 1964). This simple dating technique is not usable, however, in dating fires because we do not know how soon living trees become established after burns (Fig. 13). On the other hand, the method of cross-dating specimens directly affected by a fire with a master chronology for the region can provide rather accurate dating information.



Fig. 13. A pinyon pine began growing in the burned-out base of a juniper about 1880, and thereby established a baseline from which to work back in time to determine the date of the fire. This site is on Big Mesa in the eastern part of the Mesa Verde. An 18-inch increment borer provides a scale.

In the Mesa Verde, for example, the northern ridge of Moccasin Mesa is covered with a scattering of young pinyon-junipers, most of which were established around the turn of the present century. All the charred specimens collected for dating purposes, however, placed the burn in the 18th century. Perhaps recurrent flash fires prevented the return of pinyon-junipers for almost a century. In any event, this information would not have been available from simple ring counts.

In summary, where master chronologies are available or can be built, cross-dating trees destroyed or otherwise affected by fire provides reliable data concerning the time of the disturbance. This technique might well be applied to other ecological work of this sort.

DISCUSSION AND CONCLUSIONS

Pinyon-Juniper Succession after Fires on Residual Soils of Mesa Verde

In Mesa Verde sites where dense stands of pinyon-juniper on shallow, residual soils have been burned, recovery begins with the establishment of annuals, which reach a maximum density in two to three years. *Helianthus* and *Chenopodium* are the initial dominant pioneers, followed by Russian thistle (*Salsola kali*) and *Machaeranthera bigelovii*. By the fourth year perennial grasses dominate the burn. Under natural conditions, these consist of Indian ricegrass (*Oryzopsis hymenoides*), muttongrass (*Poa fendleriana*), and squirreltail (*Sitanion hystrix*). The grass and forb stage eventually gives way to a persistent mountain-brush vegetation type. This postfire sere is generally consistent with the one reported by Arnold, Jameson, and Reid (1964) in Arizona.

When fires recurred periodically in prehistoric times, a chaparral fire climax persisted along the upper reaches of Mesa Verde. But under the present protective regime, a young, open stand of trees is gradually suppressing the shrub element, and eventually a mature forest may again be established. These successional stages following a fire are given in Figure 14.

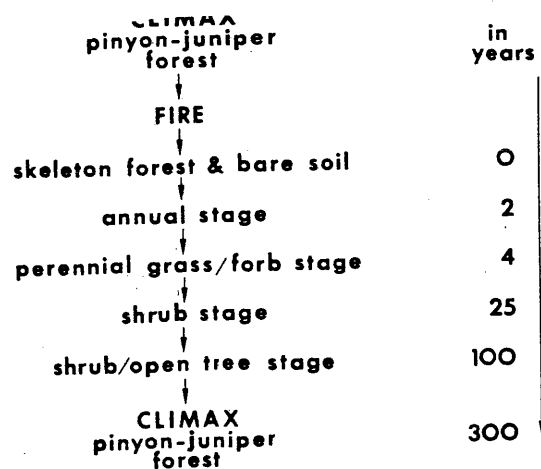


Fig. 14. Suggested successional stages after fire on residual soils of the Mesa Verde.

Details of species change in the postfire sere, summarized in Table 13, lead to the following conclusions. First, in the change toward a climax status there is a definite trend towards impoverishment in the floristic composition. In the young Morfield Burn community there were 47 species, compared to 40 in the older Wetherill Burn, 28 in the Long Mesa Burn, and 26 in the climax forest. This trend is due primarily to the reduction of weedy annuals and biennials.

TABLE 13
SPECIES LISTING BY COMMUNITY ACCORDING TO SUCCESSIONAL STATUS*

Species**	1959 Burn	1934 Burn	1873 Burn	Climax Forest
Trees				
<i>Pinus edulis</i> Engelm.		+	+	+
<i>Juniperus osteosperma</i> (Torr.) Little			+	+
Shrubs				
<i>Chrysothamnus nauseosus</i> (Pall.) Britt.	+	+		+
<i>Quercus gambelii</i> Nutt.	+	+	+	+
<i>Amelanchier utahensis</i> Koehne	+	+	+	+
<i>Cercocarpus montanus</i> Raf.	+	+	+	+
<i>Fendlera rupicola</i> A. Gray	+	+	+	+
<i>Yucca baccata</i> Torr.	+	+	+	+
<i>Purshia tridentata</i> (Pursh) DC.		+		+
<i>Symphoricarpos oreophilus</i> A. Gray		+		
Grasses				
<i>Agropyron desertorum</i> (Fisch.) Schult.	+			
<i>Agropyron intermedium</i> (Host.) Beauv.	+			
<i>Bromus carinatus</i> Hook. & Arn.	+			
<i>Bromus inermis</i> Leyss.	+			
<i>Bromus japonicus</i> Thunb.	+			
<i>Triticum aestivum</i> L.	+			
<i>Bromus tectorum</i> L.	+	+	+	+
<i>Oryzopsis hymenoides</i> (R. & S.) Ricker	+	+	+	+
<i>Poa fendleriana</i> (Steud.) Vasey	+	+	+	+
<i>Sitanion hystrix</i> (Nutt.) J. G. Smith	+	+	+	
<i>Koeleria gracilis</i> Pers.		+		
<i>Stipa comata</i> Trin. & Rupr.			+	
<i>Bouteloua gracilis</i> (H.B.K.) Lag.			+	
<i>Sporobolus cryptandrus</i> (Torr.) A. Gray			+	
Subshrubs and Forbs				
<i>Helianthus annuus</i> L.	+			
<i>Chenopodium pratericola</i> Rydb.	+			
<i>Salsola kali</i> L.	+			
<i>Camelina microcarpa</i> Andr.	+			
<i>Descurainia pinnata</i> (Walt.) Britt.	+			
<i>Descurainia sophia</i> (L.) Webb. ex E. & P.	+			
<i>Melilotus officinalis</i> (L.) Lamb	+			
<i>Arabis selbyi</i> Rydb.	+			
<i>Astragalus scopulorum</i> T. C. Porter	+			
<i>Lithospermum ruderale</i> Dougl.	+			
<i>Cirsium cf. undulatum</i> (Nutt.) Spreng.	+	+		
<i>Lactuca scariola</i> L.	+	+		
<i>Machaeranthera bigelovii</i> (Gray) Greene	+	+		
<i>Moldavica parviflora</i> (Nutt.) Britt.	+	+		
<i>Tragopogon dubius</i> Scop.	+	+		
<i>Viguiera multiflora</i> (Nutt.) Blake	+	+		
<i>Erigeron flagellaris</i> A. Gray	+	+		
<i>Eriogonum racemosum</i> Nutt.	+	+		
<i>Heterotheca villosa</i> (Pursh) Shinnars	+	+		+
<i>Lupinus caudatus</i> Kell.		+		
<i>Zygadenus paniculatus</i> (Nutt.) Wats.		+		
<i>Sphaeralcea coccinea</i> (Pursh) Rydb.	+	+	+	+
<i>Lappula redowskii</i> (Hornem.) Greene	+	+	+	+
<i>Polygonum sawatchense</i> Small	+	+	+	+
<i>Schoenocrambe linifolium</i> (Nutt.) Greene	+	+		+
<i>Balsamorhiza sagittata</i> (Pursh) Nutt.	+	+		+
<i>Comandra umbellata</i> (L.) Nutt.	+	+	+	+
<i>Opuntia polyacantha</i> Haw	+	+	+	+
<i>Penstemon linarioides</i> A. Gray	+	+	+	+
<i>Petradoria pumila</i> (Nutt.) Greene	+		+	
<i>Senecio multilobatus</i> T. & G. ex A. Gray			+	
<i>Senecio mutabilis</i> Greene		+	+	
<i>Artemisia ludoviciana</i> Nutt.	+	+		

TABLE 13 (Continued)

<i>Gutierrezia sarothrae</i> (Pursh) B. & R.	+	+	
<i>Crepis</i> sp.	+		
<i>Cymopterus bulbosus</i> A. Nels.	+		
<i>Penstemon strictis</i> Benth. ex DC.		+	
<i>Cryptantha bakeri</i> (Greene) Payson		+	+
<i>Eriogonum umbellatum</i> Torr.		+	+
<i>Lupinus ammophilus</i> Greene			+
<i>Pedicularis centranthera</i> A. Gray ex Torr.			+

*Within groups pioneer plants are listed first while those more restricted to the climax forest are last.

**Nomenclature follows that of Welsh and Erdman (1964); more recent nomenclatural changes were provided by William A. Weber, University of Colorado Museum.

Inasmuch as several of the grasses listed in Table 13 are adventives, the permanency of those artificially seeded will require further study. *Poa fendleriana*, on the other hand, is the most characteristic grass in the Mesa Verde area and in much of the pinyon-juniper climax region of the Southwest.

All the shrubs listed, except rabbitbrush (*Chrysothamnus nauseosus*), are common in the pinyon-juniper/mountain-brush forests of the Southwest; and probably all of these, except rabbitbrush, reproduce in varying degrees by crown-sprouting. Resprouting of the bitterbrush (*Purshia tridentata*) was not observed, although it is known to sprout or stem layer in California (Nord, 1959). Snowberry (*Symphoricarpos oreophilus*) may propagate similarly, for it occurs in the fairly recent burn at Wetherill Mesa. Another species of snowberry, *S. rivularis*, crown-sprouts along coastal California (Wells, 1962). The rapid recovery of the subshrubs after the Morfield fire suggests that they, too, must resprout.

Crown-sprouting shrubs have a decided advantage over Utah juniper and pinyon pine during at least the first 100 years of succession because reestablishment of these trees depends entirely on seed production. The chief agents for dispersal of juniper seed are animals, as reported in a scat analysis by Arnold, Jameson, and Reid (1964). Cheek pouches of a chipmunk trapped in Mesa Verde were full of such seeds (C. L. Douglas, personal communication). The means by which pinyon seeds are spread are not as well known, but rodent caches are probably a major factor.

Woodbury (1947) stated that Utah juniper may precede pinyon pine in succession towards climax, although I found no conclusive evidence for this occurring in the Mesa Verde area. In the sample on Wetherill Mesa, pinyon was the first tree in forest establishment; but on Long Mesa, Utah juniper preceded pine by several years (Table 6). Juniper may have a small recovery advantage in that it needs no nurse plant, whereas pinyon invariably does (Phillips, 1909; Meagher, 1943; Erdman, MS.).

Shade has traditionally been considered the factor required to produce sufficiently moist conditions for

pinyon pine germination. But data collected in 1964 (Table 14) indicate that tree canopies may intercept a considerable amount of precipitation, with the result that soil moisture regimes under the litter beneath the trees are poorer than are those in the more insolated openings. Or, the lack of moisture under the canopies may be the result of depletion due to roots in that area.

TABLE 14

COMPARISON OF SOIL MOISTURE (% DRY WEIGHT) BETWEEN TREE CANOPIES AND ADJACENT OPENINGS, CHAPIN MESA*

Date	Canopy	Opening
1 May 1964	11.7	20.0
1 June 1964	8.9	11.0
1 July 1964	7.4	6.5
1 August 1964	9.5	14.3
1 September 1964	7.9	8.1

*Based on gravimetric samples from six inches below the soil surface; about four inches of litter covered the soil under the canopy.

An alternative explanation is the relatively low optimum temperature required for germination. I have found that 70°F is the optimum germinating temperature for pinyon pine seeds from Mesa Verde and this agrees with earlier studies by Kintigh (1949). Kintigh not only found that germination was most rapid and complete at this temperature, but that it was also most favorable for the growth of the seedlings. I discovered that the lethal threshold occurred between 85° and 100°F. In a recent study of the regional and local environments (Erdman, Douglas, and Marr, 1969), it was found that temperatures two inches below the ground surface in unshaded sites during summer and early fall months were commonly above 100°F, albeit for only a few hours at a time. Even at 6-inch depths, temperatures exceeded 90°.

By comparison, soil temperatures under the tree canopies were found to be moderate. Such conditions are believed to be due more to the insulating effects of tree litter than to the shade afforded by the trees themselves (Oosting, 1956).

The Status of the Present Forest Stands

The pinyon-juniper stands on Mesa Verde are approaching climax status, the condition in which no appreciable change is taking place under prevailing conditions (Hanson and Churchill, 1961). These stands have been largely free of disturbance for several centuries, yet the structure of age-classes in the pinyon population does not fit the typical structure of a climax stand. The oldest age-class, 400 to 500 years (Table 15), is younger than the age this species is capable of attaining in this environment (Smiley, 1958). Furthermore, there is a dearth of dead and fallen pinyon trees. At the same time, there

is an abundance of old and of dead juniper trees (Erdman, MS.). I have been able to determine the age of some of the smaller juniper trees by cross-dating cores with the master tree-ring chronology for Mesa Verde. Extrapolating from these data, it is reasonable to conclude that the oldest junipers are several hundred years older than the most ancient pinyons.

These observations suggest the possibility that some factor in the environment has affected adversely the pinyon component of an otherwise relatively stable climax forest. Several possible factors such as porcupine feeding pressure, blight, and drought are discussed below.

Spencer, (1964), after making a thorough timber survey of Mesa Verde, stated that the scattered, older pinyons are from 300 to 500 years of age, indicating a relatively young pinyon element on the mesa. Dates in support of this finding are given herein (see Table 15). Spencer contended that porcupines have contributed to the maintenance of this condition, but the evidence he presents does not entirely bear out his conclusion. While feeding pressures were high in the canyons and along the perimeters of the mesa, the incidence of porcupine feeding on the mesa tops ranged from zero to only 7 percent. This can hardly account for the relatively young stands of pinyons extant on the mesa tops.

A more serious toll on pinyon pine has been exacted by the root fungus, *Leptographium*, as reported by Mielke (MS.), and by Wagener and Mielke (1961). This disease was first discovered in Mesa Verde in 1942, but field evidence indicates the infestation is of long standing. Losses of mature trees seem to have been heavy, but there are no indications that the fungus ever threatened to eliminate pinyon altogether. Wagener and Mielke observed:

Most of the escapes [sic] are small trees with limited root systems that do not come in close contact with diseased roots. These escapes provide the nucleus for a new stand on the areas over which the disease has passed. In Mesa Verde National Park all stages of residual and replacement stands of pinyon in old disease areas can be found.

Such blights also occur in many areas of the mesa beyond the park boundaries, and it may well be that these diseased stands, with a spread rate of about 40 feet each 6 years, could account for a youthful pinyon forest, especially where the incidence is highest in the deeper-soil mesa centers.

Bark beetles of the genus *Ips* are known to invade *Leptographium*-infected trees. Broods originating in such trees sometimes attack and kill neighboring pinyons, but losses from primary *Ips* attack are apparently low (Wagener and Mielke, 1961).

Pressures by porcupine and *Leptographium* may have been minor compared to the effects of wide-

TABLE 15

AGES OF STANDS SURVEYED SUBSEQUENT TO THE TIMBER CRUISES OF SPENCER (1964)*

Stand Location	Inside Ring Date As of 1965	Age
Ute climax, Mesa Verde Mine**	1539	426
Long Mesa climax***	1576	389
Glades climax, Chapin***	1711	254
Knife-Edge, North Rim***	1581	384
M1 station, Chapin	1529	436
M2 station, Chapin***	1647	318
CCC Camp, Chapin	1538	382
Spur, Chapin	1561	404
Research Laboratory, Chapin	1601	364
Cedar Tree Tower, Chapin	1531	434
Rock Springs, Wetherill	1457	508
Mug House, Wetherill	1606	359
South end, Wetherill	1581	384
Park-Ute boundary, Wetherill	1586	379
Double House***	1500	465
Step House	1669	296
Rock Canyon, west talus	1594	371
Rock Canyon, east talus	1644	321
Navajo Canyon, west talus	1698	267
Navajo Canyon, east talus	1723	242

*The majority of these dates are from an unpublished catalog of collections made the summer of 1961 by Thomas P. Harlan, Laboratory of Tree-Ring Research.

**Dated by James A. Erdman.

***Dated by David G. Smith.

spread drought the Southwest experienced several centuries ago, causing considerable die-out of the less resistant species, pinyon included (Smiley, 1958). According to Malde (1964), this drought occurred about A.D. 1600, and in the following two centuries the "forests expanded again around small stands of the older trees (those which flourished between 1300 and 1500) that had survived in sheltered habitats." Malde concluded: "It is a remarkable fact that most conifers in the Southwest are not older than 350 years, but that a few are nearly twice that age." These data resulted from research done under the Navajo Land Claim Project (Smiley, 1958). Smiley suggested that with the advent of a more moderate climate after the drought, the forests spread from the "islands" of older trees that acted as seed sources.

In a dendroclimatic study of western North America, Fritts (1965b) mapped regional variations in climate, based upon 10-year departures in tree-ring indices, which tend to support Smiley's theory. Of the period A.D. 1566-85, Fritts writes, "Dry conditions intensify in the Southwest and northern Rockies; a major drought develops until it finally extends throughout the entire West." In the Mesa Verde area, a center of low growth persisted from 1571-95. The 1600's ushered in an extremely good growth regime, for, as Fritts relates for the 1601-25 period, "An extensive, extremely moist climate expands throughout the central portions of the West." And of the period between 1641 and 1650, Fritts says, "Moist conditions intensify in the Rio Grande and Upper Colorado River Basins, expand into the southern and north-central portions of the West, but do not reach their previous maximum extent." Though the maps represent only a tentative reconstruction of otherwise undocumented climatic patterns, they do provide a plausible answer to the problem of age relations in the pinyon-juniper forests of the Mesa Verde. Utah juniper, the more xerophytic species, apparently was able to withstand the drought conditions.

A final problem in regard to climax at Mesa Verde involves the role of ponderosa pine. Getty (1935) stated, "Only rarely does yellow pine (*Pinus ponderosa*) occur in the [prehistoric] ruins, indicating that then, as now, this tree grew only in the northern and higher parts of the Mesa Verde, remote from most of the ruins." This misconception that ponderosa pine grows only along the upper reaches of the mesa seems quite prevalent. I have found pockets of this species, however, throughout the plateau in especially mesic sites, from Morfield Canyon on the east to Horse Springs and beyond in the Ute Indian Reservation; from the rimrock above The Knife-Edge at the northern escarpment to an extensive stand in the Pine Canyon area overlooking the Mancos Canyon to the south.

Some of these stands admittedly are no more than single fire- and lightning-scarred sentinels, looming above the surrounding brush and pinyon-juniper—possibly relicts of formerly more extensive stands. Yet in Bobcat Canyon on Wetherill Mesa, trees approaching 100 feet in height tower over saplings and seedlings of the same species. But in this instance the exceptional growth and probably the success of the stand are products of good ground-water supplies from local seeps and springs. Rand (1966) discussed factors related to distribution of ponderosa and pinyon pines at the Grand Canyon, Arizona. Some of the factors discussed are relevant to the Mesa Verde.

There is little indication that ponderosa pine has changed appreciably during the last millenium from its present pattern of distribution. As Getty (1935) said, ponderosa pine is rarely found in the prehistoric ruins, which predate the fourteenth century. And in the Wetherill Mesa excavations, those sites yielding some ponderosa artifacts are near the present stand of this species in Bobcat Canyon. During numerous surveys along the North Rim I found many large stumps charred from undated fires; but the trees were pinyon pine and Rocky Mountain juniper (*Juniperus scopulorum*), both common along the North Rim today.

It is true that with elevations generally above 7,000 feet and yearly precipitation averaging 18 inches, Mesa Verde should support a better stand of ponderosa pine. But because of its physiography, temperatures over most of the plateau exceed those normally expected at such an altitude. Based on the findings of Pearson (1931) and of Curtis and Lynch (1957) Parsons (MS.) attributed the status of ponderosa pine in Mesa Verde to an unfavorable temperature regime. Pearson (1950) summarized the climate of the forest interior:

The geographic range of interior ponderosa pine in the Southwest is associated with certain climatic characteristics which vary little from one locality to another. In general terms, the climate may be described as cold and dry, mean annual temperature varying from 42° to 48°F and growing season temperatures (June through September) from 58° to 65°. Maximum temperatures seldom exceed 95° and frost may occur in any month of the year. Precipitation ranges generally between 18 and 22 inches, though occasionally it may be higher or lower.

A comparison of these values with data from the weather station near park headquarters (Table 16) would suggest that Parsons' contention is valid. But similar measurements from Park Point, given in the same table, cast doubt on the temperature argument,

TABLE 16

COMPARISON OF THE MESA VERDE CLIMATIC DATA WITH SIMILAR DATA CHARACTERISTIC OF THE INTERIOR PONDEROSA PINE FORESTS OF THE SOUTHWEST

Station	Mean Temperature °F		Precipitation in inches
	Annual	June-September	
Mesa Verde, park headquarters*	50.5	68.9	18.28
Mesa Verde, Park Point**	45.4	62.5	18.84
Forest Interior***	42-48	58-65	18-22

*U.S. Weather Bureau, 1964. Data are from a Weather Bureau station at 7,070 feet elevation for the period 1923-1963.

**Erdman, Douglas, and Marr, 1969. Data are from Park Point on the North Rim at 8,575 feet elevation for the period 1962-1963.

***Pearson, 1950.

TABLE 17
COMPARISON OF TEMPERATURE AND
PRECIPITATION AT MESA VERDE (PARK POINT)*
AND AT PAGOSA SPRINGS, COLORADO**
RECORD PERIOD, 1962-1963

Month	Mean Temperature, °F		Precip. in inches	
	Park Point	Pagosa Springs	Park Point	Pagosa Springs
January	23.0	17.2	1.02	1.84
February	30.9	28.5	2.00	1.99
March	28.5	29.8	1.25	1.12
April	41.6	43.2	.47	.69
May	52.6	50.5	.54	.20
June	59.6	57.1	.55	.21
July	66.9	64.3	1.99	.64
August	64.1	62.6	4.79	2.70
September	59.2	57.4	1.29	2.28
October	50.7	48.5	2.82	2.56
November	37.9	35.5	1.27	1.58
December	29.8	26.1	.82	.74
Annual	45.4	43.4	18.84	16.20

*Erdman, Douglas, and Marr, 1969. Data are from a temporary weather station on the North Rim at 8,575 feet elevation.

**U.S. Weather Bureau, 1963 and 1964. Data are from a standard Weather Bureau station at 7,238 feet elevation.

for they fall well within the ranges of the ponderosa forest interior.

A comparison of weather data (U.S. Weather Bureau 1963, 1964) from Pagosa Springs, Colorado, located in the heart of a ponderosa pine climax region

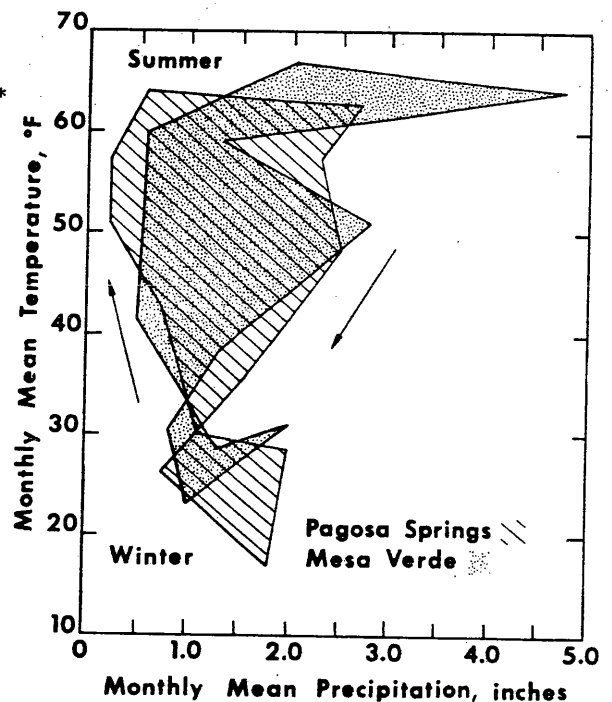


Fig. 15. Climographs comparing temperature and precipitation in the Mesa Verde (Park Point) and at Pagosa Springs, Colorado. Monthly temperature means and total precipitation have been plotted against each other and the points connected by lines. Except for the marked difference in August rainfall, the polygons are quite similar.

100 miles east of Mesa Verde, with data from Park Point (Table 17) reveals a striking similarity of monthly and annual values. Park Point is warmer but has more precipitation than Pagosa Springs. Climographs based on these data (Fig. 15) only serve to underscore the enigma concerning the scarcity of this species of pine in the Mesa Verde.

Pinyon seedlings and saplings are abundant today even in stands where juniper is dominant in the older age-classes. Although Spencer (1964) asserted that pinyon mortality is high during the first 100 years, I

found that seedlings, at least, survive very well. In five 1-meter quadrats established in 1962 under various microhabitats, 42 pinyon and 3 juniper seedlings were marked and their progress was followed. The latest observations in 1966 showed a loss of only four pinyon pines; the remaining seedlings appeared firmly established. In light of the greater number of pinyon seedlings than juniper seedlings and their good survival rate, some change in the present forest can be expected. It is reasonable to conclude that the percentage of pinyon tree cover will increase in the older age-classes during the next few hundred years in those stands left undisturbed.

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