

Fire History and Fire Effects of Mesa Verde National Park

FINAL REPORT

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ABSTRACT

Mesa Verde National Park supports, along with many other plant communities, large expanses of piñon-juniper woodland and mountain shrub communities. The spatial distribution of these communities, with a predominance of pinon pine and juniper on the south end of the mesas and mountain shrubs on the northern end, led us to hypothesize that frequent fires may be one factor controlling this pattern. The study of fire history and fire effects at Mesa Verde Park took place in 1991, 1992, and 1994 and had several objectives. One study determined the vegetation patterns which have resulted since the 1989 Long Mesa fire. This large fire impacted at least three different vegetation types, piñon-juniper woodland, mountain shrub stands, and the Douglas Fir-Shrub community found on the north escarpment. The second objective was to develop and apply a method of dating past fires in Mesa Verde. As few fire-scarring tree species occur in Mesa Verde National Park, we developed a method in which shrubs, which reprodut vigorously after fires, were aged by annual ring counts to determine their time of origin. The third study involved evaluation of fuels in the recently-defined vegetation communities (Floyd-Hanna et al, 1994) throughout the park. Fuel models were developed using BEHAVE to predict possible fire regimes.

A method was developed to date past fire disturbance using *Quercus gambelii* clonal ages. In the northwest section of the park, large fires were detected, dating to the 1850's, 1870's, 1880's, and 1910's. We completed the stand origin map of the northeastern section of the Park by dating oak clones from Moccasin Mesa to the eastern escarpment. Large stand replacing fires date in the 1860's, 1870's, 1880's, while smaller fires date within the 1890's and the 1900's. One small fire was detected in 1910, and several old patches exceeded our ability to resolve stand dates. The interval between fires varied from 21 years (1850-1875), 44 years (1875-1906, to 122 years (1906-present).

In a related study, we defined 14 major vegetation communities in Mesa Verde Park. Here we report our efforts to sample woody fuels in these communities. Woody fuels data included down and standing fuels. These data were incorporated into custom fuel models using BEHAVE, a modeling program which predicts fire behavior under varying fuel and site conditions.

Finally, we determined the stand structure of pinon-juniper woodlands, focusing specifically on the possible origin these woodlands. Were the woodlands established by a rapid invasion following a catastrophic event, providing a uniform, old-aged structure? Or, are old trees uneven aged? We determined, in a pilot study, that sampled pinon-juniper woodlands are uneven aged with adult pinon pines reaching 370 years and adult junipers reaching 500 years of age.

TABLE OF CONTENTS

- Chapter 1 : The Fire History of Mesa Verde**
- Chapter 2: Post-fire Succession after the 1989 Long Mesa Burn**
- Chapter 3: Modeling Fire Behavior in Mesa Verde National Park**
- Chapter 4: Stand Structure of Mesa Verde's Pinon-Juniper Woodlands**
- Chapter 5: Developing A Fire Risk Model for Mesa Verde National Park**

CHAPTER 1

THE FIRE HISTORY OF MESA VERDE

Prehistoric fire history is poorly known in southwestern Colorado in elevations occupied by piñon-juniper woodlands. Erdman (1970) estimated that an extensive fire had occurred in 1873 on Long Mesa, and a fire occurred sometime in the late 1800s on southern Chapin Mesa (the "Glade burn"), but otherwise prehistoric fire history in the Park is unknown. However, the historic (since 1906) fire frequency within Mesa Verde National Park has been documented. Small fires burned as frequently as 7.6 times per year from 1927 to 1976, while the recorded frequency increased dramatically to 13.7 per year during 1976 and 1989. Large fires occurred in 1934 on Wild Horse Mesa, in 1959 in Morefield Canyon, and in 1972 a fire was documented near Rock Springs as well as on Moccasin Mesa. The most recent large fire was in 1989 on Long Mesa. This burn lasted for 15 days (July 8 to July 22, 1989) and impacted approximately 1200 hectares in a tract of 6.9 km length and 0.9-2.5 km width (see Chapter 2).

RECONSTRUCTING FIRE HISTORY

A striking feature of large forest fires is the variation in fire intensity over time and across the landscape. The underlying patterns in fuel and moisture conditions combine with vagaries of wind and temperatures to produce a mosaic of patches burned at various degrees of severity. Ecologists have only recently begun to address this heterogeneity of fire effects in a rigorous fashion (Turner and Romme 1994) but at least two elements are important in assessing the effects of fire in Mesa Verde National Park.

First, high-intensity fires may damage archeological materials on the surface of the ground or buried at some depth. This hazard has been recognized for many years, and has been studied following the 1989 Long Mesa fire (Eininger, 1990). We need to know, for example, if there are thresholds in fire intensity beyond which the damage to artifacts increases dramatically. It is possible that low or moderate-intensity fires cause minimal damage, whereas high-intensity fires cause severe damage. It is even conceivable that buried materials are largely unaffected by all fires; soils studies after the recent Yellowstone fires revealed that high soil temperatures generally were restricted to the upper few centimeters even under the hottest burning conditions (Romme et al. 1993). The goal of this phase of the research is not to determine precisely the extent of archeological damage caused by fires of varying intensity, but rather to add to the spatially explicit (GIS-based) data sets which will model potential archeological damage. The questions surrounding cultural effects have been addressed by Mesa Verde Park personnel and other NPS researchers (Eininger, 1990; Romme, Floyd-Hanna, Towle, 1992). Eininger concludes that of the potential pinon 188 archeological sites within the reach of the Long Mesa Fire, only 68 sites were damaged. In other sites, both macrobotanical and dendrochronological data retrieval may also have been reduced where temperatures reached particularly high levels.

Fire scars form when the vascular cambium is damaged by heat from fire, generally forming on one side of the tree where heat is most intense. Open scars, or the catface, which result from repeated exposure to fire are used to document fire history. Each fire scar has an individual fold on each side of the catface. Sectioning of catfaced trees and dendrochronological analysis of fire scars allows precise reconstruction of past fires (Arno and Sneek 1977, Stokes 1980). This method has been successfully used in many western forest types, and the method is clearly outlined, as used in the Bitterroot National Forest in Montana, by Arno and Sneek (1977). Within the Mesa Verde system, Ponderosa pine and Douglas fir are two species which form fire scars and could potentially be used to reconstruct fire history by this method. However, the most abundant trees are piñon pine and Utah

juniper, species which do not form fire scars with regularity; indeed the heat necessary to form fire scars kills the cambium entirely. Therefore, we have developed a new method of fire history determination utilizing shrub ages rather than fire scars.

Rowe (1983) describes how several boreal plant species resprout after moderate fire but must reinvade by seed after severe fires that kill the rhizomes and rootstocks. The response to fire of 20 shrub species from dry forests of Idaho and Montana shows resprouting, post-fire invasion by seeds, as well fire tolerance strategies (Noste and Bushey, 1987). In Mesa Verde National Park, the shrub responses vary in post-fire successional seres (Chapter 2). *Quercus gambelii* and *Amelanchier utahensis* resprout vigorously, while other species are killed by high intensity fire. Because fire scars are not available in the piñon-juniper ecosystem, and because resprouting shrub species cover a large proportion of the Park, we developed a new method to date the time of origin of shrub stands using shrub ages. In this Chapter we describe the development of our method and its application to the northern, shrub rich, section of Mesa Verde National Park.

METHODS

DEVELOPMENT OF SHRUB-DATING METHOD

We located, in 1991, healthy stands of Gambel Oak, Fendlerbush, Mountain Mahogany, Serviceberry and Bitterbrush in areas of known fire history. The sampling locations were in the 1934 Wildhorse and Wickiup fires, the 1972 Rock Springs and Moccasin Mesa fires, and the 1959 Morefield fire.

Shrubs were cut with a bow-saw as low to the ground as possible. Cross sections were taken back to the lab, sanded, and annual ring counts were made with a dissecting microscope. Each sample was aged by two investigators to check the accuracy of the method. In addition, several samples were taken from the same individual of a given species to determine how shoot production varies over time as the shrub resprouts after a fire.

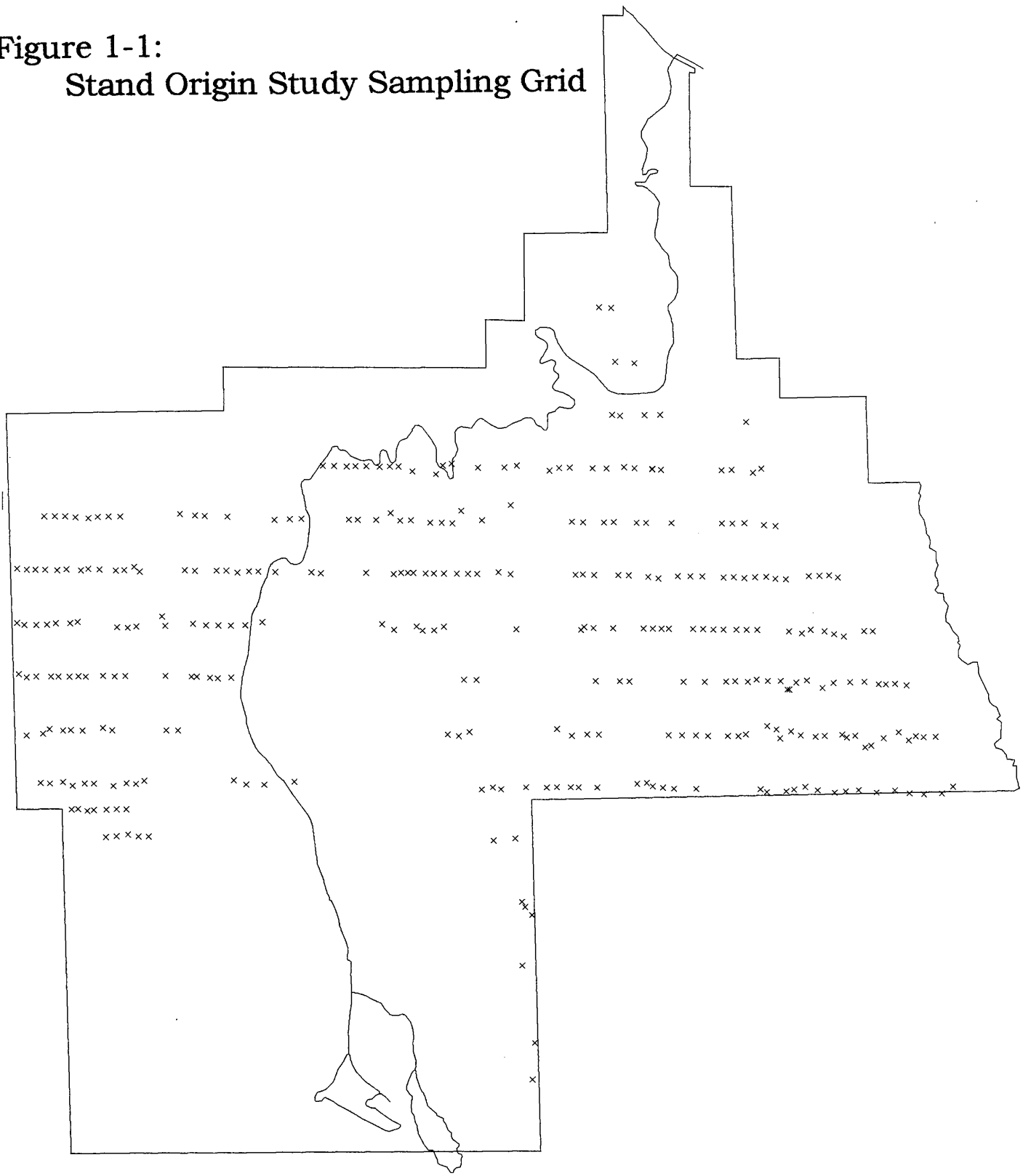
We determined that the ages of Gambel oak coincided closely with known fire dates (see Results section) but the ages of the other species were not related to the fire dates. Therefore, our subsequent work focused on Gambel oak.

STAND ORIGIN MAPPING

Once it was determined that Gambel oak provided the most accurate dating, we applied the method to areas of unknown fire history in the northern half of MVNP. A systematic grid of 330 sampling points was laid out on the map, starting along the western park boundary and moving eastward (Figure 1-1). Sample points were 200 m apart in the east to west direction, and 1000 m apart from south to north. Each point then was located in the field, whereupon the samplers looked for the largest, oldest appearing oaks in the vicinity. Because of natural variability in oak distribution and abundance, it sometimes was necessary to move as much as 30 m from the line created by the sampling grid to locate suitable oaks for sampling. The actual sampling location was marked on the map. If no oaks were present within 30 m. of the established point, then the point was skipped.

At each point, the samplers collected cross sections of representative large stems from approximately 10 clumps of oak within a radius of approximately 30 m. of the point marked on the map. The sampled stems generally were in the center of the clump, and the cross section was taken as low as possible, usually at a height of about 10 cm. If there appeared to be two or more distinct age classes in the area, i.e., if there was a pronounced gap in size distribution of the oak stems, then at least ten representative samples of each size class were taken. Samples were taken only from living stems, except in the area that burned in 1989, where fire-killed stems were collected and the date of death recorded.

Figure 1-1:
Stand Origin Study Sampling Grid



All of the cross sections were sanded and the rings counted in the laboratory. A table was made showing the ages, in descending order, of oak stems at each point and estimated the time of the last fire (see Results).

Many points contained two recognizable age classes, both of which were recorded. The points also were plotted on the map, and by looking at the spatial distribution of points we were able to assign a few additional earlier fire dates to points that had burned more recently. For example, if a point was surrounded by points dating clearly from the 1880's, and contained a small but recognizable cohort of stems dating from that decade as well as a larger cohort from a more recent period, then we concluded that the site had burned both in the 1880's and in the more recent period. We were conservative in assigning fire dates, however, and probably have reported a minimal number of fire dates and a minimal spatial extent of those fires.

Finally, we drew lines around points of the same age to construct a map showing the date of the last stand-replacing fire throughout the study area as of 1995. The boundaries of the 4 historical fires in our study area that we mapped in this way were compared to actual fire maps in the Park's GIS: the correspondence was very close, suggesting that our method was reasonably reliable.

FIRE HISTORY STATISTICS

We applied our stand age data to the negative exponential probability distribution to calculate "b", which is the average prospective lifetime or average time between successive fires at a point (Johnson and Gutsell 1994). The inverse of b is the average proportion of the study area that burns in a year or the probability of fire occurring at a point. We used the negative exponential model rather than the Weibull model because there is no evidence that probability of burning changes as stands become older; recent large fires in the Park have been observed to burn through many age classes of shrublands with no apparent effect of stand age. We computed b for three historically distinct time periods in which the plot of cumulative "time-since-fire" (Johnson and Gutsell 1994), or stand age, (see Results, Figure 1-4) indicated different fire regimes.

RESULTS

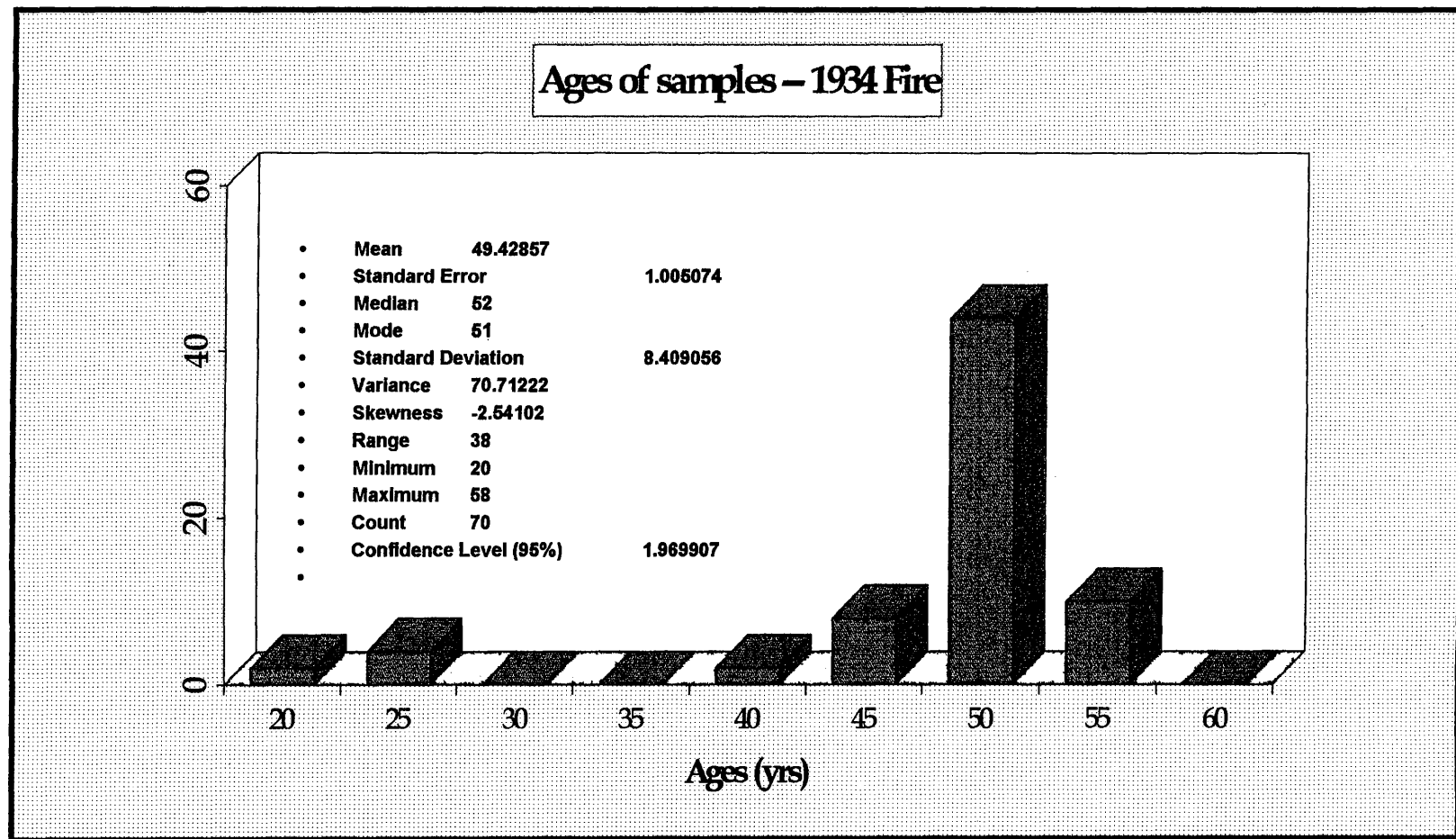
SHRUB-DATING METHOD

ANOVA using oak ring counts as the dependent variable and known fire date as the independent variable revealed a significant ($p < 0.05$) added variance component among fires for oak annual ring numbers. Thus, we concluded that oaks are more closely related in their dates of origin within each known fire than between fires. Also the mean age of each cohort was similar to that expected for the fire based on the historic fire records (e.g. the oaks growing in the 1934 burn were close to 58 years old when sampled in 1992). We concluded that the proposed method for determining stand origin dates from oak annual ring counts is valid.

Even though oak stems ages were strongly related to the date of the previous fire, indicating that most had sprouted soon after that fire, there was considerable variability in stem age. For example, the distribution of shrub ages collected in the 1934 Wickiup and Wildhorse Mesa fires (the oldest historically documented fires) is summarized in Figure 1-2. Ages of all stems from areas known to have burned in 1934 were aggregated and plotted in the frequency histogram. We found that indeed most stems were close to 58 years old in 1992. This distribution indicates that, if a substantial cohort of the original sprouts remain, the date of the disturbance which initiated regrowth can be determined. Smaller diameter stems also were present, and indicated recruitment from sprouts in later years. Thus, sampling must be restricted to the oldest cohort of stems-- generally the centermost stems of

Figure 1-2:
Distribution of stem ages that burned in 1934

Histogram of 1934 Samples



largest diameter. Alternatively, or in addition, some of the ages other than 58 may be the result of false or missing rings, since we did not attempt to cross-date the oak sections. Nevertheless, the ages are clumped tightly enough around the expected age of 58 to show that roughly even-aged cohorts of resprouting stems remain detectable for at least 58 years.

Oaks sampled in the 1959 Morfield burn and in the two 1972 fires showed a similar pattern, except that stem ages were more tightly clustered around the expected age in these more recent burns. We concluded, therefore, that oak ages can be used to estimate the stand origin dates in this kind of vegetation.

Although other species of shrubs were sampled -- *Purshia tridentata*, *Amelanchier utahensis*, *Fendlera rupicola* -- only *Quercus gambelii* consistently produces annual rings, rarely shows false rings, and is adequately distributed in Mesa Verde Park to be sufficient for use in dating stand origins.

STAND ORIGIN MAPPING

We examined the age distribution of oak stems at each of the 330 sampling points, and estimated the date of the last stand-replacing fire. At most points, there was a clear cohort of stems that could be interpreted as having sprouted soon after the last fire, i.e., there was a distribution similar to that shown in Figure 1-2. Appendix 1 contains all of the stem ages and the stand ages assigned to each point. Several points had no clear cohort of ages, but included a very broad spread of ages including some very old stems (>100 years old). We interpreted these as having burned more than 140 years ago, and the postfire cohort of sprouts is no longer evident. A few stands (<10%) had no clear cohort of stems ages and no very old stems; these could not be dated directly, so we assumed that their age was similar to stands close by.

Figure 1-3 shows the date of the last stand-replacing fire at each point within the study area as of 1988 (just before the large 1989 Long Mesa burn). The region immediately to the south of the study area was dominated by piñon-juniper woodlands whose stand age could not be determined with this method because they contain few oak. However, piñon-juniper stands in this portion of the park are thought to be >150 years old (Erdman 1970), and our data show that > 300 years is likely (Chapter 4). With either estimate, the piñon-juniper woodlands are much older than most of the oak-dominated stands within our study area.

The cumulative time-since-fire plot (Figure 1-4) reveals three distinct periods of fire history. First was the 1850s through 1870s, before major Euro-American settlement began in southwestern Colorado, and when Utes may have done extensive burning. The second period was the 1870s through 1906, the period of Euro-American settlement, when heavy, unregulated livestock grazing occurred and Native American cultures were disrupted. The third period was from the Park's establishment in 1906 until 1995, the historical period when the Park actively suppressed all fires.

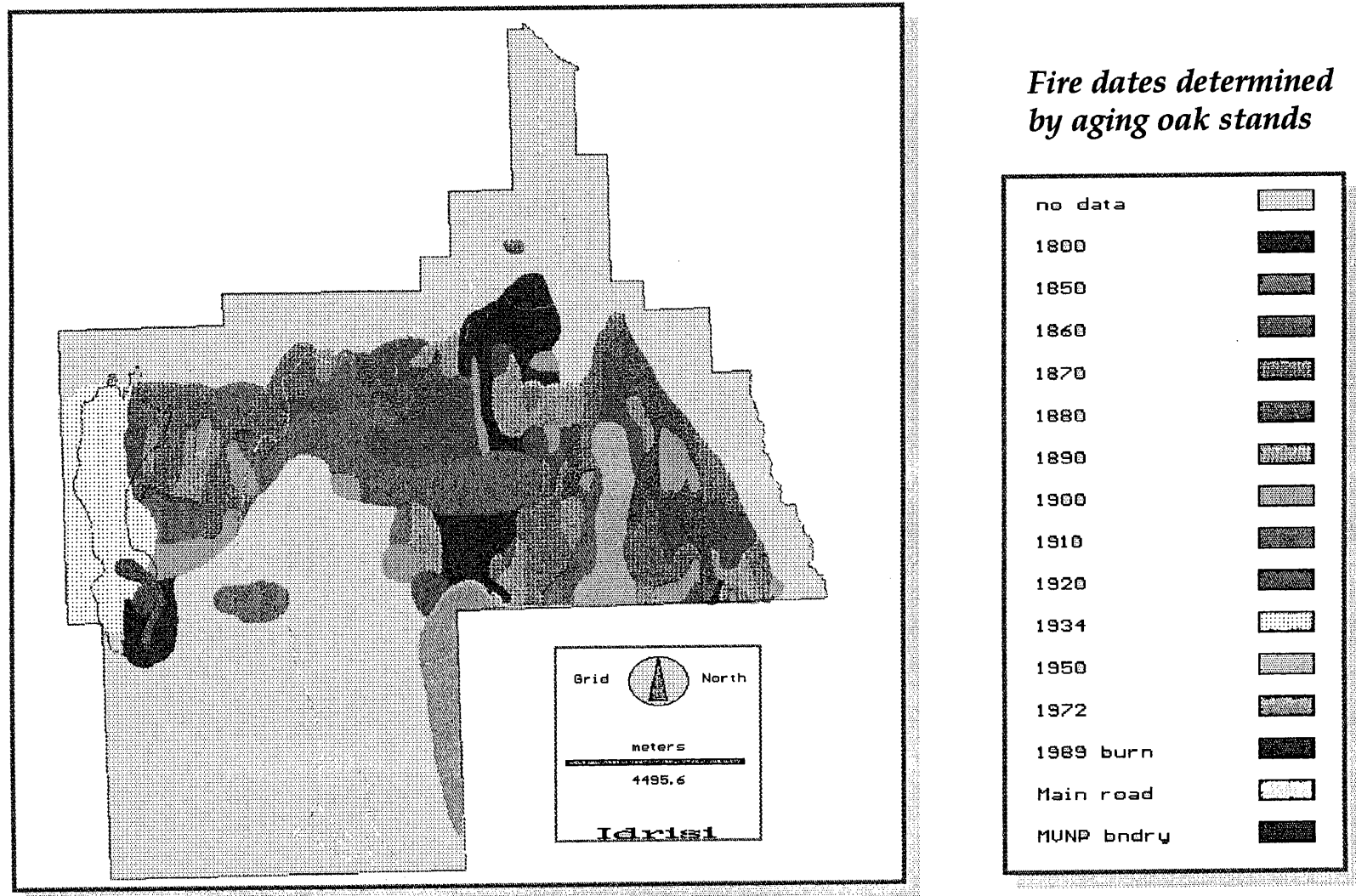
The "b" parameter of the negative exponential time-since-fire-probability distribution (Johnson and Gutsell 1994) was calculated as shown in Appendix 2. For the period before Euro-American settlement (1850s-1870s), $b = 26$ years; for the Euro-American settlement period (1870s-1906), $b = 44$ years. For the historic period (1906-1994), $b = 122$ years. This means that the average interval between successive fires at a single sample point, or the time required to burn an area equal to the entire study area varied from 26 years to 44 years to 122 years during these three periods.

DISCUSSION

The method developed here enabled us to successfully reconstruct prehistoric fire history in a type of vegetation where fire history research has been difficult because of the lack of fire-scarred trees. The dating of post-fire oak stem cohorts permits detection of past

Figure 1-3:

Stand Origin Map Mesa Verde National Park



fires up to about 140 years ago, within a resolution of about a decade. While more precise fire dates would be desirable, this resolution is useful for many purposes of interpretation and management of the vegetation of Mesa Verde National Park. The method probably could be applied in other areas of the Colorado Plateau where Gambel oak is common. It may be applicable also in vegetation types dominated by other shrub species, but initial testing of shrub ages in areas of known fire history would be required first.

It is important to stress that the oak populations we sampled, especially the older ones, were not necessarily even-aged. At most of the sample points there were many smaller -- and presumably younger -- stems as well as the largest stems, and it was only the latter that we sampled. Even many of the large stems had sprouted many years or decades after the last major fire (e.g., distribution of ages in Figure 1-2). Thus, the Gambel oak shrubs in MVNP apparently recruit new stems continuously, in a manner similar to most of the shrub species in southern California chaparral (Keely 1993). Despite the continual mortality and recruitment of stems in these populations, however, there is a large cohort of similar-aged sprouts produced after fires intense enough to kill all of the above-ground vegetation. This post-fire cohort persists and be detected for many decades after the fire.

We calculated the average fire interval "b" at any given point in the study area for three distinct time periods. These periods were selected because each showed a unique slope when viewed as the cumulative percent of fires over time (Figure 1-4) which we perceive as the result of distinct fire behaviors. The average fire interval was 26 years during pre-European settlement, then extended to 44 years between 1875 and 1906. After the establishment of Mesa Verde National Park, the interval between fires increases dramatically to an average of 122 years. Several different factors may have contributed to this change in fire frequency.

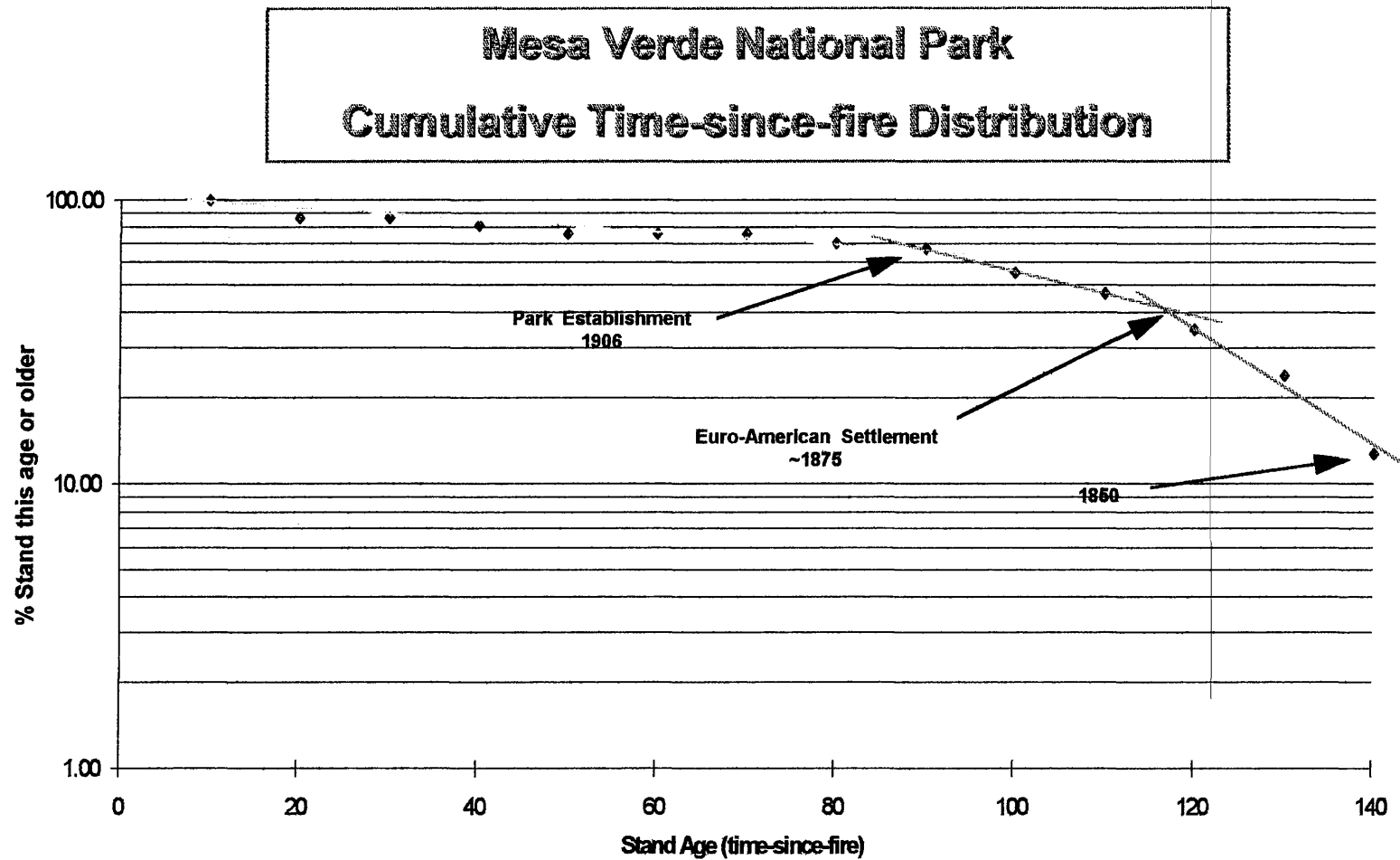
The Ute Mountain Ute Indian Reservation and the historic homeland of the Ute people lies just west of MVNP at the western edge of our study area. Oral histories (Marylin Colyer, MVNP resource management specialist, personal communication, 1993) indicate that the Utes regularly ignited fires in many parts of southwestern Colorado until they were forced to stop sometime early in the 20th century. This may have contributed to the relatively short interval between fires prior to 1875. During the second interval, 1875 through 1906, the introduction of livestock grazing throughout the southwest caused widespread changes in fuel continuity and could, along with other factors, have altered the fire cycles. Our data coincide with decreases in fire frequencies in Ponderosa Pine forests throughout the southwest in the 1880's which are generally attributed to grazing effects (Covington and Moore 1992; Savage and Swetnam, 1991). Finally, our data show a dramatic decrease in fire frequency during the period following 1906. This coincides with the establishment of Mesa Verde National Park in 1906 and its policy to control wildfires as a means to protect cultural resources.

There exists a north-south gradient in stand age and presumably also in fire interval. The age distribution of the shrub-dominated stands that we sampled does not differ substantially between northern and southern portions of the shrublands that dominate the north end of MVNP, but the entire region south of the study area is dominated by piñon-juniper forests that apparently are much older. Although research on prehistoric fire history has not been conducted to date in these forests -- due to methodological difficulties -- it is thought that centuries have passed since the last intense fire in most of this area, given the extremely slow rate of succession in the piñon-juniper type (Erdman 1970). Chapter 4 presents stand structural analyses which verify that old piñon and juniper trees are common in the southern portions of most of the mesas in MVNP.

The north-south gradient in stand age and fire recurrence is difficult to explain at this time, although it is one of the most striking features of the vegetation pattern in MVNP. One reason for generally younger shrub stands in the north may be that large fires, at least the ones observed historically, have all been ignited in the southern or central portion of Mesa Verde and spread generally northward, fanning out laterally as they spread.

However, the reason for the restriction of mature piñon-juniper forests to the southern end of Mesa Verde still remains elusive. Our findings do support Erdman's hypothesis that recurring fires maintain the shrublands in the northern portion of MVNP, but other factors

Figure 1-4:



may be involved also in explaining the distribution of forests & shrublands in the Park. For example, fire starts actually are more numerous in the piñon-juniper vegetation types to the south than in the shrubland types to the north (Omi and Emrick, 1980)), yet the infrequent large fires since 1930 (for which we have written records) have burned predominantly in the shrubland vegetation types to the north. Moreover, seedlings of piñon and juniper are abundant in the forests at the south end of the Park, but extremely rare in most of the shrublands to the north. The north end of the Park is a few hundred meters higher in elevation and has somewhat different soils than the south end, so there remains the possibility that soil and climatic differences are as important in explaining the overall vegetation patterns of the Park as are differential fire recurrence intervals. Research is in progress to better understand these other aspects of Mesa Verde ecology as well as the interactions among the various factors (e.g. Douglas Ramsey, SCS, personal communication regarding soils mapping in MVNP).

CONCLUSIONS

We developed a new method for dating prehistoric fires based on the ages of Gambel oak stems that resprouted following fire. Using this method, we developed a stand origin map for the shrublands of northern Mesa Verde. Fires were documented for every decade of the late 1800s and early 1900s. The average fire interval at a sampling point varied from 22 years in the 1850s-1870s, to 44 years in the 1870s -1906, and 122 years in the period 1906 -1994. These differences in fire frequency can be explained by changes in human activities in the area during those time periods.

Chapter 1

Appendix 1

The age, as estimated by the number of annual rings, of *Quercus gambelii* samples collected throughout the northern portion of Mesa Verde National Park in 1992 and 1994. The ages shown in boldfaced lettering are even-aged cohorts which were used to date the stand origin for that point. The oaks which sprouted before or after that cohort are shown in regular type.

Sheet1

ID	Stand	Fire Years																
17046		1972	19	20	20	21	21	22	22	22	22	23	23					
17047		1972	17	17	18	20	20	21	21	23	23							
18047		1972	17	19	19	20	20	20	21	22	23							
19046		1972	19	20	20	20	22	22	24	25	26	27	27	30	34	38	58	
20046	b46	1972	20	20	20	21	21	21	21	21	22	22	27					
20047	b47	1972	14	17	18	18	20	20	21	21	21	21	21					
20475		1972	21	21	21	22	23											
21005	a5	1890s	31	39	48	49	78	81	94	98	99	100						
21006	a6	1880s	95	96	98	100	100	101	103	105	108	111						
21007	a7	1850s	51	75	76	88	99	118	120	132	132	133	159					
21008	a8	pre1850s	63	77	78	80	80	80	86	86	92	108	143					
21009	a9	pre1850s	27	27	28	43	48	64	65	167								
21045	a45	1972	9	13	20	44												
21047	a47	1972	19	20	20	21	21	21	21	21	22							
	A1	1934--1972	17	17	17	17	18	18	18	19	48	54						
	A2	1910s--1972	14	15	15	16	16	17	17	18	18	18	18	43	43			
	A2*		75	76	79	83												
	A4	1972	14	15	15	15	15	15	15	15	16	17						
	A5	1870s	89	92	97	103	105	105	106	108	112	119	121	122				
	A7	1910s	26	40	76	76	77	77	79	90	102							
	B3	1934	38	39	50	53	54	54	55	58	58	59						
	B4	1934	28	40	42	49	49	50	51	51	52	53	55	55				
	B5	1934	43	43	47	48	49	50	51	51	51	51	55	56				
	B6	1934--1972	15	15	16	17	17	17	17	34	49	52	53					
22007	B7	1934	52	53	53	55	56	56	56	56	56	64						
22008	B8	1870s	47	59	86	90	93	95	102	103	116	120						
22010	B10	1920s	27	27	54	62	63	72										
22011	B11	1920s	24	56	66	67	68	69	69	76	106							
22012	B12	1880s	71	82	85	87	91	97	100	104	106	108						
22013	B13	1910s	48	54	54	59	63	65	68	68	78	81						
22021	B21	1910s	26	32	44	67	69	70	71	76	88	110						
22022	B22	1910s	44	44	73	74	74	77	78	79	96							
22024	B24	1910s	23	32	33	40	43	65	71	79	79	86	86					
22044	B44	1920s	31	44	44	64	70	70	70	85	86	110						
22045	B45	1920s	55	55	55	56	60	63	69	69	69	69						
22046	B46	1920s	19	19	30	30	39	39	63	72	73	90						
22048	B48	1972	19	20	21	22	22	22	23	23	23	24	26					
22050	B50	1972	19	20	21	21	21	21	21	22	23	23	23					
22051	B51	1972	13	21	21	21	21	22	22	22	23	24	24					
22052	B52	1972	13	14	14	20	21	21	22	22	22	22	23	24				
22053	B53	1890s	51	65	73	74	83	87	90	92	94	96	181					
22054	B54	pre1850	89	89	90	95	96	126	128	157	162	178						
22055	B55	1890s	60	79	79	88	94	94	99	100	100	108						
22058	B58	1870s	46	77	89	103	104	105	116	117	118	126						
22059	B59	1870s	44	44	59	60	82	97	108	114	114	117						
22060	B60		70															
22060	B60*	1900s	75	77	80	80	81	86	87	90	99							
22061	B61	1900s	18	20	52	54	64	65	71	74	83	85						
22062	B62	1900s	25	38	54	57	64	75	80	81	83							
22064	B64	1959	28	28	29	33	36	36	37	46								
22065	B65	1959	30	31	34													
22070	B70	1900s--1959	24	24	30	30	31	32	34	34	53	75	83	90	93			
22071	B71	1890s	24	41	62	69	70	80	91	93	103	104	115					
22072	B72	1890s	19	34	70	70	76	78	80	92	93	97						

22073	B73	1860s		29	87	87	91	91	91	94	99	108	112	125					
22074	B74	1900s		37	77	79	83	86	90	90	102								
22075	B75	1900s		38	62	63	63	77	77	78	80	80	83	85	86				
22077	B77	1860s		27	34	66	74	84	85	85	90	96	111	117	128				
22078	B78	1860s		23	39	68	75	81	91	91	92	93	122						
22079	B79	1880s		74	79	80	81	85	86	95	96	110	111						
22081	B81	pre1850		35	40	40	40	42	43	75	91	141							
22082	B82	1860s		40	42	85	87	88	88	117	118	122							
22083	B83	1860s		64	67	73	77	85	87	91	105								
22084	B84	1860s		84	85	87	87	88	89	90	106	120	124						
22085	B85	1890s		26	51	56	72	76	84	90	92	95	100						
22088	B88	1870s		47	51	57	64	68	83	86	88	115	117						
22089	B89	1900s		63	63	64	66	68	68	74	76	77	87	91	91	133			
22265		1910s		53	54	54	56	70	70	70	78	83	84						
	C2		1934	49	49	51	53	53	55	56	57	58	58						
	C3		1934	33	45	45	47	50	52	53	54	58							
	C4		1934	37	48	49	49	50	55	56	57	57	58	66					
	C5		1934	32	38	48	49	50	50	50	51	52	54						
23006	C6		1934	50	50	50	50	51	51	51	51	52	53	53					
23007	C7	1880s		41	46	49	53	55	56	56	85	99	105	107					
23009	C9	1880s		48	63	63	69	80	87	88	98	102	110						
23010	C10	1910s		70	71	72	75	76	79	80	83	101							
23011	C11	1870s		84	92	93	93	98	108	108	111	116	117						
23015	C15	1900s		27	30	50	52	63	73	83	83	96							
23016	C16	1900s		27	30	54	55	55	80	82	83	85	85	88					
23041	C41	1900s		27	27	27	43	71	72	75	78	90	90	90	91				
23042	C42	1900s		54	59	70	84	89	89	90	94	95	105						
23043	C43	1900s		57	73	73	76	77	86	87	89	89	152						
23052	C52	pre1850		32	48	73	74	77	79	88	88	128	165						
23052	C52*	pre1850		50	51	53	78	80	86	87	92	97							
23054	C54	1860s		70	94	107	109	114	114	122	124	157							
23055	C55	1880s		83	84	84	88	88	89	91	91	107	110	112					
23062	C62	1870s		55	84	101	103	103	111	113	117	119	123						
23063	C63	1870s		72	88	100	101	103	105	107	110	111	119						
23064	C64	1850s		39	79	93	103	108	115	117	130	131	137						
23065	C65		1959	30	30	31	32	33	33	34	34	37	81						
23067	C67		1959	20	26	29	30	30	31	32	32	33	33						
23068	C68		1959	28	30	31	31	32	32	32	32	33	33						
23069	C69		1959	17	23	25	27	29	29	30	31	32	32						
23070	C70	pre1850		69	75	75	75	76	86	88	120								
23071	C71	pre1850		60	60	70	77	79	81	85	88	107	128						
23072	C72	1870s		49	69	86	107	114	117	118	120	140							
23073	C73	1850s		75	76	99	121	133	134										
23074	C74	1870s		44	67	81	95	99	102	105	115	115	115						
23075	C75	1860s		40	74	85	89	95	95	96	99	122	122	123					
23076	C76	1840s		80	85	109	117	124	141	147	149								
23077	C77	1870s		68	77	80	83	83	83	114	118	120	121						
23078	C78	1900s		38	65	68	81	81	81	83	85	90	96	114					
23079	C79	1880s		57	60	66	69	77	81	83	88	101							
23080	C80	1880s		57	77	82	97	103	103	106	107	110	113	142					
23081	C81	1880s		50	51	52	67	73	92	94									
23082	C82	1860s		58	66	66	72	82	88	94	111	122	127						
23083	C83	1860s		75	75	79	80	83	92	95	119	127							
23084	C84	1890s		20	22	26	42	70	78	86	91	93							
23085	C85	1890s		74	77	77	78	94	95	96	104	124							

23086	C86	1870s		59	66	76	97	97	113	117								
23087	C87	1870s		55	56	65	70	76	77	78	87	96						
24001	D1		1934	51	52	52	52	52	52	52	54	54	56					
24002	D2		1934	22	28	43	45	53	53	53	54	55	57					
24003	D3		1934	42	46	47	52	52	54	54	55	57	57					
24004	D4		1934	28	31	35	43	44	44	45	45	53	53	55	56			
24005	D5		1934	50	54	57	57	58	59	59	59	61	61					
24006	D6		1934	42	45	47	48	53	54	54	56	56	56	61				
24007	D7		1934	51	51	56	56	56	57	57	58	59	63					
24008	D8		1934	52	55	55	55	55	55	56	56	56	56					
24011	D11		1934	52	53	54	56	56	56	57	58	60	60					
24015	D15	1910s		43	57	57	59	66	73	76	76	80	86					
24017	D17	1910s		45	46	48	52	53	60	65	66	75	76	82				
24018	D18	1910s		62	69	75	76	76	78	80								
24019	D19	1870s		25	25	63	81	81	82	86	102	113	114					
24020	D20	1880s		82	82	85	85	97	99	101	103	105	107					
24021	D21	1900s		45	51	52	60	67	71	72	73	87	87					
24043	D43	1910s		42	44	73	75	75	77	77	81	87	150					
24044	D44	1890s		56	57	73	76	77	87	87	93	100	101					
24055	D55	pre1850		59	65	72	76	76	95	98	111	114	125	149				
24055	D55*			61														
24057	D57	1870s		43	77	78	81	88	91	96	98	114						
24058	D58	1870s		56	74	87	88	90	101	102	103	110	116					
24063	D63	1890s		71	71	75	75	75	87	89	97	97	99					
24065	D65	1840s		29	47	50	61	76	80	82	87	101	140	144				
24067	D67		1959	20	21	22	22	26	27	30	33	33	33	34	35			
24068	D68		1959	28	28	31	31	32	32	32	33	33						
24069	D69		1959	27	30	30	31	33	33	33	34	34	35	36				
24070	D70		1959	27	29	30	31	32	33	33	33	33	35					
24071	D71	1880s		39	73	80	83	87	87	88	98	99	100	106	108			
24072	D72	1870s		96	97	101	102	105	107	111	111	115	116	131				
24073	D73	1870s		24	61	61	62	63	70	76	80	85	85	90	96			
24074	D74	1860s		23	25	27	27	38	63	91	93	102	125	127	127			
24075	D75	1860s		59	74	75	84	86	87	119	119	119	124					
24076	D76	1860s		82	87	88	110	114	122	124	126	129						
24077	D77	1880s		20	32	37	53	67	85	90	94	104	105	106	109	110		
24079	D79	1880s		75	80	88	89	91	96	98	102	106						
24080	D80	1860s		40	75	82	85	85	94	114	120	120	124					
24081	D81	1860s		62	81	82	83	86	96	98	102	109	113					
24082	D82	1860s		90	91	91	94	96	99	114	121	124						
24083	D83	1860s		50	64	65	81	83	83	83	84	84	97	105	113			
24084	D84	1860s		51	73	77	78	80	80	86	92	93						
25001	E1		1934	47	54	55	56	56	56	56	56	57	57	57				
25002	E2		1934	47	47	51	52	52	53	53	53	53	56					
25003	E3		1934	45	50	51	51	51	51	51	51	52	52	53				
25004	E4		1934	50	51	51	52	52	54	54	54	55	55					
25005	E5		1934	48	48	49	50	50	51	52	53	55	55					
25006	E6		1934	42	44	52	53	53	53	54	54	56	58					
25007	E7		1934	48	48	49	50	51	51	52	53	53						
25010	E10	1870s		74	74	84	88	97	110	110	116	121	133					
25011	E11	1910s		72	72	74	78	80	80	80	82	87						
25012	E12	1870s		60	64	84	84	86	97	125								
25014	E14	1870s		36	102	106	110	111	111	112	112	113	115					
25015	E15	1890s		79	79	79	80	96	99	100	101	105						
25018	E18	1890s		62	64	73	77	79	80	80	94	94	94					

Sheet1

25019	E19	1870s	39	39	39	39	58	77	92	112	113						
25020	E20	1850s	86	123	125	134	134										
25021	E21	1870s--1900s	80	83	83	84	86	86	93	116	121						
25023	E23	1900s--1959	17	30	30	31	31	33	35	89	90	111					
25024	E24	1900s	60	65	69	69	73	73	82	83	102	104					
25035	E35	1800s--1900s	83	84	84	84	88	120	124	137	146	158	182	189			
25036	E36	1850s--1900s	57	73	79	80	81	87	88	115	129	133					
25038	E38	1850s	74	90	129	129	130	136	138	139	141	143	143				
25039	E39		126														
25039	E39*	1850s	74	78	83	90	112	119	125	126	134	141					
25040	E40	1850s	72	83	87	88	117	119	120	121	124	128					
25040	E40*		52	56	70	70	72	75	80	90	120	134					
25048	E48	1850s	37	62	64	72	76	81	83	85	137	138					
25053	E53	1850s	32	34	40	44	46	51	77	86	96						
25054	E54	1850s	66	75	78	81	88	121	124	136							
25055	E55	1840s	73	78	92	99	108	113	122	138	144	149	150				
25056	E56	pre1850	46	46	60	61	71	74	78	143							
25059	E59		76	88	91	91	95	97	99								
25059	E59*	1890s	88	94	95												
25060	E60	1870s	60	76	90	92	93	112	113	114	116						
25061	E61	1850s	38	40	45	55	63	70	115	132	135						
25062	E62	1860s	79	93	103	104	108	115	118	124	124	126					
25064	E64	1880s	34	76	82	87	91	91	92	94	107	111					
25065	E65	1900s	43	86	87	88	89	90	91	93	94	95					
25066	E66	1860s	28	77	80	100	104	106	112	112	120	131					
25067	E67	pre1850	57	66	67	79	84	86	88	97	98	142					
25068	E68		96														
25068	E68*	1959	31	32	33	33	34	34	37	38							
25069	E69	1959	27	28	29	29	29	30	30	33	34	35					
25070	E70	1959	26	29	29	30	31	31	31	32	32	32					
25073	E73	1880s	47	51	73	98	98	99	103	104	106	106	109				
25074	E74	1870s	20	52	65	72	73	85	97	98	99	121	121				
25075	E75	1900s	67	75	76	77	79	82	82	82	84	84	85	103			
25076	E76	1900s	51	60	65	69	71	75	84	85	89	94					
25077	E77	1880s	59	75	89	91	97	101	103	106	109	115					
25078	E78	1900s	58	69	75	77	78	86	88	88	88	95					
25080	E80	1870s	45	74	80	84	85	86	92	102	112	118					
25081	E81	1870s	14	101	110	112	112	113	114	115	117	119					
26001	F1	1934	51	54	54	55	56	57	57	57	58	59	59				
26002	F2	1934	45	50	50	50	52	53	53	53	54						
26003	F3	1934	51	51	52	53	53	53	53	54	54	54	55				
26004	F4	1934	45	45	46	46	47	49	50	55	56						
26005	F5	1934	36	48	49	49	50	51	51	52	52	52					
26006	F6	1934	37	46	47	49	49	49	49	50	51						
26007	F7	1934	29	31	34	38	45	47	50	51	51						
26008	F8	1934	23	23	32	36	44	48	50	50	53						
26009	F9	1860s--1934	48	53	53	56	77	104									
26010	F10	1860s	47	56	63	66	71	100	100	106	120	120	127				
26011	F11	1890s	53	70	80	85	85	88	99	99	99	101	104				
26012	F12	1890s	55	80	97	100	100	101	102	121							
26013	F13	1870s	85	87	88	108	111	111	116	116	117	127					
26017	F17	1890s	79	93	94	95	96	96	96	106	113						
26018	F18	1890s	72	72	74	79	82	83	84	86	88	88	99	118			
26020	F20	1890s	36	71	71	72	76	93	93	98	98						
26021	F21	1870s--1900s	82	83	83	87	87	87	91	91	111	119					

Sheet1

26022	F22	1900s	80	83	86	86	86	89	89	90	107						
26023	F23	1910s	60	61	62	73	73	74	80	80	85	101					
26024	F24	1910s	55	64	64	70	73	74	74	78	78						
26025	F25	1880s	33	59	63	63	66	73	89	95	105	106					
26029	F29	pre1850--1910s	27	44	74	76	78	79	79	80	148						
26030	F30	pre1850--1900s	46	71	79	80	80	81	83	85	127	170					
26034	F34	1890s	65	69	70	83	84	97	97	103	104	134					
26037	F37	1890s	80	81	90	93	94	94	97	98	99	114					
26038	F38	1900s	80	80	80	81	82	82	88	89	116						
26039	F39	1860s	57	72	73	80	91	97	110	114	118	129					
26040	F40	1860s	80	84	100	108	111	117	125	128							
26041	F41	1860s	27	48	58	77	80	84	98	100	103	104	128	130			
26042	F42	1860s	50	58	80	80	81	83	102	123							
26043	F43	pre1850	33	36	70	75	80	84	86	87	103	170					
26044	F44	1900s	45	58	60	60	75	82	89	91	91	92					
26046	F46	1860s	65	90	94	109	113	121	122	126	129	131					
26047	F47	1860s	66	67	94	118	125	125	128	129	131	138					
26053	F53	1900s	26	29	45	73	76	86	89								
26054	F54	pre1850--1900s	37	74	76	77	77	81	84	85	87	88	88	129	148		
26055	F55	1850s	76	81	81	84	89	89	89	102	129	139					
26057	F57	1880s	64	90	90	93	93	94	100	102	107	113					
26058	F58	1860s	102	108	112	119	122	122	123	123	126						
26060	F60	1840s	55	81	82	87	100	104	127	139	143	146					
26061	F61	1900s	52	54	56	63	76	77	85	85	86	89					
26063	F63	1860s	39	53	62	83	88	89	89	122	129	136					
26064	F64	1880s	80	93	94	94	96	96	100	102	103	108					
26065	F65	1870s	33	47	47	94	96	104	108	115	116						
26067	F67	1959	28	31	31	32	33	34	34	34							
26068	F68	1959	28	29	30	31	33	33	33	34	35	37					
26069	F69	1959	26	27	28	30	32	33	34	34	35						
26070	F70	1959	20	32	32	32	34	37	37	39							
26071	F71	1860s	91	104	120	121	121	121	121	124	126	130					
26072	F72	1880s	69	71	73	83	83	89	89	90	101	107					
26073	F73	1890s	88	90	90	92	92	94	95	96	97	97	101				
26075	F75	1900s	34	34	76	78	78	79	85	86							
26076	F76	1900s	16	20	26	33	40	40	45	46	79	85					
26077	F77	1880s	81	82	88	90	96	99	101	102	102	104	105				
26078	F78	1880s	64	75	77	79	81	87	101	102	104	112	113				
26375		1880s	52	64	69	74	75	77	77	84	99	101					
27005	G5	1934	30	39	45	45	46	46	47	47	48						
27006	G6	1870s--1934	50	51	52	52	53	53	53	54	57	114	125				
27007	G7	1870s--1934	50	51	52	52	53	55	55	55	83	100					
27008	G8	1934	46	46	46	47	48	48	51	52	53	53					
27009	G9	1934	52	52	54	54	54	55	56	56	56	56					
27010	G10	1870s--1910s-- 1934	41	41	41	53	54	54	78	80	81	82	96	117			
27011	G11	1870s--1910s	72	73	73	73	74	75	77	79	80	82	96	120			
27017	G17	1870s	73	73	74	87	87	105	113	114	117	126					
27018	G18	1880s--1900s	70	82	82	82	83	84	88	106	106	109	111				
27019	G19	1870s	69	77	83	91	92	114	115	117	119						
27021	G21	1850s--1900s	84	85	85	88	89	120	132	132	133	134	140				
27026	G26	1880s	73	75	75	83	86	95	103	104	105	106					
27027	G27	pre1850	60	79	82	86	96	101	180								
27028	G28	1870s	70	70	71	72	77	93	101	113	118	119					
27032	G32	1860s	11	50	83	84	86	120	120	121	131	132					

Sheet1

27033	G33	1860s--1920s	63	63	64	65	66	67	67	87	95	108						
27035	G35	1860s	40	54	71	82	84	86	94	122	126	130						
27036	G36	pre1850	56	57	65	70	72	73	79	107	122	150						
27037	G37	1850s	80	101	110	131	131	132	135	136	143	174						
27038	G38	pre1850	37	37	49	79	93	96	101	111	121	202						
27039	G39	1900s	55	60	61	87	87	89	89	90	90	127						
27040	G40	1900s	50	50	51	51	62	63	65	76	78	78	87					
27041	G41	1900s	69	69	69	77	77	81	81	84	92	106						
27042	G42	1880s	87	89	97	100	101	101	105	106	107	107	108					
27043	G43	1880s	80	89	89	92	92	92	98	103	104	110						
27045	G45	1880s	100	100	101	101	101	104	105	106	108	109	117	135				
27047	G47	1860s	61	63	75	116	120	122	122	123	125	148						
27053	G53	pre1850	55	67	67	74	76	76	100	102	143							
27054	G54	1890s	70	70	72	76	80	81	82	92	97	106						
27055	G55	1890s	96															
27056	G56	1890s	89	91	91	92	94	94	95	95	100							
27057	G57	1890s	64	76	90	92	92	93	94	95	96	96						
27059	G59	1870s	53	66	80	84	86	115	117	118	118							
27060	G60	1890s	43	45	46	54	82	89	90	95	97	129						
27062	G62	1890s	49	72	75	84	84	84	88	88	89	89	91	93	96			
27063	G63	1890s	45	70	88	89	94	97										
27067	G67	1870s	35	59	62	72	81	85	85	117	120							
27068	G68	1860s	63	85	87	88	90	108	117	126	126							
27069	G69	1860s	85	88	91	104	106	108	114	126	130	137						
27071	G71	1890s	66	74	84	85	88	93	97	97	102	102						
27072	G72	1880s	94	99	100	103	105	110	112	112	112	121						
28025	H25	pre1850	66	70	76	87	88	95	98	111	156	168						
28030	H30	pre1850	71	71	73	75	90	91	100	116	135							
28031	H31	1870s--1890s	89	90	93	93	94	96	96	111	116	119						
28032	H32	1880s	65	68	80	82	82	83	83	84	94	101						
28033	H33	1880s	57	65	71	73	84	88	90	97	103	108						
28034	H34	1880s	68	84	87	88	98	100	101	101	101	105						
28035	H35	pre1850	63	63	63	70	73	83	93	94	100	131	131	160				
28036	H36	pre1850	65	80	81	85	86	87	120	121	131	138						
28037	H37	pre1850	81	83	108	133	135	139	148	153	211							
28038	H38	1880s	82	95	101	110	111	111	112	112	112							
28039	H39	1860s	82	82	90	91	103	110	112	115	119	127	129					
28040	H40	1860s	66	69	73	75	83	85	89	101	120							
28041	H41	1860s	78	79	83	83	90	100	120	121	129	129						
28042	H42	pre1850	72	76	78	78	84	88	100	100	134							
28044	H44	1890s	64	65	80	84	88	93	93	95	100	101	114	117				
28047	H47	1880s	82	95	100	108	109	110	110	110								
28048	H48	1890s	92	97	98	98	99	99	101	101	110							
28051	H51	pre1850	37	40	49	60	63	75	75	87	106	120	123	130	134	161		
28052	H52	pre1850	44	66	80	88	89	91	92	125								
28053	H53	pre1850	55	82	85	93	97	97	102	118	131	140						
28055	H55	1860s	45	68	74	75	77	78	126	128	129	129						
28056	H56	1890s	85	88	89	90	91	93	96	97	103	105						
28058	H58	1900s	40	54	67	68	69	70	80	82	84							
28061	H61	1900s	20	37	38	42	51	62	64	65	84	91						
28062	H62	1900s	62	69	69	84	86	86	88	91	92	92	92	100	106			
28067	H67	1870s	80	87	87	110	111	111	114	118	119	120						
28068	H68	1880s	67	77	87	88	89	90	100	103	107							
28070	H70	1880s	81	86	99	101	101	110	111									
28071	H71	1880s	82	84	98	102	103	104	104	105	105	105	108	108	108			

Sheet1

29050	I50	pre1850	48	65	68	84	90	93									
29051	I51	pre1850	21	44	56	69	80	99	105	110	121						
29057	I57	1880s	69	85	86	98	102	103	104	105	108						
29058	I58	1880s	91	94	95	97	102	102	102	104	104	119					
29060	I60	1880s	32	52	63	75	87	89	92	97	105	107					
29061	I61	1900s	54	69	80	80	82	84	87	89	94						
29069	I69	pre1850	32	52	69	73	78	89	90	107	113	114	127				
30057	J57	pre1850	74	77	77	116											
30059	J59	1840s	79	87	92	126	147	147									
31056	K56	1870s	72	79	82	83	83	85	85	95	114	116					
31057	K57	1870s	103														

Chapter 1

Appendix 2

Calculations of the time between fires in Mesa Verde National Park was calculated according to the following formula (Johnson and Gutsell, 1994) for truncated stand origin mapping:

$$\hat{b} = \frac{(a_i x_i)^+ + \sum_{i=1}^r a_i x_i}{N}$$

Where:

$(a_i x_i)^+$ = the time-since-fire age in which the data are truncated times the proportion of sample points which did not burn

$(a_i x_i)$ = the time-since-fire age times the proportion of sample points in each age grouping which did burn

N = the total number of sample points which burned

For time periods in which calculations are based, see Figure 1-4. Sample calculation for each selected time period follows:

1855-1875

$$b = 32(20) + ((10)(20) + (37)(10))/47 = 26 \text{ years between fires}$$

$$1/b = .038 \text{ the probability of a given point burning in any year}$$

1875-1905

$$b = 79(30) + ((36)(30) + (39)(20) + (28)(10))/103 = 44 \text{ years between fires}$$

$$1/b = .023 \text{ the probability of a given point burning in any year}$$

1905-1995

$$b = (118)(90) + ((40)(90) + (10)(80) + (19)(70) + (19)(40) + (15)(30) + (45)(10))/148 \\ = 122 \text{ years between fires}$$

$$1/b = .008 \text{ the probability of a given point burning in any year}$$

CHAPTER 2

POST-FIRE SUCCESSION AFTER THE 1989 LONG MESA BURN

INTRODUCTION

On July 8, 1989, a bolt of lightening struck the dry terrain of Long Mesa within Mesa Verde National Park, precipitating a two week burn that scorched 1200 hectares. The vegetation on Long Mesa was a mosaic of mature piñon-juniper woodlands and mountain shrub associations. Shrub associations range from oak, *Quercus gambelii*, and serviceberry, *Amelanchier utahensis*, to sagebrush, *Artemisia nova*, and bitterbrush, *Purshia tridentata*. Long Mesa spans an elevation 2180 m at the south to 2517 m at the north end; Long Canyon cuts down to an elevation of 2133 m. Long Mesa and surrounding areas have burned repeated in recent history. Erdman, (1970) used crossdating of trees to determine that a fire occurred in Long Canyon in 1873. In 1934 the so called Wetherill fires burned sections of Wickiup, Wildhorse and Long Canyons. In 1972 parts of Long Mesa near Rock Springs burned in a patchy pattern. We report on a study of post-fire successional patterns which have resulted from the 1989 Long Mesa fire. Our study took place from 1991-1994.

BACKGROUND INFORMATION

Although there is a body of information concerned with the succession following fire on piñon-juniper woodlands, there are no adequate studies of the shrub-rich piñon-juniper ecosystem of Colorado. An important contribution to the study of succession in piñon-juniper woodlands in other areas comes from Richard Everett and colleagues (Everett et al., 1983, 1986; Koniak and Everett, 1982) which focuses on the single-leaf piñon, *Pinus monophylla*. Quite often, information on *P. monophylla* is used to make generalizations about the responses of *Pinus edulis* (Harrington, 1987). Perhaps this is because there are few studies of succession which focus on the Colorado piñon. However, differences in the frequency of cone production (Sutton, 1984) make it difficult to draw parallels concerning Colorado piñon from patterns in single-leaf piñon woodlands. Floyd (1982) investigated the interaction of piñon pine and gambels oak, *Quercus gambelii*, finding the latter a suitable nurse plant which facilitated the invasion of piñon seedlings in later successional seres in Dolores, Colorado. Colorado piñon reproduction, early growth, and succession are summarized by Gottfried (1987).

Post-fire succession has been studied in piñon-juniper woodlands of the Great Basin. The single-leaf piñon is found in this region, and annual species, rather than shrubs, make up the early seres. These studies propose managment of woodlands to facilitate forage production (Everett and Ward, 1984; Meeuwig et al., 1979). For example, frequent fires promote grasslands, and competition from grasses postpones woodland invasion (Wright et al., 1979).

In west-central Utah, the stages of plant community development following fire are as follows. Weedy annuals appear in 3-4 years, followed by perennial grasses, perennial grass-shrub and finally grass-shrub-tree stages. Utah Juniper, *Juniperus osteosperma* invasion occurred in 85-90 years. The early invasion of juniper relative to other tree species is due to its attainment of reproductive maturity at 33 years (Barney and Frischknecht, 1974). Colorado piñon pines do not bear cones until they are 80-100 years of age (Floyd, 1983).

Following fire, succession in 5 areas of north-central Arizona was investigated, and 215 years was suggested for a return to a mature piñon (Colorado piñon) community (Tess and Klopatek, 1987). In a Great Basin fire history, all woodland species except the trees (single-leaf piñon) were found in burn sites within one year (Koniak, 1985).

Succession following fire was documented by Erdman (1970) in Mesa Verde National Park. He reported that annuals dominate initially, then perennial grasses and forbs, followed by shrub invasion. The open shrub stage becomes a "thicket" approximately 100 years after the fire. The shrubs are outcompeted by piñon and juniper trees, which dominate by about 300 years.

The study reported here differs from those discussed above because of the unique nature of piñon-juniper woodlands in southwest Colorado. Moist climatic conditions and high elevation allow for a prolific shrub assemblage, including *Cercocarpus*, *Amelanchier*, *Purshia*, *Peraphyllum*, and *Quercus* species. Our early observations suggested that resprouting of shrubs, in contrast to invasion by annuals, contributed to the greatest amount of biomass the first year after the 1989 fire. However, the trends in post-fire recovery depend on the relative abundance of shrub and tree (essentially killed by severe fires) species as well as on the pre-fire shrub composition. Piñon seedlings require shade and temperature amelioration from "nurse" species (Everett, Koniak, and Budy, 1986; Floyd, 1982) such as the resprouting shrubs; however, our observations suggest that few piñon and juniper seedlings are invading the mountain shrub areas in Mesa Verde. The combination of diverse sprouting shrub species and the episodic production of seed by piñon leads to multiple pathways of early post-fire succession in this ecosystem, creating a unique piñon-juniper habitat for study.

Little information is available regarding post-fire regeneration methods in shrub species in this ecosystem. Documented responses vary with the intensity of fire, previous vegetation community, etc. Noste and Bushey (1987) summarized what was known about shrub fire responses in Montana and Idaho. We have adapted their information and compared it with our observations of the Mesa Verde fires to create the listing below:

Reprouting Species	Seed-invading Species	Species Removed by Fire
<i>Quercus gambelii</i>	<i>Purshia tridentata</i>	Ecotypes of <i>Purshia tridentata</i>
<i>Amelanchier utahensis</i>	<i>Artemisia tridentata</i>	<i>Cercocarpus montanus</i>
<i>Rhus trilobata</i>	<i>Artemisia nova</i>	
<i>Symphoricarpos oreophius</i>		

In the terminology of Rowe (1983) the "Invader" shrubs of this ecosystem would be *Artemisia tridentata*, *A. nova* and some ecotypes of *Purshia tridentata*; the "Resister" shrubs would be *Cercocarpus montanus*, and *Rhus trilobata* (in moderate fires); the "Endurers" are *Amelanchier utahensis*, *Quercus gambelii* and *Symphoricarpos oreophius*; shrubs termed "Avoiders" include some ecotypes of *Purshia tridentata* and *Cercocarpus montanus*, both of which can die out completely in very intense fires. These are the two species of nitrogen fixing shrubs, housing *Frankia* species symbionts, in Mesa Verde National Park. The unique contribution of the actinorhizal *Purshia tridentata* in nitrogen-enrichment, and the role this may play in post-fire succession, is currently under investigation (Berry and Floyd-Hanna, in progress).

In this Chapter, we report on patterns of post-fire recovery in the Long Mesa burn between 1991 and 1994, across a gradient of pre-fire vegetation and previous fire histories.

METHODS

Three sampling grids were established in 1991 to include the range of severity and affected vegetation on Long Mesa, within Long Canyon, and on the North Escarpment of Mesa Verde National Park. The grid placements are shown in Figure 2-1 and are outlined below:

1. Long Mesa Southern Grid (Grid # 1): This grid consists of a square kilometer, sampled every 100 meters, or a total of 121 sampling points. It was chosen to represent the heterogeneity of vegetation within the piñon-juniper woodland region of MVNP which has resulted from the 1934 fires (Wickiup Canyon and Wildhorse Fires), the 1972 Rock Springs fire, the 1989 Long Mesa Fire, and possibly a fire in the region in 1873 (determined by cross-dating method by James Erdman). This sampling grid also spans Long Mesa and Long Mesa Canyon. "Control points" consist of vegetation missed by the 1989 fire. Data collection was completed October 13, 1991; data were stored and analyzed in the winter 1991. In 1992 and 1994 the grids were resampled. The corner stakes and permanent markers that indicated the central lines (north-south and east-west) of the grid were relocated. All other sampling points were relocated by traveling 100 m on the appropriate compass direction. Hence, these points are near, but not necessarily exact, to the 1991 sampling points.

2. Long Mesa Northern Grid (Grid # 2): The second grid was placed within the treeless, mountain shrub community which extends over much of the northern sector of Mesa Verde Park. As the vegetation was fairly homogenous and the known fire history less complex than that of the Southern Grid, the size was reduced to 1 km by 0.6 km, and the number of sampling points to 66. Data were collected in 1991, 1992, and 1994 as outlined above.

3. North Escarpment Grid (Grid # 3): The Long Mesa fire jumped over the North Escarpment, and ran in strips down toward the base of this steep slope. The terrain was very difficult to sample, so the grid placement and sampling structure was modified for safety of the personnel. Grid # 3 covers the Douglas-Fir Shrub association which is found infrequently and typically on north-facing slopes, in the Park. The grid ran 0.5 km in length and 0.4 km in width, and samples points were placed every 50 m. Data collection, storage and analysis as identical to that described above. Few unburned points were available for sampling. Data were collected in 1991, 1992, and 1994.

At each point we tallied all trees within a radius of 4 m and recorded the species, dbh, and condition of each (i.e. dead, injured, uninjured). The % cover of living plants, unburned litter, burned litter, bare mineral soil, and rock substrates were sampled within four 0.25 m² quadrats. Sampling within these plots was by means of the point-intercept method (Mueller-Dombois and Ellenburg, 1974). The sampling frame was placed 4 times (at 1 or 3 m either side of sampling point) and the vegetation or substrate intersected by 2 sets of crossed strings were recorded. Alternating with the placement of the sample quadrat, we excavated a shallow hole with a knife and measured the depth of soil char. The dominant grasses and forbs were recorded, and the number of burned and unburned stems of shrubs and trees were counted. Rock spalling was noted as an indicator of fire intensity. Site characteristics were recorded.

Data are stored on a MacIntosh LC computer on JMP Version 3.1 Statistical Package SAS Institute, 1989). The entire 1991-1994 data set was transferred to SPSS for final analysis (Norusis, 1993).

RESULTS

At each sampling point, a frequency grid was used four times. The frequency of each variable was transformed with an arcsin transformation, specifically the arcsin of the square root of the raw frequency is calculated (Sokal and Rolf, 1987). For simplicity, the arcsin of the frequency of encounters with each variable will be denoted in capitals, e.g. FORB represents the arcsin transformation of the frequency of data points intersecting forbs of any species.

A map of Mesa Verde National Park, showing the location of the 'X' and 'Y' sites. The park boundary is indicated by a dashed line. The 'X' site is marked with a cross-hatch pattern in the upper left corner, and the 'Y' site is marked with a solid black rectangle in the lower left corner. The title 'Mesa Verde National Park' is located in the upper left corner of the map area.

Mesa Verde National Park

FORB, grasses (GRASS), bare soils (BARESOIL), litter (LITTER), charred soil (CHARSOIL), live and dead shrubs (LIVESHURUB or DEADSHURUB) tree roots (ROOTS), and mosses (MOSESSES) were recorded. Data were collected and analyzed separately in 1991, 1992, and 1994. Two-Way Analysis of Variance tests were carried out on each variable to determine whether the variability in sampling interceptions could be explained by either *pre-fire vegetation* or by *fire history* or the interaction of these two variables. We test the null hypothesis that pre-fire vegetation and fire history have no effect on successional patterns following the fire.

Data are summarized in Figures 2-2 through 2-13. Figures 2-2 through 2-7 graphically displays the means value for each variable during each of the three sampling seasons (1991, 1992 and 1994). Figures 2-8, 2-9 and 2-10 summarize the response of all variables when grouped by unique fire history; Figures 2-11, 2-12, 2-13 summarize the response of all variables when grouped by pre-fire vegetation.

Trends demonstrated in 1991: In 1991, two years following the Long Mesa Fire, there was a significant effect of fire history on BARESOIL cover (Appendix A). Fire history was identified as pre-1940 controls, 1972, 1989 and areas which burned both in 1972 and again in 1989 (1972/1989). There was also a significant interaction effect between fire history and pre-fire vegetation. The greatest BARESOIL cover was in the piñon-juniper woodlands, clearly demonstrating the relative severity of fire in the southernmost extent of the Long Mesa fire, a trend noted by firefighters and predicted by the high density fuels. BARESOIL was also high in the sites repeatedly burnt in 1972 and 1989. Two-way ANOVAs demonstrated significant differences in LITTER, with highest values in pre-fire vegetation types piñon-juniper woodland and sagebrush. No significant differences in FORB was detected in 1991 when comparing sites of various fire history; however FORBS were significantly greater in the sagebrush areas than other pre-fire vegetation types. Significant differences were recorded in GRASS cover, with the highest GRASS cover in the control (pre-1940) areas as well as in sites which had supported sagebrush before the fire in 1989.

LIVESHURUB cover deserves special attention because the immediate resprouting of particular shrubs like *Quercus gambelii* forms the basis of our fire history detection (Chapter 1). Although oaks resprouted immediately after the 1989 burn, there is still a small, significant differences in LIVESHURUB cover in 1991 when comparing sites of different pre-fire vegetation and fire history. The difference is attributed to a low value in LIVESHURUBS in areas which burned in both 1972/1989. Apparently, repeated burning favors other plant forms over shrubs. Shrublands showed the greatest resprouting and are responsible for the significant differences noted in LIVESHURUB across pre-fire vegetation types. Not surprisingly, DEADSHURUB encounters in 1991 were significantly greatest in areas which were shrublands before the burn. ROCK differed among pre-fire vegetation types, with the highest ROCK exposure in the most severely burned areas, the piñon-juniper woodland.

Trends demonstrated in 1992: By the third year after the Long Mesa fire, the BARESOIL effect could only be seen in pre-fire vegetation types; BARESOIL was no longer different among samples from different fire histories. There was no longer a significant difference in LITTER among pre-fire vegetation types, although there remained a significant difference across the fire histories. Although no difference in FORB occurred in the previous year, a flush of FORB was observed in 1992, highest in shrublands and piñon-juniper shrublands. The uniformity of GRASS cover among all fire histories demonstrates that by 1992, grasses had invaded most sites to near-control levels. Significant differences in GRASS cover among pre-fire vegetation types occurred, with the highest values measured in the pre-fire sagebrush communities, as demonstrated the previous year.

In 1992 the trend in LIVESHURUB cover changed. There was no significant difference in pre-fire vegetation types and barely significant differences among fire history types (caused by slightly greater LIVESHURUB in the 1972 burn sites).

As we described in the previous year, DEADSHURUB and ROCK remain significantly different among sites of varying pre-fire vegetation and fire history.

Figure 2-2

Mesa Verde National Park
1989 - Long Mesa Fire Succession Study

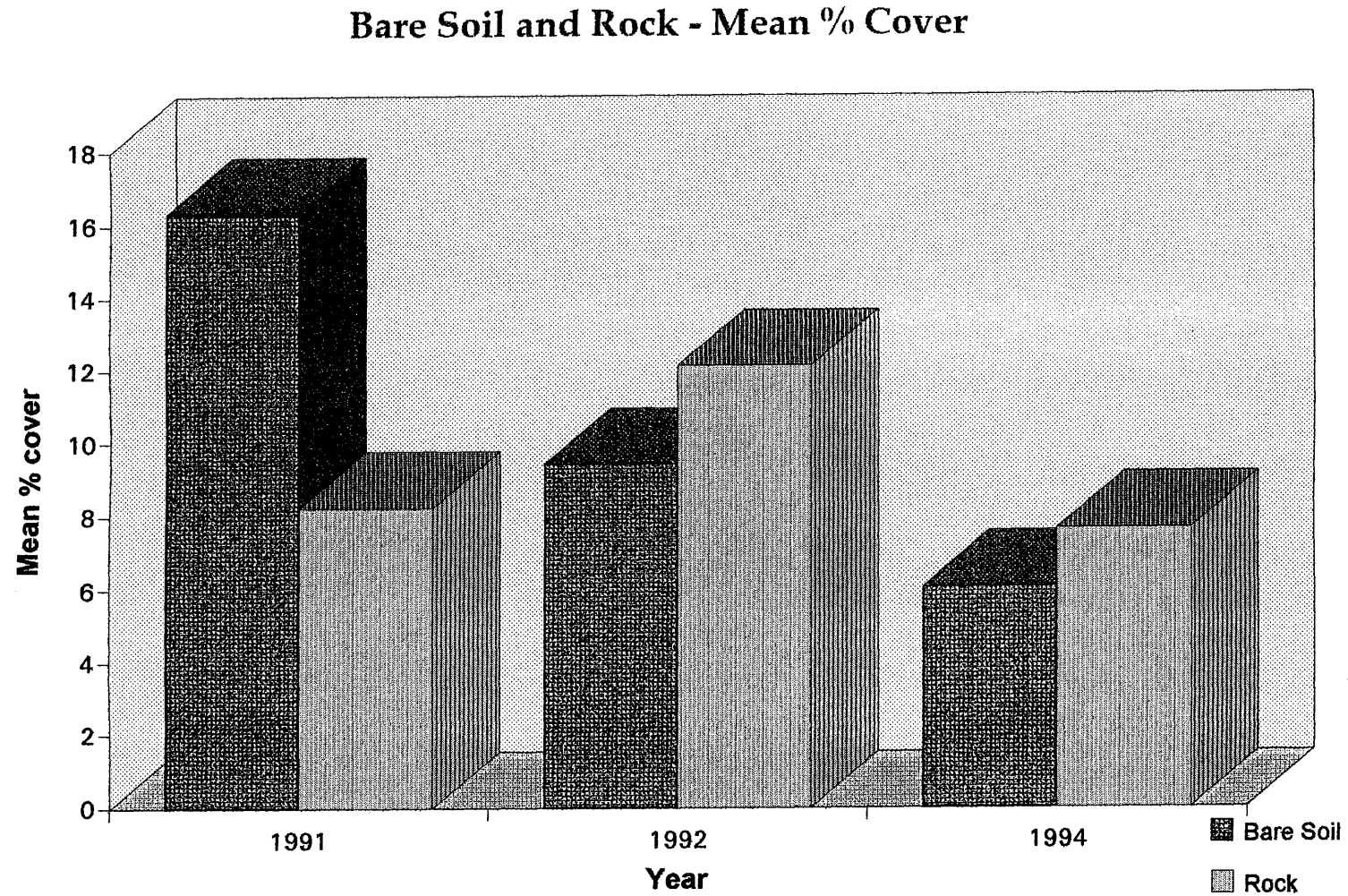


Figure 2-3

Mesa Verde National Park
1989 - Long Mesa Fire Succession Study

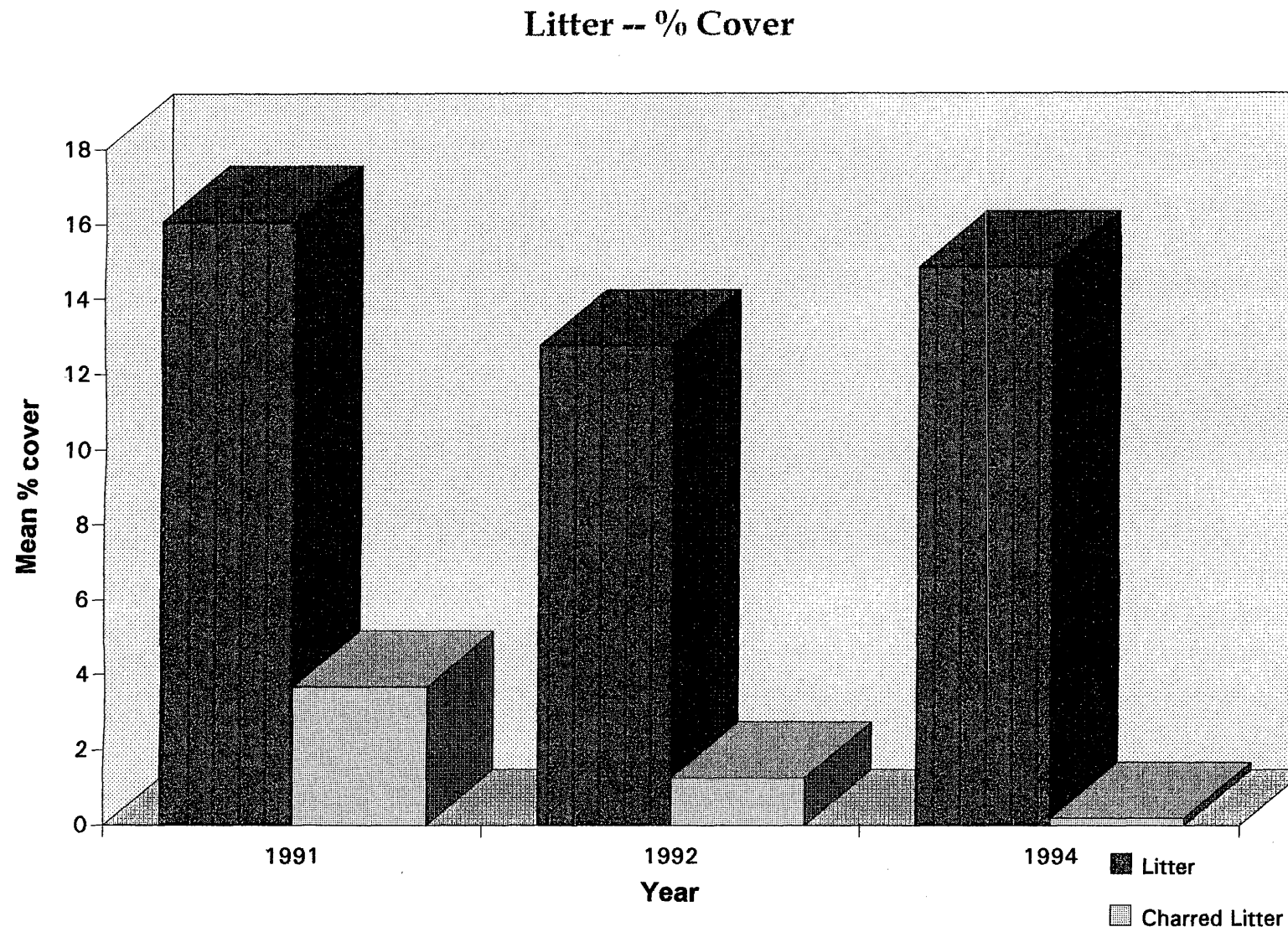


Figure 2-4

Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study

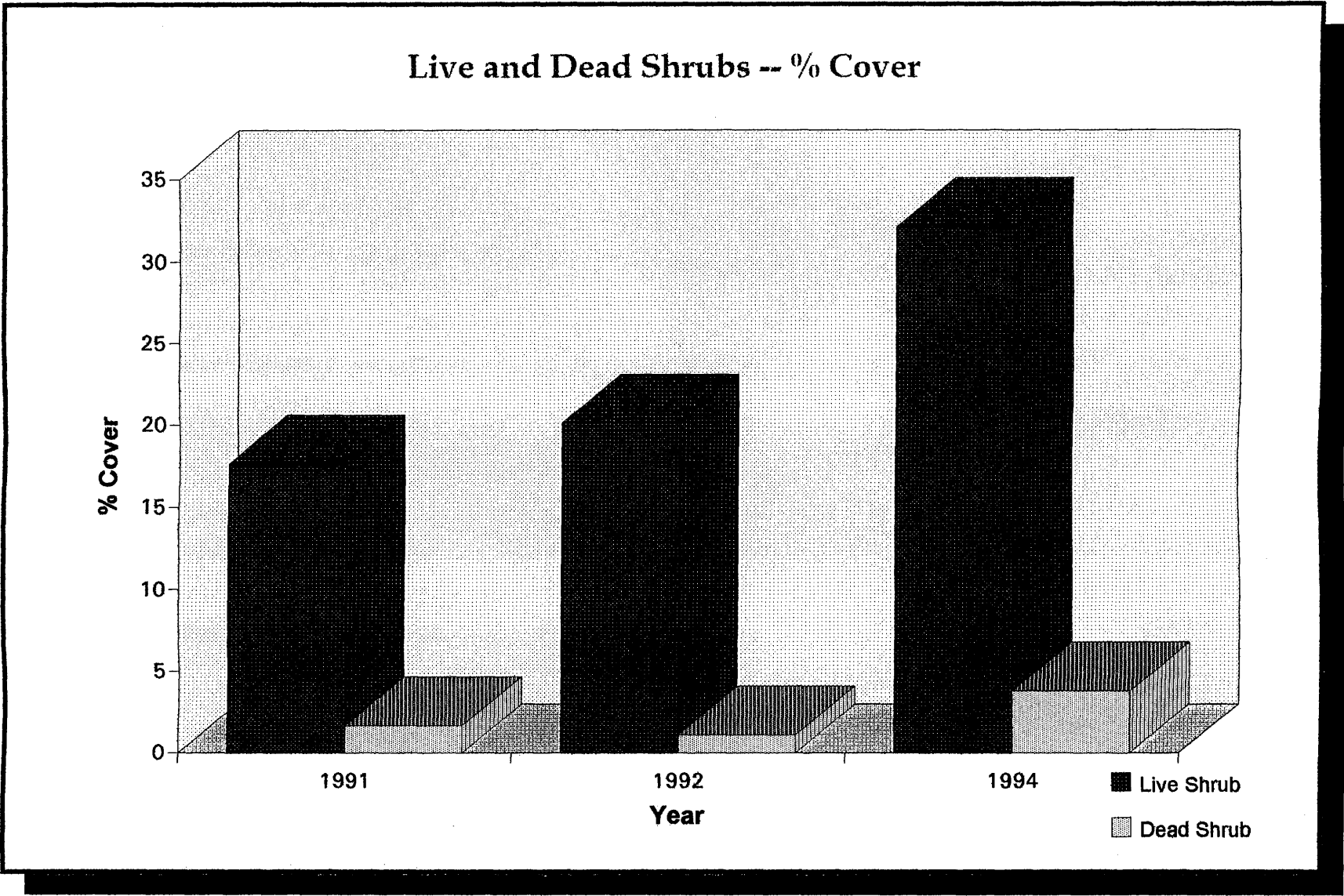


Figure 2-5

**Mesa Verde National Park
1989 Long Mesa Fire Succession Study**

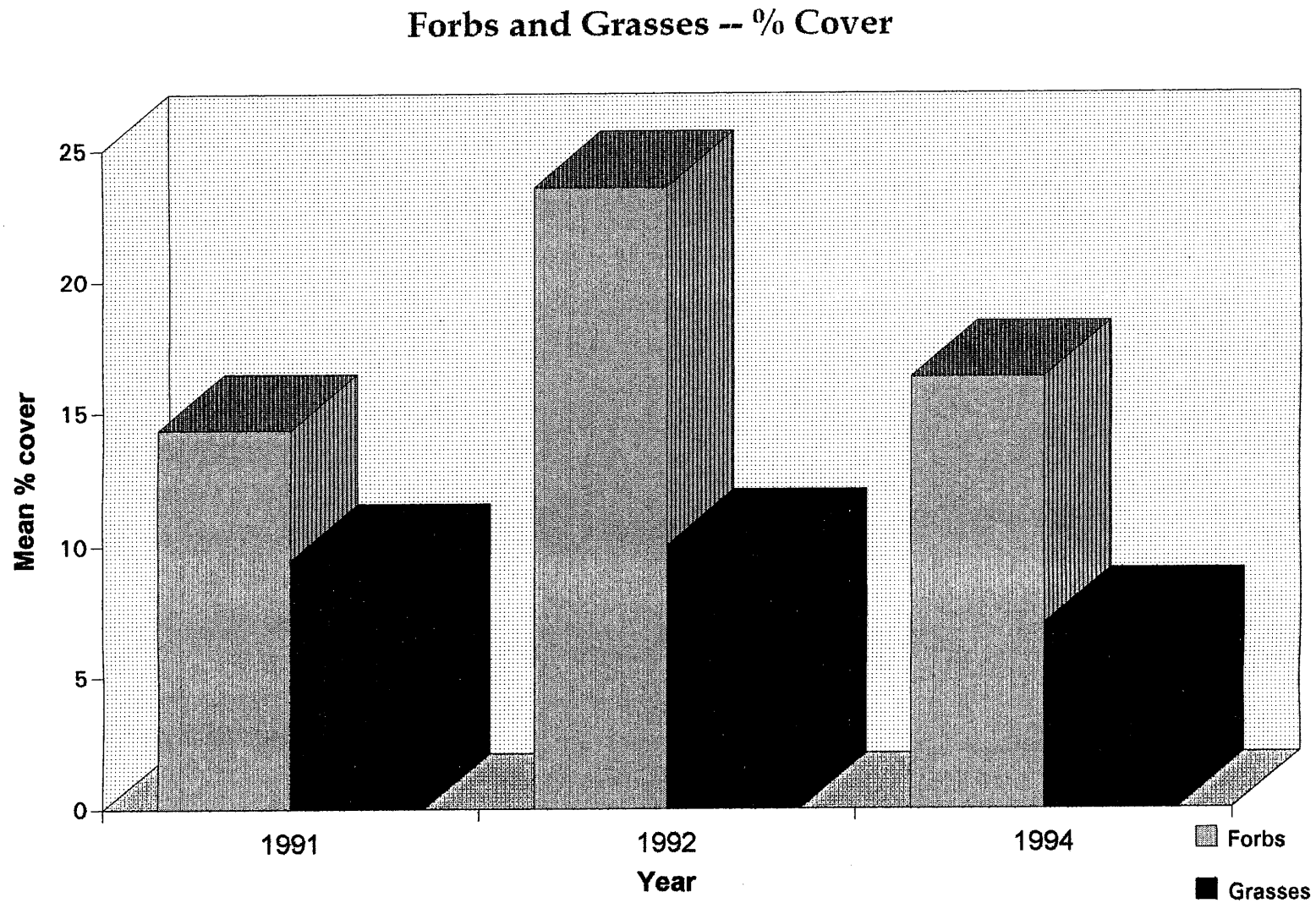


Figure 2-6

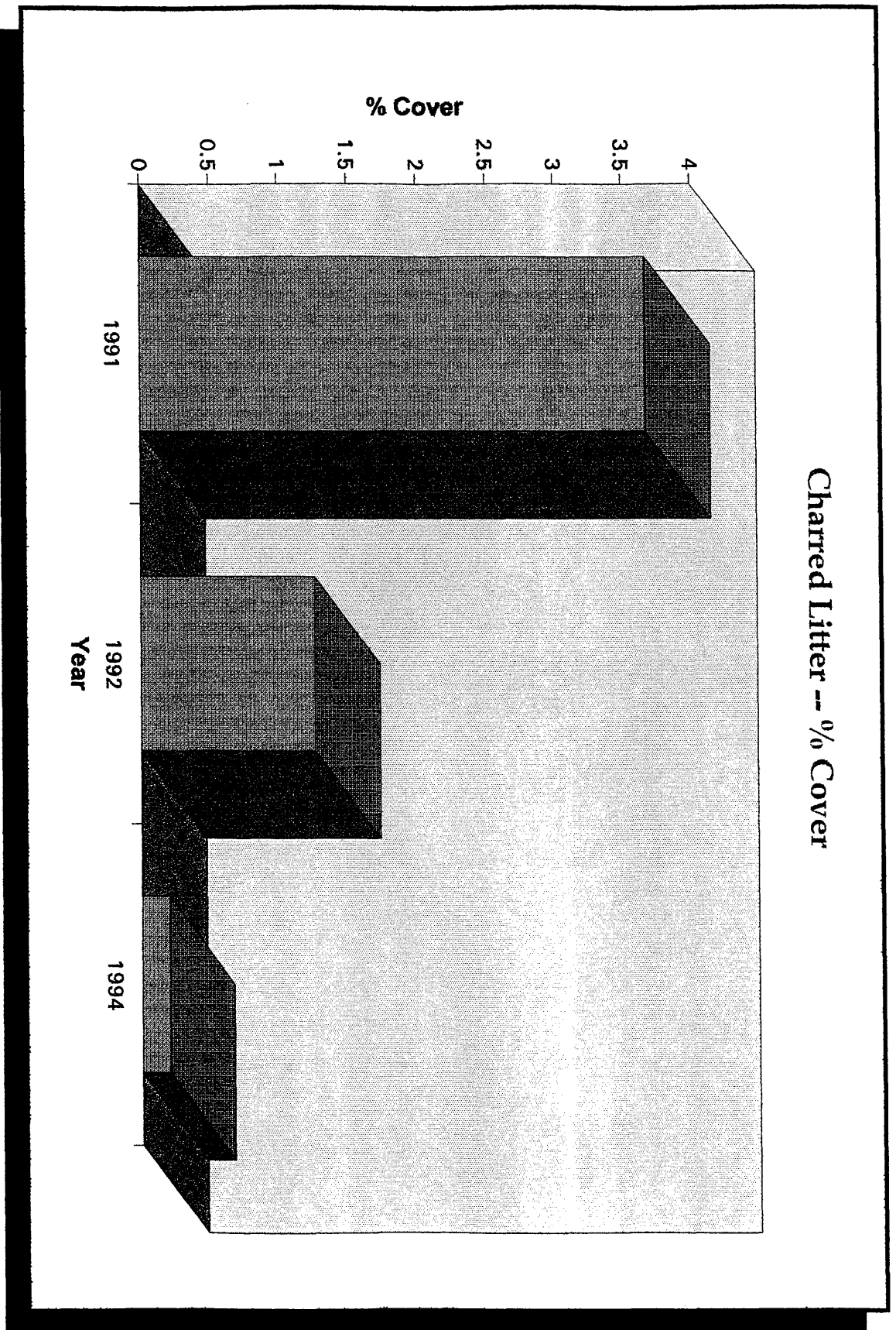


Figure 2-7

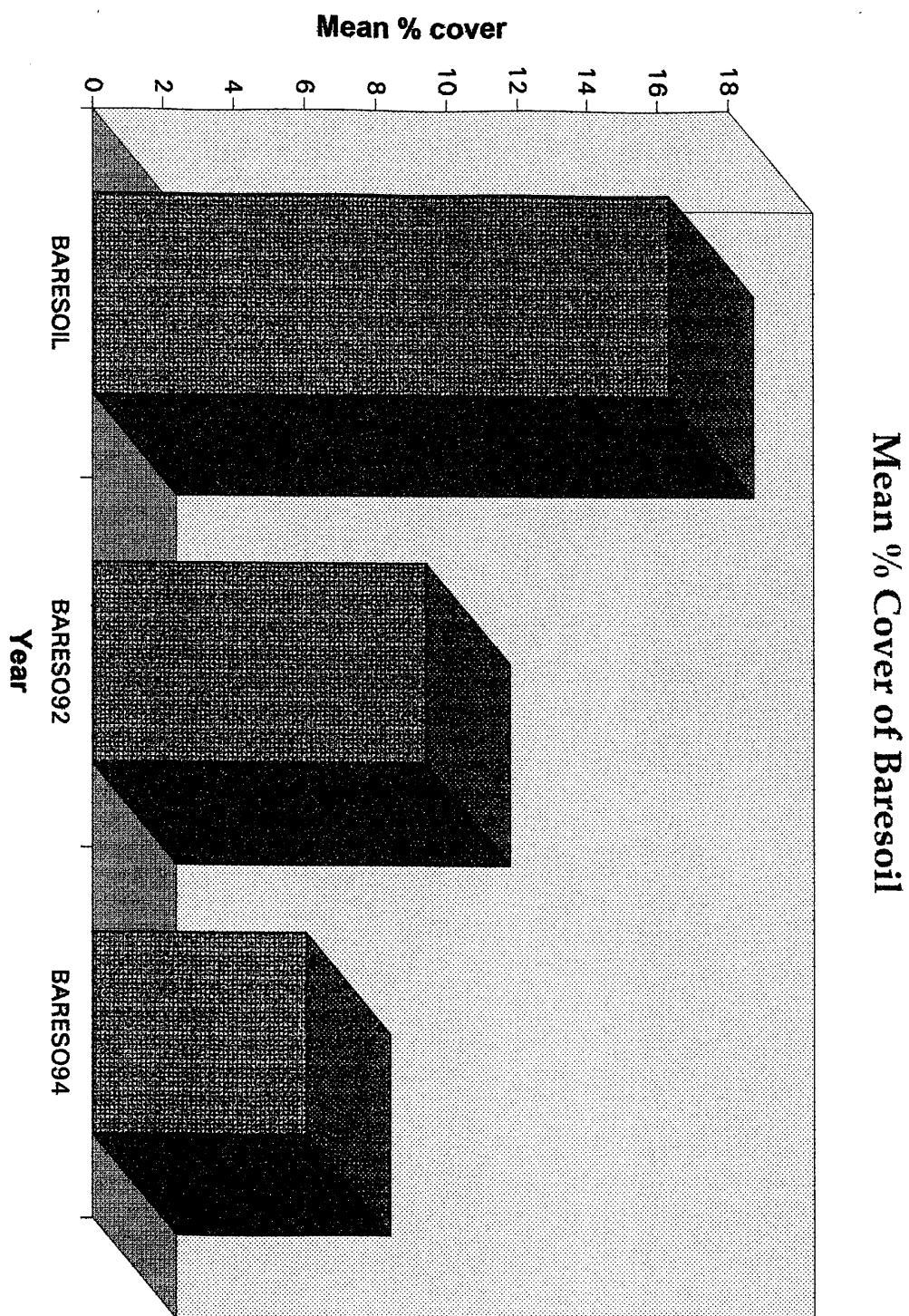


Figure 2-8

Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study

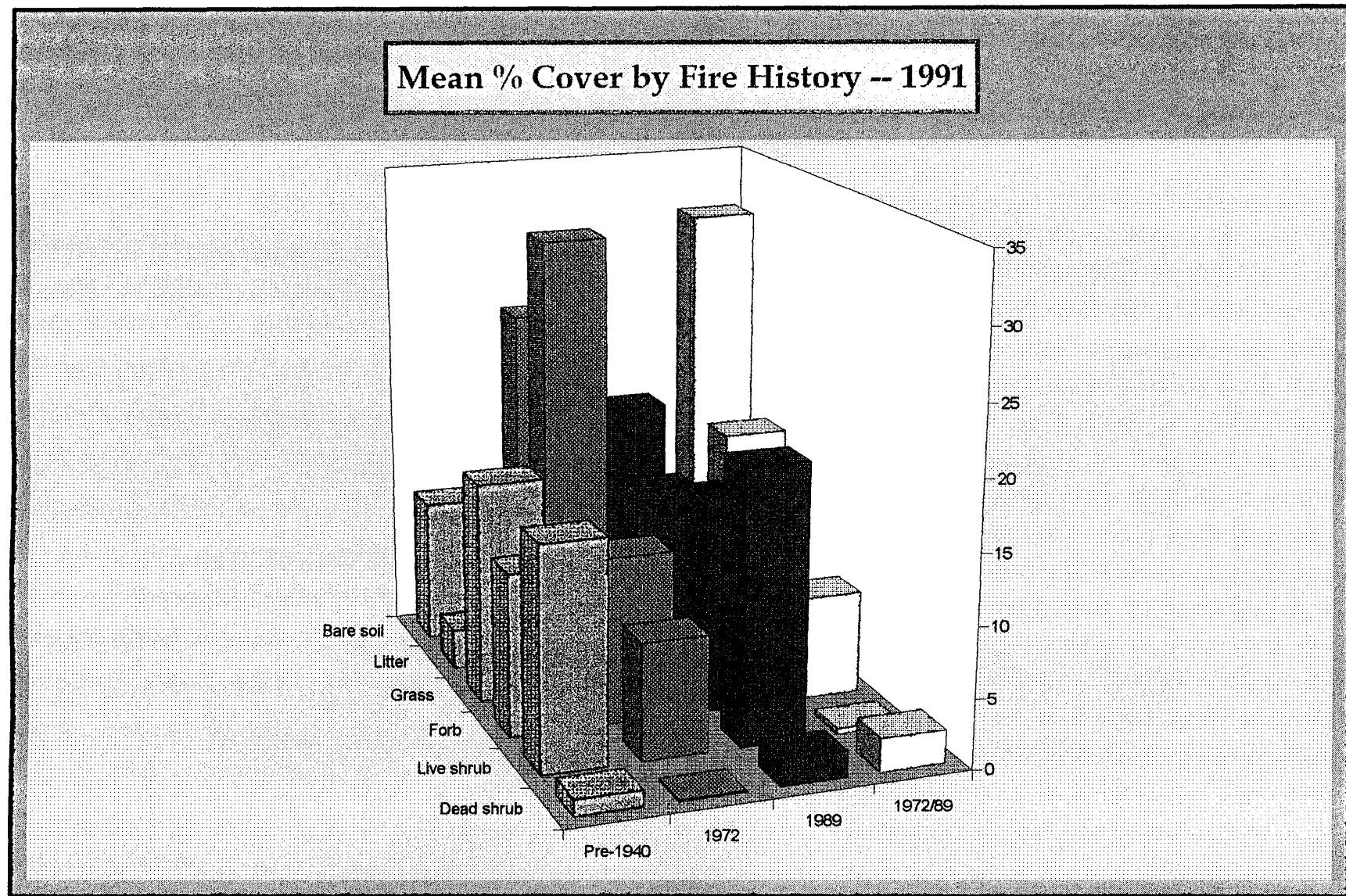
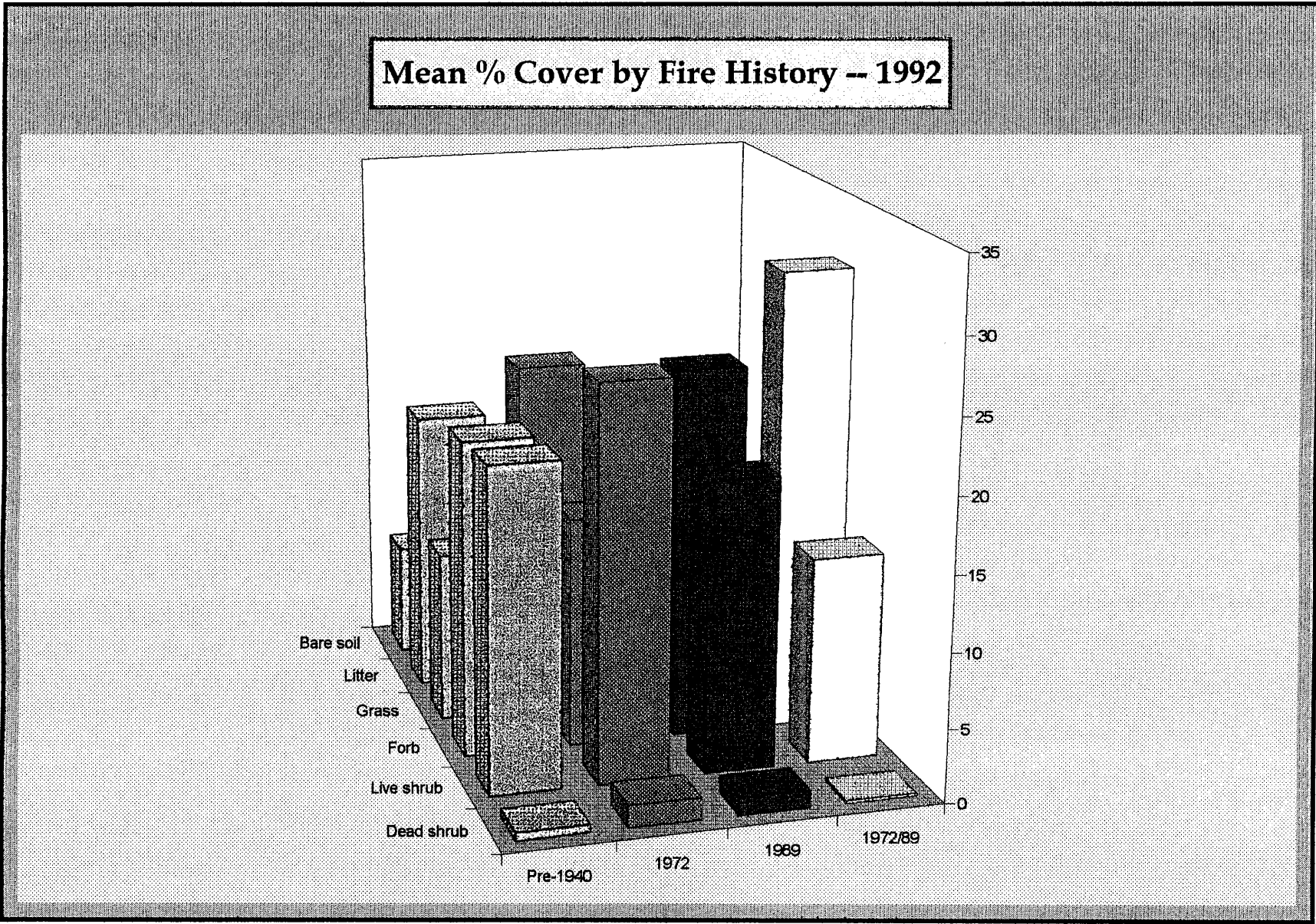


Figure 2-9

**Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study**



Trends in 1994: Within 5 years of the Long Mesa fire, the vegetation cover is well established in most sites. BARESOIL varies among fire history sites, but this is not likely an important trend. Trends in LITTER are the same as in 1992 sampling. FORBS have dropped when compared to 1992 values. This may reflect the moisture conditions as 1992 was relatively wet and promoted germination across the entire mesa. GRASS cover increased in the 1972 burn areas relative to other fire history sites, most of which did not change in GRASS structure from the 1992 sampling.

An interesting trend is demonstrated in LIVESHRUB cover five years after the Long Mesa fire. Focusing only on shrublands, where potential to resprout is greatest, the relative frequency of LIVESHRUB is:

	Burned in 1989	Unburned in 1989
1991	.30 (n=317)	.33 (n=72)
1992	.30	.36
1994	.49	.50

This simplification shows that as early as 1991, the second year after the Long Mesa fire, resprouting has returned the shrub species to pre-fire importance in sites where root-crowns and other protected subterranean material is available.

In 1994, we detected a significant difference in LIVESHRUB among pre-fire vegetation types in 1994 because of an increase in sprouting of *Artemisia nova* and *Purshia tridentata*. Although *Amelanchier utahensis* and *Quercus gambelii* resprout vigorously immediately after the burn, we have noted a delay in sprouting, or in some cases a permanent death, of the sagebrush and bitterbrush shrubs.

Finally, no difference is seen in DEADSHRUB cover by 1994. ROCK cover remains significantly different among sites of varying fire history and pre-fire vegetation.

In the southern section of the Long Mesa fire, where piñon-juniper dominated before the burn, and where the most severe fires burned, many sites are plagued by the invasion of noxious weeds (Floyd-Hanna et.al., 1993). The burn covered both mountain shrub communities and well-developed piñon-juniper woodland, and only the latter show prolific non-native weed invasion. Weedy sites were characterized by high mortality and exposure of mineral soils, and now support dense stands of musk thistle *Carduus nutans*, Canadian thistle, *Cirsium arvense* and other exotic species. It is still too early to predict confidently the long-range successional trajectories on these sites, but we presently see no evidence of these weedy invaders being replaced by native species. Rather, it appears that the exotic weeds have preempted extensive areas in the 1989 burn, particularly those of high fire intensity, and that these very competitive species will dominate these sites for a very long time--perhaps indefinitely.

DISCUSSION

In 1991, a study of post-fire succession following the 1989 Long Mesa Burn was initiated. During 1990, the widespread presence of *Chenopodium alba* and patches of *Nicotiana sp.* were documented (Colyer, pers. comm; Adams, 1991). During 1991, 1992, and 1994 we documented significant differences in post-fire recovery in areas of unique pre-fire vegetation and fire history.

The shrub species common to Mesa Verde National Park are many and several different strategies for post-fire invasion are represented. While perennial resprouts dominate in recently burned shrublands, sagebrush parks, and Douglas Fir/Shrublands, the species composition of shrub species may change following fire. For example, the robust resprouters, or fire "endurers" (Rowe, 1983) are *Amelanchier utahensis*, *Quercus gambelii* and

Symphoricarpos oreophilus. These species assume dominance after fires, perhaps at the expense of shrub species which did not resprout and tended to "invade" by seed after fires, such as *Artemisia tridentata*, and *A. nova*. The sagebrush and bitterbrush (*Purshia tridentata*) species gained somewhat in frequency in 1994 possibly by a delay of resprouting as well as by seed germination. The behavior of *Purshia tridentata* provides an interesting senerio-- our observations show that this species rarely resprouts, although it can do so in patches which were subject to low fire intensity on Long Mesa. *Cercocarpus montanus* is essentially removed by fire. Consequently, it appears that the two species of nitrogen fixing shrubs are often 'set-back" by fire and other, non-nitrogen fixers, are encouraged. This hypothesis is currently under investigation (Berry and Floyd-Hanna, 1993).

On the northern extreme of Long Mesa burn, where shrubs are common, resprouting of shrubs has allowed a dominance of perennials which preempts a forb---grass/forb---perennial sequence of succession as predicted by Erdman (1970). This has been important in reduction, by competition, of the exotic plant species which now thrive on the southern sector of the Long Mesa Burn. The northern part of the Long Mesa burn was soon dominated by perennials which resprouted, thus deterring weedy invasion (Floyd-Hanna, Romme, Colyer, Loy, 1994).

The ability of shrubs to resprout, reflected in LIVESHRUB cover, is reduced in points which are repeatedly burned (1972/1989). Shrub depletion may be explained by a carbohydrate depletion model, in which repeated major resprouting events drains carbohydrate reserves in order to produce new shoot material. Alternatively protective tissues--corns, root crowns, bulbs, stolons, may be damaged. Seed banks may also become depleted by frequent fires and this has ramifications for seed-reproducing shrubs such as *Cercocarpus montanus*. While seeds may germinate after the first fire, a second fire may kill those plants prior to their replenishment of the seed bank. This is a possible explanation why repeated fires, e.g. in 1972 and again at that site in 1989, tend to encourage FORB species and deter both GRASS and LIVESHRUB.

Of the entire Long Mesa Fire, 7.5 % is infested with *Carduus nutans* (Floyd-Hanna, 1993). However, the weedy invasion is restricted to the southern part of the burn which supported piñon-juniper woodlands prior to the 1989 fire. The burn was extremely hot in the piñon-juniper woodlands relative to the mountain shrub communities on the northern parts of Long Mesa (Budd-Jack, Kenoyer, pers. comm), exposing bare mineral soils upon which weedy species took hold. The emphasis on exotic invasions is driven partially by knowlege of the persistence of stands of exotic thistles in sites throughout La Plata and Montezuma counties since their invasion during the 1970's. While it is true that disturbance is necessary to create the conditions required for thistle invasion, patches of thistle persist in openings of mature piñon-juniper woodlands as well as in larger disturbed sites such as fires, sewage plants, Mesa Verde's water line, visitor-related facilities, and roadways. Biological invasion of Mesa Verde National Park on disturbed habitats illustrates the complexity of problems created by species migration and the role of human interference in plant establishment. Although weedy species are adapted to exactly the habitats that humans maintain, their positive influences-- soil stability, erosion prevention, for example- may be overridden if they tend to re-direct the native successional process. We have shown that the extent of ecosystem disturbance and the proximity to seed sources of aggressive weeds have created, in Mesa Verde National Park as elsewhere, a critical biological invasion.

Although we cannot yet predict with confidence the long-term effects of exotic plant invaders in Mesa Verde National Park, from other studies we know that changes in community or ecosystem function following establishment of exotic species has not always been significant; the potential effects of the new species range from modest usurpation of resources from many native species, hence no extinctions, to intense competition with one or a few native species, with significant competitive displacement of of the native(s) (Westman 1990). Indeed, invaders may have positive ecosystem effects, especially with regards to repair of damaged ecosystems. For example, weedy herbaceous invaders may sequester nutrients more efficiently than the native species in severely disturbed sites (Mooney and Drake 1989).

Despite substantial research on the problem to date, we still cannot make better than very general predictions about which species are likely to be successful invaders or which communities are most susceptible to invasion; each species and situation must be examined individually (Bazzaz 1986, Westman 1990).

CONCLUSIONS

This study investigated the fire history and post-fire succession following the Long Mesa Burn, in Mesa Verde National Park, southwestern Colorado. Three post-fire succession study grids were established across the diversity of vegetation types burned in 1989 on Long Mesa. Early successional patterns, measured in 1991, 1992, and 1994 vary with previous vegetation and burn history of the sampling site. Post-fire successional patterns will be monitored in the future by Park personnel.

Our data show perennial shrub resprouting preempts the forb and grass early successional seres. This is particularly important to soil stabilization and promotion of native (perennial) vegetation on the northern half of Long Mesa. There is no evidence of conifer invasion into the Long Mesa burn, and the southern half of the Mesa now supports primarily forbs, grasses, low shrubs, and non-native weedy species. In addition to fire history, other factors -- subtle differences in microclimate, soils, and soil microbial communities -- also may influence the overall distribution of shrublands and woodlands in MVNP. Further research is needed to disentangle the relative effects and interactions of these various factors.

Figure 2-10
Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study

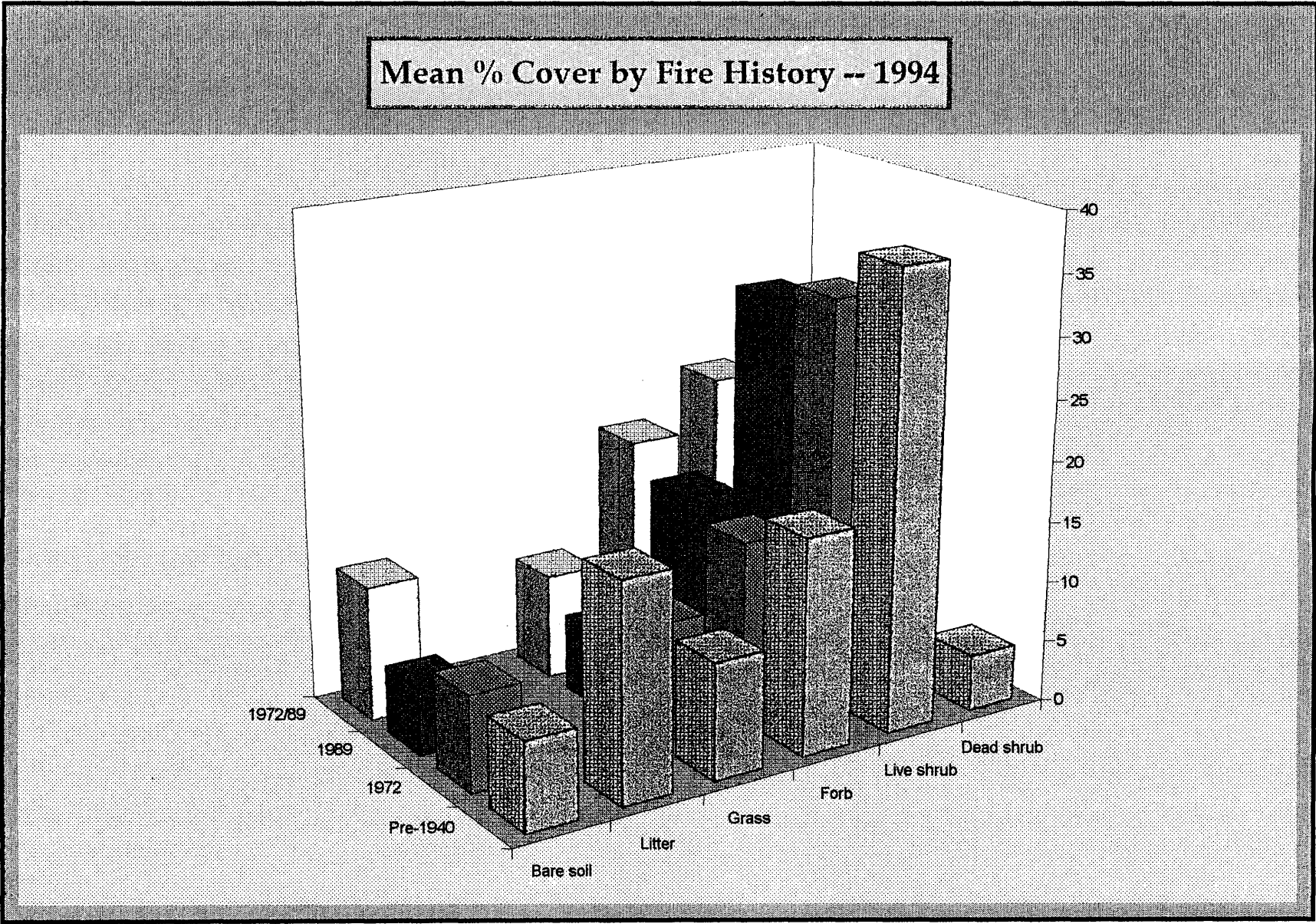


Figure 2-11

Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study

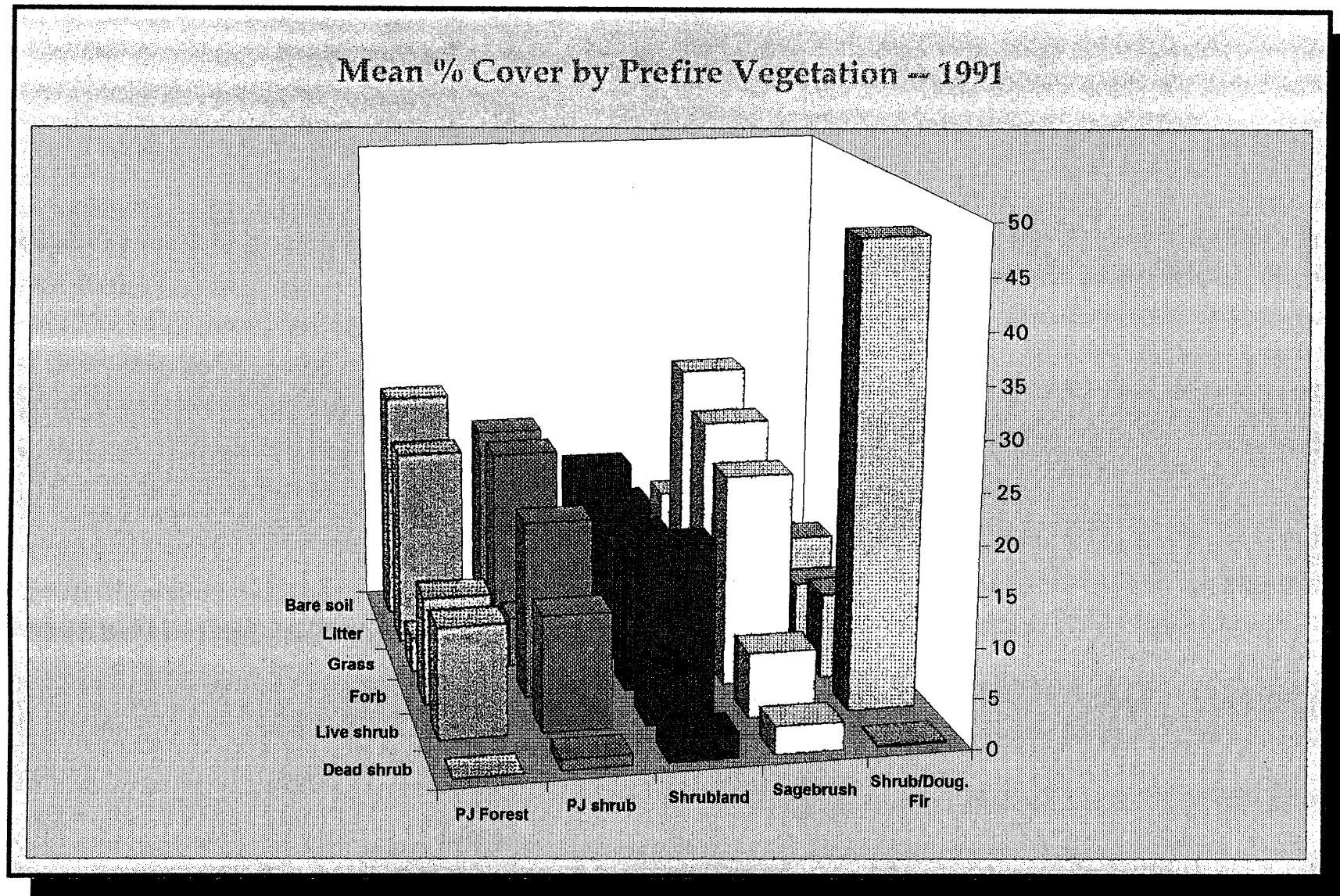


Figure 2-12

Mesa Verde National Park
1989 -- Long Mesa fire Succession Study

Mean % Cover by Prefire Vegetation -- 1992

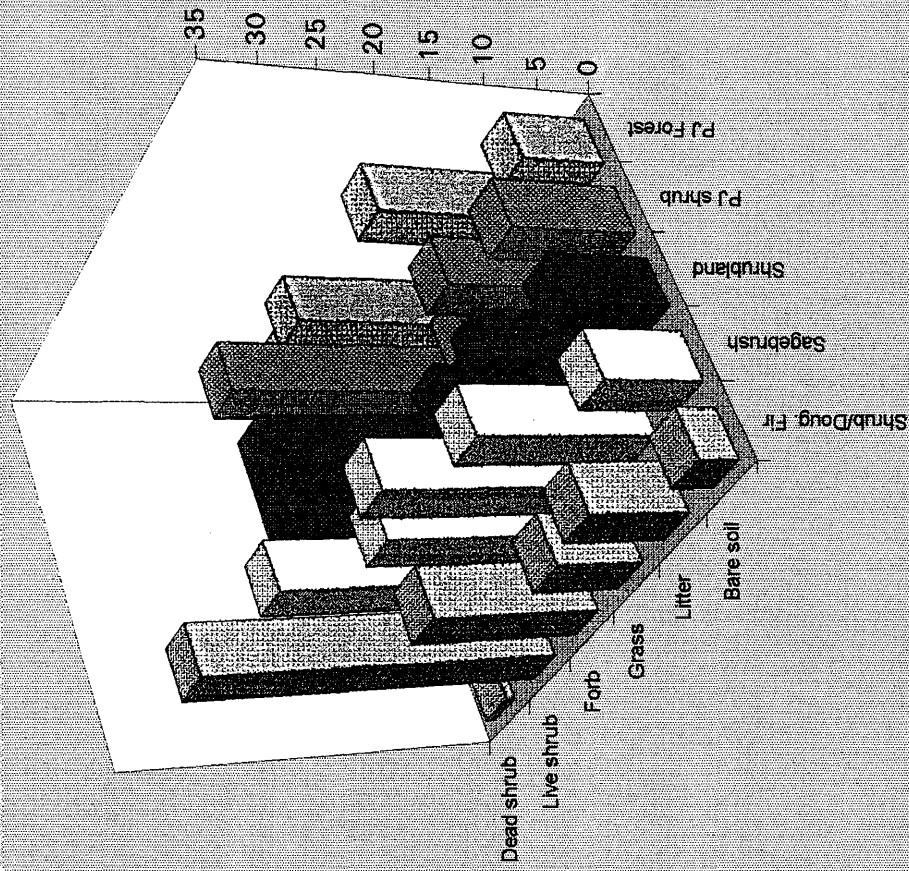
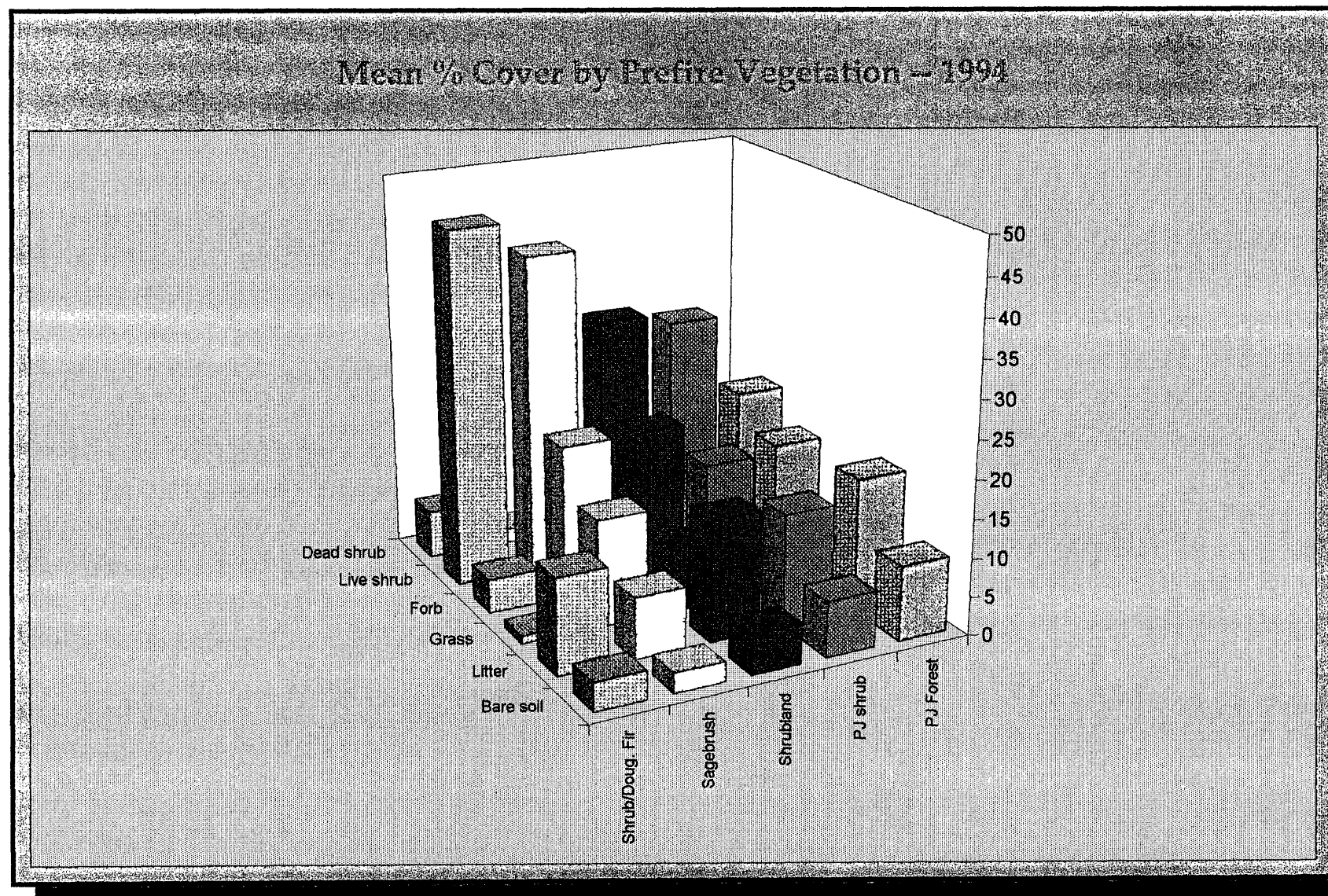


Figure 2-13

Mesa Verde National Park
1989 -- Long Mesa Fire Succession Study



CHAPTER 3

MODELING FIRE BEHAVIOR IN MESA VERDE NATIONAL PARK

David D. Hanna, William H. Romme, and Lisa Floyd-Hanna

INTRODUCTION

Mesa Verde National Park (MEVE) was established in 1906 to preserve outstanding structures and artifacts of Anasazi peoples who inhabited the region from about 400 A.D.-1300 A.D. Today the Park also contains numerous historic sites of cultural significance, such as the museum and administrative complex built in the 1930s, as well as culturally scarred trees, remnants of early homesteads, and other features representing the early human history of this area (Romme et al 1993). Many of these nationally significant cultural resources could be damaged or lost in a high-intensity wildfire. Uncontrollable wildfires have occurred in MEVE on three occasions in the last 40 years (1959, 1972, 1989). Fortunately, none of these fires threatened any of the especially significant and vulnerable cultural resources in the Park, but future fires could do so. Therefore, the objective of this study was to predict the kinds of fire behavior and fire effects possible under severe fire weather conditions in each of the major vegetation types in Mesa Verde National Park. The understanding so derived will contribute to the larger goal of evaluating fire risk and taking steps to prevent fire damage to cultural resources in MEVE.

The standard tool for simulating and evaluating wildland fire behavior is the fire behavior model called BEHAVE (Burgan and Rothermel 1984). However, none of the existing fuel models in the BEHAVE system are adequate for the piñon-juniper and mountain shrub vegetation communities that predominate in MEVE. Our preliminary attempts to simulate the kinds of fire behavior observed in MEVE during the large fires in 1959, 1972, and 1989, using standard BEHAVE fuel models were unsuccessful: the output of the models bore little resemblance to what was actually observed. Therefore, in this study we collected field data to describe fuels conditions in MEVE, then used these data to develop a series of new, custom fuel models. Fuel data were collected over a two year period at sites within MVNP representing eleven vegetation communities. This was accomplished while extensively ground-truthing satellite imagery for a vegetation study (Floyd-Hanna et.al., 1994). Finally, we ran BEHAVE using our custom fuels models to predict fire behavior and effects under the most severe burning conditions encountered in the Park, i.e., during late June and early July following a long rainless period. This is the time when large, uncontrollable fires have occurred historically in MEVE (Omi 1980).

We developed three custom fuel models for each major vegetation type in MEVE by methods outlined below. The first model (called the "normal model") incorporated mean values of all the fuels parameters that we measured in the field (Appendix 1). The second model (called the "high model") incorporated the maximum value recorded in any of our sample plots for each parameter. Maximum values for different parameters were encountered in different plots, so the "high model" does not represent any actual plot that was sampled in the field; rather it represents the highest (but still fairly realistic) fuel complex likely to be encountered in MEVE. For the third model (called "worst case model"), we departed from traditional applications of BEHAVE in that we included the tree crowns in the shrub component of the fuel bed. This was because BEHAVE runs, using even the "high model" under low fuel moisture and high wind, failed to simulate the kinds of extreme fire behavior that have been observed in MEVE under severe fire conditions, e.g., in 1972 and 1989 (Budd-Jack, Kenoyer, pers. comm).

Fuel complexes and fire behavior in piñon-juniper and mountain shrub communities in general are poorly understood. Although we focused on MEVE in our analyses, the custom fuel models that we developed may be applicable or adaptable to other areas in Colorado, New

Mexico, Utah, and Arizona where vegetation and weather conditions are similar.

METHODS

COLLECTION OF FUELS DATA

The sampling areas were chosen from among the 392 study sites used to define the vegetation of Mesa Verde National Park in a related recent vegetation study (Floyd-Hanna and Romme, 1993). Fuels were sampled in a subsample of the releve sampling points, representing each extensive vegetation type.

Standing fuels were measured and their potential fuel mass estimated by means of regression equations developed by Meeuwig and Budy (1981). This included all crowns of dead snags, live trees and shrubs, that intercepted the 45-m central transect through the stand. These equations also require the height of each intercepted tree, the diameter at root collar, the diameter at breast height, and the average height from the ground to the crown base. The regression transformations provide a fuel index in terms of the mass per meter of crown width. Then, the masses were multiplied by crown width to obtain mass per tree. These values were summed to obtain total mass for the transect. The mean crown width at each site was multiplied by the transect length (45 m) to estimate the area covered by each transect. Finally, our metric measurements were converted to English units to provide the fuel load estimate (tons/acre) needed by the BEHAVE fuel model.

Downed woody fuels also were sampled using the standard planar-intercept method (Brown 1974). In each releve sampling area we ran a 45-m transect through the long axis of the plot, then established five perpendicular lines at regular intervals and running in alternating directions from the central transect. Along each line we sampled downed woody fuels and litter with the planar intercept method (Brown 1974). We tallied the measurements of 1hr, 10hr, 100hr, and 1000hr TL fuels over all five lines, and computed a single estimate of tons/acre for the plot as per Brown (1974). Similarly, we averaged duff depth and fuel depth over all five lines and recorded a single average value for each parameter for the plot. These data on the mass (tons/acre) of fuels of various size classes have been organized for entry into an existing thermodynamic fire behavior model BEHAVE.

All field data for downed and woody fuel were manipulated using Microsoft Excel spreadsheet to calculate the fuel loads in tons/acre. These data were then grouped by vegetation community type and descriptive statistics were computed for all parameters, treating each plot as a single sample (Appendix 1). Fuels data were used to predict fire behavior potential under different weather scenarios for each major vegetation community in the Park using BEHAVE (Burgan and Rothermel 1984).

BUILDING CUSTOM FUELS MODELS WITH BEHAVE

Custom fuels models in BEHAVE require information on the following fuels components: grass, litter, slash, and shrubs. From our field data (Appendix 1) and other sources (described below), we computed each fuel component for BEHAVE as follows:

Grass: We estimated total cover of grass in 15x15-m releve plots, that coincided with our 45m fuels transects, as part of a related study to classify and map the vegetation communities of MEVE (Floyd-Hanna et al., 1994). For BEHAVE, we took the minimum cover value for the Braun-Blanquet cover class of each species of grass encountered and summed these values to obtain an estimate of total grass cover in the plot. We also estimated an average height of the grasses within the plot. These data were then grouped by vegetation community and descriptive statistics were calculated. The mean and maximum recorded grass cover and height (Appendix 1) were input into BEHAVE (for the "average" and "high" models, respectively), which used them to calculate grass fuel loading for the custom fuel model. The dominant grass species in MEVE are *Poa fendleriana*, *Stipa commata*, *Oryzopsis hymenoides*,

and *Sitanion hystrix*, which match grass type 1, density class 3 of Burgan and Rothermel (1984, Appendix 1, p.57) during dry weather conditions in late June and early July.

Litter: Average and maximum observed values of litter depth (Appendix 1) were input into BEHAVE, which then calculated litter loadings in tons/acre. For the litter component we assumed the following distribution of size classes, based on our subjective observations of the sampling plots and of similar stands elsewhere in the region: 1hr-TL= 80% , 10hr-TL= 15% , 100hr-TL= 5%.

Slash: Average and maximum observed tons/acre of each of the three size classes of slash (1hr, 10hr, and 100hr timelag fuels) were input from the planar intercept data in Appendix 1.

Shrubs: Average and maximum observed tons/acre of live foliage and dead woody components (1hr, 10hr, and 100hr TL) of true understory shrubs were input from the data in Appendix 1. These values were used in the "average" and "high" fuel models, respectively. For the "worst case model", we added the average live foliage mass of piñon and juniper crowns (Appendix 1) to the mean fuel values for true understory shrubs. Thus, the "worst case" fuel model consists of the fairly conventional "normal fuel model" plus the tree crowns that have been added to the shrub component.

In all custom fuel models we used the same values for surface/volume ratios (Table 3-1) and for heat content. The values were derived subjectively from our previous experience in each of the fuel types.

Table 3-1. Surface area to Volume Ratios and Heat Content Values use in custom fuel models for Mesa Verde National Park

Fuel Category	S/V Ratio
Grass fuels	3000
1-hr Litter fuels	2250
1-hr Slash fuels	1500
1-hr Shrub fuels	2000
Live herbaceous fuels	2000
Live woody fuels	1500
Fuel Category	Heat Value
Dead Fuels	9000
Live herbaceous fuels	7500
Live leaves and shrubs	8800

MODELING FIRE BEHAVIOR WITH BEHAVE

Normal, high, and worst-case custom fuel models were developed for three piñon-juniper vegetation communities: 1) piñon-serviceberry, 2) piñon-oak and, 3) piñon-bitterbrush. The same three models were also developed for the montane shrub communities within the park. The piñon-serviceberry community is dominated by usually dense stands of mountain shrubs, including Utah serviceberry, Gambel oak, and Fendlerbush, with a sparse canopy of piñon and Utah juniper. The piñon-oak community usually is dominated by a dense canopy of piñon and Utah juniper, with a dense understory of oak and other shrub species. The piñon-bitterbrush community also is dominated by a dense canopy of piñon and Utah juniper, but the understory is dominated relatively sparse bitterbrush and grasses. Montane shrub communities generally lack a tree component, but consist of dense stands of Gambel oak, Utah serviceberry, and other tall montane shrub species. piñon-bitterbrush communities are prevalent in the the southern portion of the Park, whereas the northern end is a mosaic composed primarily of the other three community-types.

We ran each custom fuel model under a range of severe fuel and weather conditions that

have been observed to occur every few years in late June and early July in MEVE. Fuel moisture values used were: 1hr = 2, 3, 4, 5, 6, 7, 8 percent; 10hr = 4%, 100hr = 6%; live herbaceous moisture content = 80%; live woody moisture content = 130%. Midflame windspeeds were 5, 20, and 40 mph. Terrain slope was 5% and direction of wind vector was 0 in all runs.

RESULTS

A series of representative BEHAVE runs are compiled in Appendix 1. We have included the output from one run for each fuel model to demonstrate the usefulness of the precise woody fuels data for model building.

Comparison of piñon-serviceberry, piñon-oak and, piñon-bitterbrush models: Each piñon-juniper vegetation type was run utilizing either average fuel conditions lacking trees, high fuel conditions excluding tree layers, and finally the worst-case scenario with trees and shrub species.

The possible effect of fire on cultural resources depends, among other variables, on the heat per unit area. Comparing this variable in the "Average" model across piñon-juniper vegetation types, the piñon-oak vegetation type has the highest heat value, yet the ranges are similar when the three vegetation types are compared. In all vegetation types, heat does not vary with a change in windspeed condition. In the "High Model", the heat per unit area in the piñon-oak vegetation types approaches twice that of the piñon-bitterbrush and is considerably greater than the piñon-serviceberry vegetation type. The pattern changes somewhat in the worst-case model, where the range in heat values for piñon-bitterbrush (8129-9863 btu/ft²) approaches the piñon-oak (8684-10454 BTU/ft²), while it actually drops below "High Model" levels in piñon-serviceberry. This may be explained by the fact that the worst case model uses the average fuel values yet includes data from tree species. The piñon-serviceberry community potentially has relatively fewer individuals of the tree component than do the other vegetation communities.

Mountain shrub models: The mountain shrub community in Mesa Verde comprises a significant portion of the northern areas of the park. For this reason we felt it was important to model this community type as well. The development of this model was hindered by the small sample size for the fuel data. Because of this, the fuel model was developed using the piñon-serviceberry community for the Litter and Slash fuel categories. In addition, for the worst-case model the shrub data including trees for the piñon-serviceberry community were used. Among the vegetation types sampled, the piñon-serviceberry community best approximated the situation found within the montane shrub zone.

When the result of the trial runs for this model are compared with the PJ models several patterns are apparent. In general, values for all parameters are lower in the montane shrub community than for the piñon-juniper types. This may be a result of the high level of volatile resins in the PJ fuels. This is exemplified in looking at the heat per unit area (btu/ft²) The range of values for all three piñon types at a 5 mph windspeed is 345-521, while the range for the montane shrub group is 294-397. Especially notable are the variations in between the montane shrub and piñon-oak and piñon-bitterbrush communities in the worst case models. Here, the piñon communities both show nearly a ten-fold increase in heat per unit area (9863-10454 as compared to 1088 at 2% 1-hr fuel moistures). One exception is the high models for the piñon-bitterbrush and montane shrub. Results of these models are nearly equivalent. It is difficult to assess reasons for this similarity, yet it must be recognized that the high fuel models are based upon single samples with high fuel loadings and not on the average of many samples. Thus, this similarity may be an artifact of low sample sizes.

Comparisons across all shrub and woodland models: Table 3-2 compares reaction intensity (btu/ft²/m) across all three models for the four woodland and shrubland vegetation types at 2% fuel moisture content and 20 mph windspeeds. These would be considered severe burning conditions, although not the most severe conditions possible. Predicted intensities for the

Table 3-2: ✓

Reaction Intensity (Btu/ft²/m) at 2% moisture, 20 mph windspeed.

	Normal	High	Worst Case
Montane Shrub	2100	4886	5269
PJ - Amut	2579	9634	5535
PJ - Oak	2782	12877	46556
PJ - Putr	2372	5375	43662

Table 3-3:

Flame length (ft.) at 2% moisture, 20 mph windspeed.

	Normal	High	Worst Case
Montane Shrub	8.3	15.7	24
PJ - Amut	17.9	50.5	25.1
PJ - Oak	24.1	57.2	110.9
PJ - Putr	11.5	14.5	83.2

is little difference among the four community types; intensities range from 2,100 - 2,782 btu/ft²/m. However, with the "high" model (maximum sampled values for dead woody fuel loadings and understory shrubs), the intensity in piñon-serviceberry and piñon-oak types is substantially greater than in montane shrub and piñon-bitterbrush (9,634-12,877 compared to 4,886-5,375 btu/ft²/m). The greatest differences are apparent in the "worst case" model (average loadings for dead woody fuels and understory shrubs, plus tree biomass). Here the piñon-oak and piñon-bitterbrush stand out with extremely high intensities of 43,662-46,556, compared to the relatively low intensities of montane shrub and piñon-serviceberry at 5,269-5,535 btu/ft²/m.

Flame lengths (Table 3-3) show a similar pattern. The highest flame lengths are predicted for the piñon-oak and piñon-bitterbrush vegetation types (83-111 feet under conditions of 2% moisture and 20 mph winds) using the "worst case" model.

Fuel models for other community types: Most of the other vegetation community types found within Mesa Verde Park are not spatially extensive and are made up of many disjunct patches. Thus, it is difficult to develop models specific to these communities. In many of them fire effects will be dictated more by the nature of the fuels in the surrounding community than by the floristic and fuel makeup of these small patches. For some communities the standard NFFL fuel models may be as effective a predictor of fire behavior as can be developed in custom models for communities of such limited extent. The sagebrush grasslands which are found in the bottom of many of the canyons in the park are extensive enough to warrant fuel modeling. NNFL model #2 provides an adequate indication of fire effects in this community. The Douglas Fir communities may also be modeled with standard fuel models. These communities are not spatially extensive however and may react more to the fire behavior in the surrounding montane shrub or piñon-juniper communities. In this case, Fuel model 8 may be an effective predictor where Douglas Fir stands are prominent.

DISCUSSION

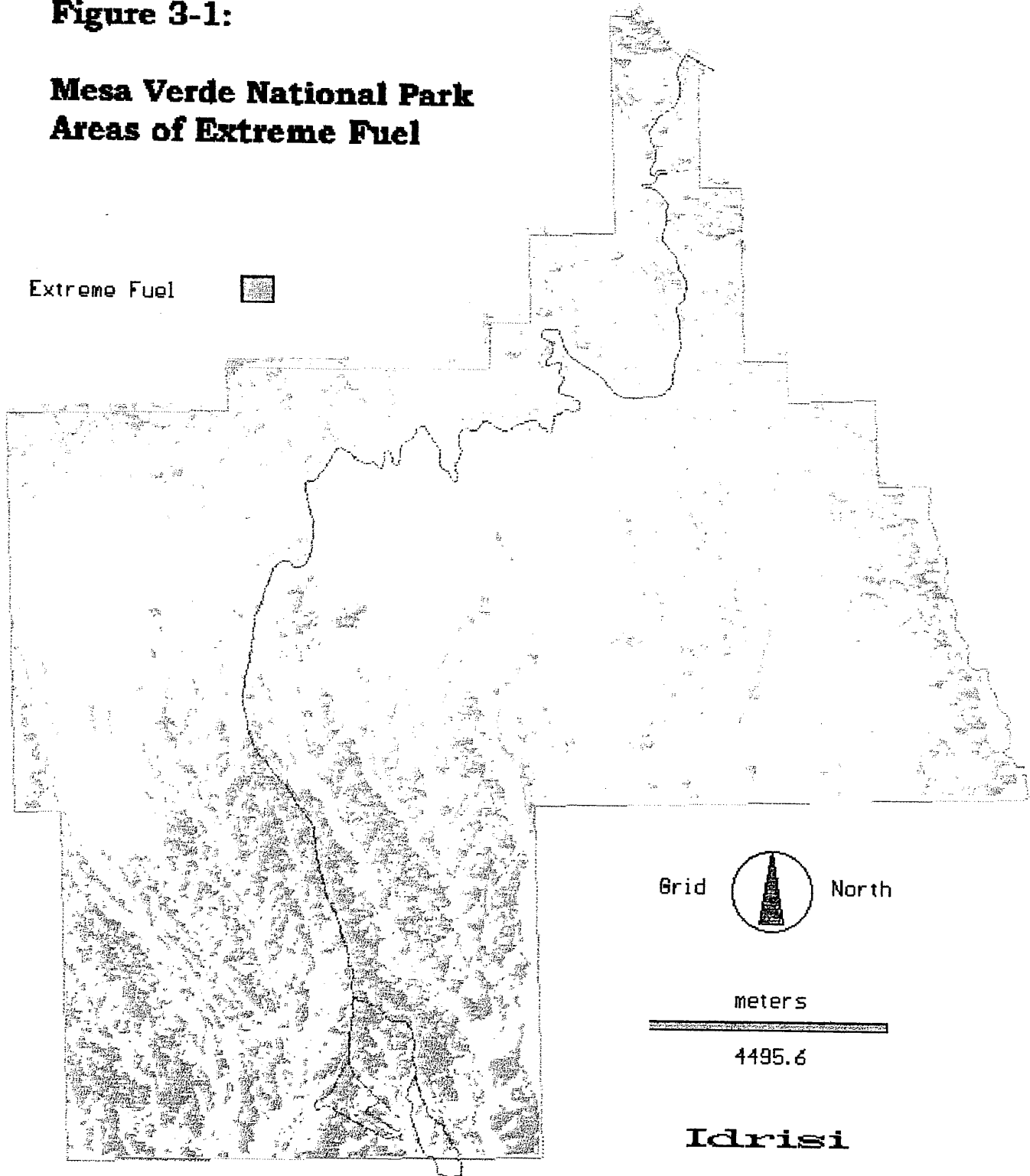
The fire prediction model BEHAVE and similar models have been used for over a decade to predict fire behavior from the types of fuels, fuel moisture conditions, and environmental parameters (Burgan and Rothermel 1984). However, rarely are the standard models useful for the shrub-rich piñon juniper woodland of southwestern Colorado. Also, it is unusual to have available an extensive data set of precise values for the standing and down fuels for a particular geographic area. We present custom fuel models, or suggest the appropriate standard BEHAVE model, for the predominant vegetation communities at Mesa Verde National Park.

The modeling results shown in Tables 3-2 and 3-3 and in Appendix 1 show that our predictions were greatly aided by incorporating the tree component of the fuels complex. For example, there was little difference in predicted reaction intensity among the three woodland types and the montane shrub type using the "normal" model (dead woody fuels and understory shrubs only). These are the fuels components that are used in all of the traditional BEHAVE models. Yet fire-fighters on the 1989 Long Mesa fire observed that fire behavior was more extreme in piñon-juniper woodlands than in montane shrublands. When we incorporated the canopy fuels (the "worst case" model), however, this difference was brought out: piñon-oak and piñon-bitterbrush displayed reaction intensities as much as 9 times greater than that predicted for montane shrub and piñon-serviceberry (Table 3-2).

The piñon-juniper woodlands of Mesa Verde surround rich cultural resources, including the impressive cliff dwellings of the Anasazi occupation and historic wood structures built by the Civilian Conservation Corps (Romme et al. 1993). Predicting fire in this region is a critical component to cultural resource management and protection. These fire behavior modeling results indicate that piñon-oak and piñon-bitterbrush communities have the potential for the most severe fire behavior in MVNP. These communities also cover a large proportion of the Park (Figure 3-1) and contain many significant cultural resources. Piñon-oak and piñon-

Figure 3-1:

**Mesa Verde National Park
Areas of Extreme Fuel**



bitterbrush woodlands should receive highest priority in fire protection activities. Montane shrub and piñon-serviceberry communities also have the potential for high intensities and flame lengths, but fire behavior in these and other plant communities in MVNP are likely to be less severe than in the piñon-oak and piñon-bitterbrush types.

The utility of custom fuels models demonstrated here suggests that there may be many other opportunities for similar kinds of research. The models that we constructed for MVNP may be applicable to other piñon-juniper woodlands elsewhere in the Colorado Plateau.

ACKNOWLEDGMENTS

We would like to thank Tim Oliverias, Fire management Officer, Mesa Verde National park, and Tom Zimmerman, Fire Ecologist, NPS/Interagency Fire, for their help in interpreting the data and building of the custom fuel models.

Chapter 3

Appendix 1

- A. Descriptive statistics for woody fuels data, grouped by vegetation type. Data were used as input for BEHAVE runs described in text.
- B. Sample output from BEHAVE runs utilizing woody fuels data for pinon-juniper and mountain shrublands at Mesa Verde National Park.

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for LITTER		
Data By Veg. Type		
Douglas Fir/Shrub		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.206	0.856
Standard Error	0.053	0.046
Median	0.182	0.850
Mode	#N/A	0.767
Standard Deviation	0.130	0.113
Variance	0.017	0.013
Range	0.325	0.267
Minimum	0.043	0.733
Maximum	0.368	1.000
Sum	1.235	5.133
Count	6.000	6.000
Confidence Level (95%)	0.104	0.090
Ponderosa Pine		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.051	0.824
Standard Error	0.027	0.101
Median	0.060	0.882
Mode	#N/A	#N/A
Standard Deviation	0.048	0.202
Variance	0.002	0.041
Range	0.094	0.467
Minimum	0.000	0.533
Maximum	0.094	1.000
Sum	0.154	3.297
Count	3.000	4.000
Confidence Level (95%)	0.054	0.198
Aspen		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.211	0.767
Standard Error	0.116	0.000
Median	0.211	0.767
Mode	#N/A	0.767
Standard Deviation	0.165	0.000
Variance	0.027	0.000
Range	0.233	0.000
Minimum	0.094	0.767
Maximum	0.327	0.767
Sum	0.421	1.533
Count	2.000	2.000
Confidence Level (95%)	0.228	#NUM!

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for LITTER		
Pinon/Amut		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.063	0.588
Standard Error	0.019	0.058
Median	0.062	0.583
Mode	#N/A	#N/A
Standard Deviation	0.054	0.164
Variance	0.003	0.027
Range	0.158	0.533
Minimum	0.000	0.333
Maximum	0.158	0.867
Sum	0.501	4.700
Count	8.000	8.000
Confidence Level (95%)	0.037	0.114
P/J-Oak		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.074	0.618
Standard Error	0.025	0.085
Median	0.054	0.600
Mode	0.002	0.833
Standard Deviation	0.075	0.256
Variance	0.006	0.066
Range	0.207	0.663
Minimum	0.002	0.233
Maximum	0.208	0.897
Sum	0.666	5.563
Count	9.000	9.000
Confidence Level (95%)	0.049	0.167
P/J-Bitterbrush		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.063	0.527
Standard Error	0.027	0.071
Median	0.033	0.533
Mode	0.002	0.833
Standard Deviation	0.088	0.237
Variance	0.008	0.056
Range	0.308	0.600
Minimum	0.000	0.233
Maximum	0.308	0.833
Sum	0.693	5.800
Count	11.000	11.000
Confidence Level (95%)	0.052	0.140

Mesa Verde National Park
 Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
 1/12/95

Summary Statistics for LITTER		
Sagebrush		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.073	0.575
Standard Error	0.044	0.117
Median	0.057	0.617
Mode	#N/A	#N/A
Standard Deviation	0.088	0.233
Variance	0.008	0.054
Range	0.179	0.533
Minimum	0.000	0.267
Maximum	0.179	0.800
Sum	0.293	2.300
Count	4.000	4.000
Confidence Level (95%)	0.086	0.228
Rabbitbrush		
	Avg. Duff Depth	FFuel Con. Index
Mean	0.037	0.622
Standard Error	0.016	0.122
Median	0.042	0.500
Mode	#N/A	0.500
Standard Deviation	0.028	0.212
Skewness	-0.702	1.732
Range	0.055	0.367
Minimum	0.008	0.500
Maximum	0.063	0.867
Sum	0.112	1.867
Count	3.000	3.000
Confidence Level (95%)	0.031	0.240

Summary Statistics for GRASS		
Data By Veg. Type (grass type = 1; density = 3)		
	% Grass Cover	Depth (ft.)
Mean	0.018	1.312
Standard Error	0.006	0.000
Median	0.025	1.312
Mode	0.025	1.312
Standard Deviation	0.014	0.000
Variance	0.000	0.000
Range	0.030	0.000
Minimum	0.000	1.312
Maximum	0.030	1.312
Sum	0.110	7.874
Count	6.000	0.500
Confidence Level (95%)	0.012	#NUM!
	% Grass Cover	Depth (ft.)
Mean	0.267	1.312
Standard Error	0.176	0.000
Median	0.200	1.312
Mode	#N/A	1.312
Standard Deviation	0.306	0.000
Variance	0.093	0.000
Range	0.600	0.000
Minimum	0.000	1.312
Maximum	0.600	1.312
Sum	0.800	3.937
Count	3.000	0.250
Confidence Level (95%)	0.277	#NUM!
	% Grass Cover	Depth (ft.)
Mean	0.010	1.312
Standard Error	#N/A	0.000
Median	0.010	1.312
Mode	#N/A	1.312
Standard Deviation	#DIV/0!	0.000
Variance	#DIV/0!	0.000
Range	0.000	0.000
Minimum	0.010	1.312
Maximum	0.010	1.312
Sum	0.010	2.625
Count	1.000	0.167
Confidence Level (95%)	#NUM!	#NUM!

Mesa Verde National Park
 Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
 1/12/95

Summary Statistics for GRASS		
	% Grass Cover	Depth (ft.)
Mean	0.020	1.312
Standard Error	#DIV/0!	#DIV/0!
Median	0.020	1.312
Mode	#N/A	#N/A
Standard Deviation	#DIV/0!	#DIV/0!
Variance	#DIV/0!	#DIV/0!
Range	0.000	0.000
Minimum	0.020	1.312
Maximum	0.020	1.312
Sum	0.020	1.312
Count	1.000	0.083
Confidence Level (95%)	#DIV/0!	#DIV/0!
	% Grass Cover	Depth (ft.)
Mean	0.058	1.312
Standard Error	0.024	0.000
Median	0.047	1.312
Mode	0.000	1.312
Standard Deviation	0.075	0.000
Variance	0.006	0.000
Range	0.260	0.000
Minimum	0.000	1.312
Maximum	0.260	1.312
Sum	0.576	13.123
Count	10.000	0.833
Confidence Level (95%)	0.046	#NUM!
	% Grass Cover	Depth (ft.)
Mean	0.073	1.312
Standard Error	0.018	0.000
Median	0.050	1.312
Mode	0.030	1.312
Standard Deviation	0.056	0.000
Variance	0.003	0.000
Range	0.150	0.000
Minimum	0.010	1.312
Maximum	0.160	1.312
Sum	0.725	13.123
Count	10.000	0.833
Confidence Level (95%)	0.035	#NUM!

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for SLASH						
Data By Veg. Type						
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.228	1.024	1.065	2.007	0.253	0.856
Standard Error	0.037	0.141	0.408	1.477	0.051	0.046
Median	0.226	1.034	0.581	0.742	0.250	0.850
Mode	#N/A	#N/A	0.581	0.000	#N/A	0.767
Standard Deviation	0.091	0.345	1.000	3.617	0.124	0.113
Variance	0.008	0.119	1.001	13.086	0.015	0.013
Range	0.248	0.973	2.323	9.325	0.352	0.267
Minimum	0.124	0.608	0.290	0.000	0.105	0.733
Maximum	0.372	1.581	2.614	9.325	0.457	1.000
Sum	1.370	6.143	6.389	12.039	1.519	5.133
Count	6.000	6.000	6.000	6.000	6.000	6.000
Confidence Level (95%)	0.073	0.276	0.801	2.895	0.099	0.090
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.051	1.414	1.162	4.275	0.690	0.824
Standard Error	0.018	0.878	0.777	2.227	0.549	0.101
Median	0.037	0.699	0.436	2.953	0.177	0.882
Mode	#N/A	#N/A	0.290	#N/A	#N/A	#N/A
Standard Deviation	0.036	1.755	1.555	4.455	1.098	0.202
Variance	0.001	3.081	2.418	19.845	1.206	0.041
Range	0.079	3.771	3.195	10.235	2.259	0.467
Minimum	0.025	0.243	0.290	0.479	0.074	0.533
Maximum	0.105	4.014	3.485	10.714	2.333	1.000
Sum	0.203	5.656	4.647	17.099	2.761	3.297
Count	4.000	4.000	4.000	4.000	4.000	4.000
Confidence Level (95%)	0.036	1.720	1.524	4.366	1.076	0.198
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.115	1.444	3.340	13.845	0.260	0.767
Standard Error	0.004	0.228	2.469	5.424	0.185	0.000
Median	0.115	1.444	3.340	13.845	0.260	0.767
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	0.767
Standard Deviation	0.006	0.323	3.491	7.670	0.261	0.000
Variance	0.000	0.104	12.188	58.836	0.068	0.000
Range	0.008	0.456	4.937	10.848	0.369	0.000
Minimum	0.111	1.216	0.871	8.421	0.075	0.767
Maximum	0.119	1.673	5.808	19.268	0.444	0.767
Sum	0.230	2.889	6.680	27.689	0.520	1.533
Count	2.000	2.000	2.000	2.000	2.000	2.000
Confidence Level (95%)	0.008	0.447	4.838	10.630	0.362	#NUM!

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for SLASH						
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.131	0.753	0.980	5.071	0.158	0.588
Standard Error	0.034	0.136	0.239	4.149	0.078	0.058
Median	0.110	0.851	0.871	0.090	0.087	0.583
Mode	#N/A	#N/A	0.871	0.000	#N/A	#N/A
Standard Deviation	0.096	0.385	0.676	11.735	0.221	0.164
Variance	0.009	0.148	0.456	137.713	0.049	0.027
Range	0.267	1.095	2.033	33.823	0.663	0.533
Minimum	0.029	0.061	0.000	0.000	0.035	0.333
Maximum	0.296	1.156	2.033	33.823	0.697	0.867
Sum	1.052	6.021	7.841	40.570	1.267	4.700
Count	8.000	8.000	8.000	8.000	8.000	8.000
Confidence Level (95%)	0.067	0.266	0.468	8.132	0.153	0.114
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.082	0.500	0.452	5.685	0.088	0.618
Standard Error	0.026	0.148	0.200	3.758	0.023	0.085
Median	0.044	0.365	0.290	0.958	0.063	0.600
Mode	#N/A	0.365	0.000	0.000	0.057	0.833
Standard Deviation	0.078	0.445	0.601	11.274	0.070	0.256
Variance	0.006	0.198	0.361	127.113	0.005	0.066
Range	0.210	1.277	1.452	34.950	0.252	0.663
Minimum	0.025	0.000	0.000	0.000	0.000	0.233
Maximum	0.235	1.277	1.452	34.950	0.252	0.897
Sum	0.740	4.501	4.066	51.163	0.791	5.563
Count	9.000	9.000	9.000	9.000	9.000	9.000
Confidence Level (95%)	0.051	0.290	0.392	7.366	0.046	0.167
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.158	0.982	1.320	8.788	0.111	0.527
Standard Error	0.049	0.430	0.553	3.483	0.023	0.071
Median	0.097	0.365	0.290	4.069	0.106	0.533
Mode	0.178	0.365	0.290	#N/A	#N/A	0.833
Standard Deviation	0.162	1.426	1.834	11.553	0.076	0.237
Variance	0.026	2.032	3.363	133.470	0.006	0.056
Range	0.569	4.951	5.518	34.950	0.221	0.600
Minimum	0.041	0.158	0.000	0.000	0.018	0.233
Maximum	0.610	5.109	5.518	34.950	0.239	0.833
Sum	1.740	10.802	14.521	96.671	1.224	5.800
Count	11.000	11.000	11.000	11.000	11.000	11.000
Confidence Level (95%)	0.096	0.842	1.084	6.827	0.045	0.140

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for SLASH						
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.081	0.775	1.234	4.391	0.073	0.575
Standard Error	0.040	0.256	0.450	4.186	0.010	0.117
Median	0.060	0.760	1.452	0.309	0.073	0.617
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.080	0.512	0.899	8.371	0.021	0.233
Variance	0.006	0.262	0.808	70.077	0.000	0.054
Range	0.184	0.973	2.033	16.946	0.040	0.533
Minimum	0.010	0.304	0.000	0.000	0.053	0.267
Maximum	0.194	1.277	2.033	16.946	0.093	0.800
Sum	0.324	3.102	4.937	17.564	0.292	2.300
Count	4.000	4.000	4.000	4.000	4.000	4.000
Confidence Level (95%)	0.078	0.502	0.881	8.204	0.021	0.228
	1hr-TL	10hr-TL	100hr-TL	1000hr-TL	Avg. Fuel Depth (ft.)	FFuel Con. Index
Mean	0.059	0.284	1.549	9.242	0.091	0.622
Standard Error	0.055	0.177	0.844	5.808	0.077	0.122
Median	0.010	0.243	1.743	7.769	0.030	0.500
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	0.500
Standard Deviation	0.095	0.306	1.462	10.060	0.133	0.212
Variance	0.009	0.094	2.137	101.209	0.018	1.732
Range	0.168	0.608	2.904	19.958	0.244	0.367
Minimum	0.000	0.000	0.000	0.000	0.000	0.500
Maximum	0.168	0.608	2.904	19.958	0.244	0.867
Sum	0.178	0.851	4.647	27.727	0.274	1.867
Count	3.000	3.000	3.000	3.000	3.000	3.000
Confidence Level (95%)	0.107	0.346	1.654	11.384	0.151	0.240

Summary Statistics for SHRUBS_1						
Data By Veg. Type (includes trees)						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	28.999	64.782	93.422	17.134	15.474	0.824
Standard Error	3.683	8.815	16.030	2.059	3.863	0.141
Median	32.038	68.578	101.319	18.983	13.606	0.793
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	9.021	21.593	39.266	5.045	9.463	0.345
Variance	81.385	466.248	1541.786	25.448	1074.619	0.119
Range	23.184	59.688	114.389	13.075	26.706	0.932
Minimum	14.390	29.320	27.036	8.653	1.312	0.471
Maximum	37.574	89.008	141.425	21.728	28.018	1.403
Sum	173.992	388.690	560.531	102.802	92.844	4.944
Count	6.000	6.000	6.000	6.000	0.500	6.000
Confidence Level (95%)	7.218	17.277	31.418	4.036	7.572	0.276
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	16.929	44.980	509.911	10.124	20.531	0.804
Standard Error	6.315	20.679	100.811	3.645	4.805	0.272
Median	15.155	32.748	509.911	9.711	19.392	0.566
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	10.938	35.818	174.609	6.313	8.322	0.471
Variance	119.634	1282.908	30488.333	39.849	831.114	0.221
Range	21.659	68.431	349.218	12.605	16.527	0.846
Minimum	6.987	16.880	335.302	4.027	12.836	0.499
Maximum	28.645	85.311	684.520	16.632	29.364	1.346
Sum	50.786	134.939	1529.733	30.371	61.592	2.411
Count	3.000	3.000	3.000	3.000	0.250	3.000
Confidence Level (95%)	12.377	40.531	197.585	7.143	9.417	0.532
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	19.123	37.384	20.945	12.983	8.096	0.837
Standard Error	6.772	13.257	9.640	5.869	6.504	0.229
Median	19.123	37.384	20.945	12.983	8.096	0.837
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	9.577	18.749	13.633	8.300	9.198	0.324
Variance	91.716	351.515	185.864	68.887	1015.148	0.105
Range	13.544	26.515	19.280	11.738	13.007	0.459
Minimum	12.351	24.127	11.305	7.114	1.592	0.608
Maximum	25.895	50.642	30.586	18.852	14.600	1.067
Sum	38.245	74.769	41.891	25.966	16.192	1.675
Count	2.000	2.000	2.000	2.000	0.167	2.000
Confidence Level (95%)	13.273	25.984	18.894	11.503	12.747	0.449

Summary Statistics for SHRUBS 1						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	0.063	0.086	0.008	0.069	1.476	0.030
Standard Error	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Median	0.063	0.086	0.008	0.069	1.476	0.030
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Skewness	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Range	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.063	0.086	0.008	0.069	1.476	0.030
Maximum	0.063	0.086	0.008	0.069	1.476	0.030
Sum	0.063	0.086	0.008	0.069	1.476	0.030
Count	1.000	1.000	1.000	1.000	0.083	1.000
Confidence Level (95%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	1.072	1.567	1.092	0.716	3.727	0.533
Standard Error	0.629	0.852	1.051	0.359	0.939	0.242
Median	0.206	0.299	0.027	0.231	1.886	0.213
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	1.990	2.694	3.324	1.136	2.970	0.767
Variance	3.961	7.259	11.046	1.290	105.824	0.588
Range	6.346	8.579	10.550	3.641	7.505	2.489
Minimum	0.004	0.004	0.000	0.004	1.550	0.165
Maximum	6.351	8.583	10.550	3.645	9.055	2.654
Sum	10.716	15.671	10.920	7.165	37.271	5.326
Count	10.000	10.000	10.000	10.000	0.833	10.000
Confidence Level (95%)	1.233	1.670	2.060	0.704	1.841	0.475
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	12.587	25.797	23.029	8.534	9.709	1.061
Standard Error	4.257	9.215	9.886	2.947	2.489	0.292
Median	7.981	14.744	2.425	4.768	6.843	0.836
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	13.463	29.139	31.261	9.319	7.871	0.922
Variance	181.246	849.103	977.234	86.838	743.351	0.851
Range	35.307	76.439	83.288	24.001	24.975	2.578
Minimum	0.075	0.083	0.006	0.073	1.271	0.068
Maximum	35.382	76.521	83.294	24.074	26.247	2.646
Sum	125.873	257.972	230.286	85.338	97.091	10.615
Count	10.000	10.000	10.000	10.000	0.833	10.000
Confidence Level (95%)	8.344	18.060	19.375	5.776	4.878	0.572

Summary Statistics for SHRUBS 1						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	12.699	27.156	22.962	8.762	8.385	0.718
Standard Error	3.778	8.438	8.232	2.576	2.198	0.179
Median	7.018	13.346	7.255	5.384	6.053	0.557
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	13.089	29.231	28.516	8.923	7.614	0.622
Variance	171.310	854.467	813.149	79.617	695.745	0.386
Range	35.343	76.461	83.288	24.027	25.180	2.004
Minimum	0.039	0.060	0.006	0.047	1.066	0.068
Maximum	35.382	76.521	83.294	24.074	26.247	2.072
Sum	152.384	325.872	275.549	105.150	100.614	8.614
Count	12.000	12.000	12.000	12.000	1.000	12.000
Confidence Level (95%)	7.405	16.539	16.134	5.048	4.308	0.352
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	0.989	1.953	0.578	0.604	11.968	0.220
Standard Error	0.889	1.821	0.566	0.498	7.427	0.136
Median	0.160	0.231	0.023	0.183	8.372	0.101
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	1.540	3.155	0.980	0.863	12.864	0.235
Variance	2.372	9.953	0.960	0.744	1985.655	0.055
Range	2.726	5.561	1.708	1.563	24.962	0.423
Minimum	0.040	0.033	0.001	0.033	1.285	0.068
Maximum	2.766	5.594	1.709	1.596	26.247	0.491
Sum	2.966	5.858	1.733	1.811	35.903	0.660
Count	3.000	3.000	3.000	3.000	0.250	3.000
Confidence Level (95%)	1.743	3.570	1.109	0.976	14.556	0.266
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	Mean Ht. (ft.)	% Cover
Mean	0.073	0.100	0.009	0.080	2.474	0.070
Standard Error	0.045	0.062	0.006	0.050	1.572	0.003
Median	0.073	0.100	0.009	0.080	2.474	0.070
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.064	0.088	0.008	0.070	2.223	0.005
Variance	0.004	0.008	0.000	0.005	59.314	0.000
Range	0.091	0.124	0.011	0.100	3.144	0.007
Minimum	0.028	0.038	0.003	0.031	0.902	0.066
Maximum	0.118	0.163	0.015	0.130	4.046	0.073
Sum	0.146	0.201	0.018	0.161	4.949	0.139
Count	2.000	2.000	2.000	2.000	0.167	2.000
Confidence Level (95%)	0.089	0.122	0.011	0.098	3.081	0.006

Mesa Verde National Park
Fuel Inventory Data by vegetation type

[FUELINV.XLW]FuelStats_1_95
1/12/95

Summary Statistics for SHRUBS 2						
Data By Veg. Type (shrubs only)						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.033	0.051	0.021	0.046	0.212	9.580
Standard Error	0.023	0.032	0.017	0.027	#DIV/0!	3.287
Median	0.018	0.036	0.006	0.040	0.212	7.427
Mode	0.000	0.000	0.000	0.000	#N/A	#N/A
Standard Deviation	0.045	0.064	0.035	0.055	#DIV/0!	6.573
Variance	0.002	0.004	0.001	0.003	#DIV/0!	518.511
Range	0.096	0.132	0.072	0.106	0.000	14.498
Minimum	0.000	0.000	0.000	0.000	0.212	4.484
Maximum	0.096	0.132	0.072	0.106	0.212	18.982
Sum	0.132	0.205	0.084	0.185	0.212	38.319
Count	4.000	4.000	4.000	4.000	1.000	4.000
Confidence Level (95%)	0.044	0.063	0.034	0.053	#DIV/0!	6.442
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.004	0.007	0.001	0.005	0.047	6.491
Standard Error	0.002	0.003	0.000	0.003	0.009	3.818
Median	0.005	0.010	0.001	0.007	0.052	4.662
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.004	0.006	0.001	0.004	0.015	6.613
Variance	0.000	0.000	0.000	0.000	0.000	524.860
Range	0.007	0.010	0.002	0.008	0.029	12.842
Minimum	0.000	0.000	0.000	0.000	0.030	0.984
Maximum	0.007	0.010	0.002	0.008	0.058	13.826
Sum	0.012	0.020	0.003	0.015	0.140	19.473
Count	3.000	3.000	3.000	3.000	3.000	3.000
Confidence Level (95%)	0.004	0.006	0.001	0.005	0.017	7.484
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.004	0.003	0.000	0.003	0.070	8.150
Standard Error	0.004	0.003	0.000	0.003	0.052	3.229
Median	0.004	0.003	0.000	0.003	0.070	8.150
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.005	0.004	0.000	0.004	0.074	4.566
Variance	0.000	0.000	0.000	0.000	0.005	250.180
Range	0.007	0.006	0.000	0.006	0.104	6.457
Minimum	0.000	0.000	0.000	0.000	0.017	4.921
Maximum	0.007	0.006	0.000	0.006	0.122	11.379
Sum	0.007	0.006	0.000	0.006	0.139	16.300
Count	2.000	2.000	2.000	2.000	2.000	2.000
Confidence Level (95%)	0.007	0.006	0.000	0.006	0.102	6.328

Summary Statistics for SHRUBS 2						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.063	0.086	0.008	0.069	0.030	3.937
Standard Error	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Median	0.063	0.086	0.008	0.069	0.030	3.937
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Variance	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Range	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.063	0.086	0.008	0.069	0.030	3.937
Maximum	0.063	0.086	0.008	0.069	0.030	3.937
Sum	0.063	0.086	0.008	0.069	0.030	3.937
Count	1.000	1.000	1.000	1.000	1.000	1.000
Confidence Level (95%)	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.184	0.295	0.042	0.224	0.502	6.918
Standard Error	0.067	0.131	0.022	0.096	0.211	2.481
Median	0.135	0.188	0.021	0.147	0.304	3.609
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.200	0.392	0.065	0.288	0.634	7.442
Variance	0.040	0.154	0.004	0.083	0.402	664.541
Range	0.651	1.269	0.205	0.935	1.989	20.100
Minimum	0.008	0.007	0.000	0.007	0.165	1.226
Maximum	0.659	1.276	0.206	0.942	2.154	21.325
Sum	1.653	2.652	0.377	2.016	4.517	62.265
Count	9.000	9.000	9.000	9.000	9.000	9.000
Confidence Level (95%)	0.131	0.256	0.042	0.188	0.414	4.862
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.207	0.325	0.069	0.247	0.458	8.163
Standard Error	0.079	0.133	0.026	0.098	0.156	2.360
Median	0.125	0.190	0.040	0.144	0.306	6.208
Mode	0.000	0.000	0.000	0.000	#N/A	#N/A
Standard Deviation	0.272	0.459	0.091	0.341	0.518	8.174
Variance	0.074	0.211	0.008	0.116	0.269	801.869
Range	0.824	1.603	0.277	1.190	1.805	31.250
Minimum	0.000	0.000	0.000	0.000	0.058	1.640
Maximum	0.824	1.603	0.277	1.190	1.863	32.890
Sum	2.480	3.895	0.822	2.969	5.037	97.953
Count	12.000	12.000	12.000	12.000	11.000	12.000
Confidence Level (95%)	0.154	0.260	0.051	0.193	0.306	4.625

Summary Statistics for SHRUBS 2						
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.085	0.122	0.020	0.096	0.182	8.357
Standard Error	0.024	0.042	0.008	0.031	0.047	2.906
Median	0.070	0.082	0.008	0.071	0.121	4.632
Mode	0.000	0.000	0.000	0.000	#N/A	#N/A
Standard Deviation	0.077	0.132	0.026	0.097	0.134	9.188
Variance	0.006	0.017	0.001	0.009	0.018	1013.068
Range	0.216	0.370	0.064	0.272	0.383	31.512
Minimum	0.000	0.000	0.000	0.000	0.074	1.378
Maximum	0.216	0.370	0.064	0.272	0.458	32.890
Sum	0.848	1.222	0.203	0.962	1.458	83.567
Count	10.000	10.000	10.000	10.000	8.000	10.000
Confidence Level (95%)	0.048	0.082	0.016	0.060	0.093	5.695
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.100	0.132	0.012	0.108	0.296	5.872
Standard Error	0.060	0.099	0.011	0.075	0.195	2.342
Median	0.100	0.132	0.012	0.108	0.296	5.872
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.085	0.140	0.016	0.106	0.276	3.311
Variance	0.007	0.020	0.000	0.011	0.076	131.585
Range	0.121	0.198	0.023	0.150	0.390	4.683
Minimum	0.040	0.033	0.001	0.033	0.101	3.530
Maximum	0.160	0.231	0.023	0.183	0.491	8.213
Sum	0.200	0.264	0.024	0.215	0.592	11.743
Count	2.000	2.000	2.000	2.000	2.000	2.000
Confidence Level (95%)	0.118	0.194	0.022	0.147	0.383	4.589
	1 hr-TL	10 hr-TL	100 hr-TL	Live Foliage	% Cover	Mean Ht. (ft.)
Mean	0.073	0.100	0.009	0.080	0.070	50.607
Standard Error	0.045	0.062	0.006	0.050	0.003	48.638
Median	0.073	0.100	0.009	0.080	0.070	50.607
Mode	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Standard Deviation	0.064	0.088	0.008	0.070	0.005	68.785
Variance	0.004	0.008	0.000	0.005	0.000	56776.775
Range	0.091	0.124	0.011	0.100	0.007	97.277
Minimum	0.028	0.038	0.003	0.031	0.066	1.969
Maximum	0.118	0.163	0.015	0.130	0.073	99.245
Sum	0.146	0.201	0.018	0.161	0.139	101.214
Count	2.000	2.000	2.000	2.000	2.000	2.000
Confidence Level (95%)	0.089	0.122	0.011	0.098	0.006	95.329

1-hr Moisture Content (%)	Rate of Spread (CH/H)	Heat per unit area (BTU/SQFT)	Fireline Intensity (BTU/FT/S)	Flame Length (FT)	Reaction Intensity (BTU/SQFT/M)	Effective Windspeed (MI/H)
Average Model not including the tree species data						
Midflame Windspeed = 5 mph						
2	73	521	700	9.2	2782	5
3	67	487	597	8.5	2598	5
4	62	459	519	8	2447	5
5	57	436	459	7.5	2326	5
6	54	418	414	7.2	2231	5
7	51	404	379	6.9	2158	5
8	49	394	353	6.7	2103	5
Midflame Windspeed = 20 mph						
2	602	521	5752	24.1	2782	20
3	550	487	4906	22.4	2598	20
4	507	459	4260	21	2447	20
5	472	436	3769	19.9	2326	20
6	443	418	3397	18.9	2231	20
7	420	404	3115	18.2	2158	20
8	402	394	2901	17.6	2103	20
Midflame Windspeed = 40 mph						
2	1037	521	9912	31	2782	28.5*
3	852	487	7603	27.4	2598	26.6*
4	716	459	6019	24.6	2447	25.0*
5	616	436	4924	22.5	2326	23.8*
6	543	418	4160	20.8	2231	22.8*
7	489	404	3624	19.5	2158	22.1*
8	449	394	3245	18.6	2103	21.5*
High Model not including the tree species data						
Midflame Windspeed = 5 mph						
2	105	2424	4655	21.9	12877	5
3	96	2266	3986	20.4	12036	5
4	89	2137	3474	19.1	11348	5
5	83	2032	3083	18.1	10795	5
6	78	1950	2785	17.3	10360	5
7	74	1887	2560	16.6	10024	5
8	71	1840	2388	16.1	9772	5
Midflame Windspeed = 20 mph						
2	843	2424	37472	57.2	12877	20
3	772	2266	32085	53.2	12036	20
4	714	2137	27961	50	11348	20
5	666	2032	24815	47.3	10795	20
6	627	1950	22421	45.1	10360	20
7	595	1887	20604	43.4	10024	20
8	570	1840	19223	42.1	9772	20
Midflame Windspeed = 40 mph						
2	2451	2424	108939	93.4	12877	40
3	2245	2266	93276	87	12036	40
4	2075	2137	81288	81.6	11348	40
5	1936	2032	72140	77.3	10795	40
6	1823	1950	65182	73.7	10360	40
7	1731	1887	59899	70.9	10024	40
8	1657	1840	55884	68.7	9772	40
Worst Case Scenario including data on Trees as well as shrub species						
Midflame Windspeed = 5 mph						
2	126	10454	24234	46.8	46556	5
3	120	10063	22146	44.9	44815	5
4	114	9714	20357	43.2	43261	5
5	109	9405	18824	41.6	41882	5
6	105	9132	17512	40.3	40666	5
7	101	8892	16389	39.1	39600	5
8	97	8684	15429	38	38672	5
Midflame Windspeed = 40 mph						
2	825	10454	158210	110.9	46556	20
3	784	10063	144578	106.4	44815	20
4	746	9714	132895	102.3	43261	20
5	713	9405	122888	98.7	41882	20
6	683	9132	114322	95.5	40666	20
7	656	8892	106993	92.6	39600	20
8	633	8684	100725	90.1	38672	20
Midflame Windspeed = 40 mph						
2	2171	10454	416177	173	46556	40
3	2061	10063	380318	166	44815	40
4	1963	9714	349585	159.7	43261	40
5	1875	9405	323262	154	41882	40
6	1796	9132	300729	149	40666	40
7	1726	8892	281450	144.5	39600	40
8	1664	8684	264961	140.6	38672	40

* MEANS YOU HIT THE WIND LIMIT.

1-hr Moisture Content	Rate of Spread	Heat per unit area	Fireline Intensity	Flame Length	Reaction Intensity	Effective Windspeed
(%)	(CH/H)	(BTU/SQFT)	(BTU/FT/S)	(FT)	(BTU/SQFT/M)	(MI/H)
Normal Model not including the tree species data						
Midflame Windspeed = 5 mph						
2	18	457	149	4.5	2372	5
3	16	429	127	4.2	2224	5
4	15	405	110	3.9	2099	5
5	14	385	97	3.7	1995	5
6	13	368	87	3.5	1910	5
7	12	355	79	3.4	1842	5
8	11	345	73	3.2	1788	5
Midflame Windspeed = 20 mph						
2	138	457	1157	11.5	2372	20
3	126	429	990	10.7	2224	20
4	116	405	860	10.1	2099	20
5	107	385	757	9.5	1995	20
6	97	368	653	8.9	1910	19.5
7	86	355	561	8.3	1842	18.8
8	78	345	494	7.8	1788	18.3
Midflame Windspeed = 40 mph						
2	185	457	1550	13.2	2372	24.3
3	153	429	1203	11.8	2224	22.7
4	129	405	956	10.6	2099	21.5
5	111	385	780	9.8	1995	20.4
6	97	368	653	8.9	1910	19.5
7	86	355	561	8.3	1842	18.8
8	78	345	494	7.8	1788	18.3
High Model not including the tree species data						
Midflame Windspeed = 5 mph						
2	13	1000	246	5.7	5375	5
3	12	948	214	5.3	5094	5
4	11	901	187	5	4844	5
5	10	860	165	4.7	4622	5
6	10	824	147	4.5	4427	5
7	9	792	132	4.3	4257	5
8	9	765	120	4.1	4109	5
Midflame Windspeed = 20 mph						
2	104	1000	1905	14.5	5375	20
3	95	948	1656	13.6	5094	20
4	88	901	1450	12.8	4844	20
5	81	860	1280	12.1	4622	20
6	75	824	1140	11.5	4427	20
7	70	792	1023	10.9	4257	20
8	66	765	927	10.4	4109	20
Midflame Windspeed = 40 mph						
2	303	1000	5550	23.7	5375	40
3	278	948	4823	22.3	5094	40
4	256	901	4224	20.9	4844	40
5	236	860	3728	19.8	4622	40
6	220	824	3319	18.7	4427	40
7	205	792	2981	17.8	4257	40
8	193	765	2701	17	4109	40
Worst Case Scenario including data on Trees as well as shrub species						
Midflame Windspeed = 5 mph						
2	73	9863	13136	35.3	43662	5
3	69	9481	12015	33.9	41972	5
4	66	9140	11053	32.6	40462	5
5	63	8837	10228	31.5	39120	5
6	61	8569	9522	30.4	37934	5
7	58	8334	8918	29.5	36893	5
8	56	8129	8401	28.7	35984	5
Midflame Windspeed = 20 mph						
2	469	9863	84767	83.2	43662	20
3	446	9481	77533	79.9	41972	20
4	426	9140	71325	76.9	40462	20
5	407	8837	66003	74.2	39120	20
6	391	8569	61445	71.8	37934	20
7	377	8334	57546	69.6	36893	20
8	364	8129	54213	67.7	35984	20
Midflame Windspeed = 40 mph						
2	1229	9863	222144	129.6	43662	40
3	1169	9481	203185	124.4	41972	40
4	1115	9140	186916	119.7	40462	40
5	1068	8837	172968	115.5	39120	40
6	1025	8569	161024	111.8	37934	40
7	987	8334	150805	108.5	36893	40
8	953	8129	142072	105.5	35984	40

* MEANS YOU HIT THE WIND LIMIT.

1-hr Moisture Content	Rate of Spread	Heat per Unit Area	Fireline Intensity	Flame Length	Reaction Intensity	Effective Windspeed
(%)	(CH/H)	(BTU/SQFT)	(BTU/FT/S)	(FT)	(BTU/SQFT/M)	(MI/H)
Normal Model not including the tree species data using mean values						
Midflame Windspeed = 5 mph						
2	42	505	389	7	2579	5
3	38	472	331	6.5	2410	5
4	35	445	287	6.1	2272	5
5	33	424	254	5.7	2163	5
6	31	407	229	5.5	2079	5
7	29	395	211	5.3	2016	5
8	28	386	196	5.1	1969	5
Midflame Windspeed = 20 mph						
2	326	505	3019	17.9	2579	20
3	297	472	2569	16.7	2410	20
4	273	445	2228	15.6	2272	20
5	254	424	1971	14.7	2163	20
6	238	407	1778	14.1	2079	20
7	226	395	1632	13.5	2016	20
8	215	386	1523	13.1	1969	20
Midflame Windspeed = 40 mph						
2	494	505	4578	21.7	2579	26.4*
3	406	472	3516	19.2	2410	24.6*
4	342	445	2792	17.3	2272	23.2*
5	295	424	2293	15.8	2163	22.1*
6	261	407	1948	14.7	2079	21.3*
7	236	395	1708	13.8	2016	20.6*
8	218	386	1538	13.2	1969	20.1*
High Model not including the tree species data using maximum values						
Midflame Windspeed = 5 mph						
2	107	1849	3625	19.5	9634	5
3	97	1725	3080	18.1	8988	5
4	90	1626	2673	17	8472	5
5	83	1549	2370	16.1	8069	5
6	79	1490	2145	15.3	7764	5
7	75	1447	1978	14.8	7538	5
8	71	1416	1854	14.3	7376	5
Midflame Windspeed = 20 mph						
2	844	1849	28610	50.5	9634	20
3	769	1725	24310	46.8	8988	20
4	708	1626	21097	43.9	8472	20
5	659	1549	18706	41.5	8069	20
6	620	1490	16931	39.7	7764	20
7	589	1447	15616	38.2	7538	20
8	564	1416	14635	37.1	7376	20
Midflame Windspeed = 40 mph						
2	2427	1849	82268	82.1	9634	40
3	2210	1725	69902	76.2	8988	40
4	2035	1626	60664	71.3	8472	40
5	1894	1549	53788	67.5	8069	40
6	1782	1490	46866	64.5	7764	40
7	1693	1447	44904	62.1	7538	40
8	1621	1416	42083	60.3	7376	40
Worst Case Scenario including data on Trees as well as shrub species						
Midflame Windspeed = 5 mph						
2	41	1143	862	10.1	5535	5
3	39	1086	767	9.6	5263	5
4	36	1037	689	9.1	5026	5
5	34	995	625	8.7	4821	5
6	33	959	572	8.3	4647	5
7	31	929	528	8	4499	5
8	30	903	492	7.8	4375	5
Midflame Windspeed = 20 mph						
2	300	1143	6278	25.1	5535	20
3	281	1086	5587	23.8	5263	20
4	264	1037	5017	22.7	5026	20
5	249	995	4548	21.7	4821	20
6	237	959	4161	20.8	4647	20
7	226	929	3844	20.1	4499	20
8	216	903	3583	19.4	4375	20
Midflame Windspeed = 40 mph						
2	827	1143	17325	40.1	5535	40
3	774	1086	15418	38	5263	40
4	728	1037	13845	36.2	5026	4

1-hr Moisture Content	Rate of Spread	Heat per unit area	Fireline Intensity	Flame Length	Reaction Intensity	Effective windspeed
(%)	(CH/H)	(BTU/SQFT)	(BTU/FT/S)	(FT)	(BTU/SQFT/M)	(MI/H)
Normal Model not including the tree species						
Midflame Windspeed = 5 mph						
2	10	397	72	3.2	2100	5
3	9	369	60	3	1950	5
4	8	346	51	2.8	1828	5
5	7	327	45	2.6	1729	5
6	7	313	40	2.4	1653	5
7	7	302	36	2.3	1594	5
8	6	294	33	2.3	1551	5
Midflame Windspeed = 20 mph						
2	78	397	566	8.3	2100	20
3	70	369	471	7.6	1950	19.9*
4	57	346	364	6.8	1828	18.7*
5	49	327	291	6.1	1729	17.7*
6	42	313	242	5.6	1653	16.9*
7	37	302	207	5.2	1594	16.3*
8	34	294	183	4.9	1551	15.9*
Midflame Windspeed = 40 mph						
2	87	397	631	8.7	2100	21.5*
3	70	369	471	7.6	1950	19.9*
4	57	346	364	6.8	1828	18.7*
5	49	327	291	6.1	1729	17.7*
6	42	313	242	5.6	1653	16.9*
7	37	302	207	5.2	1594	16.3*
8	34	294	183	4.9	1551	15.9*
High Model not including tree species						
Midflame Windspeed = 5 mph						
2	17	884	276	6	4886	5
3	15	813	225	5.4	4494	5
4	14	756	188	5	4179	5
5	12	712	161	4.7	3932	5
6	11	678	141	4.4	3744	5
7	11	653	127	4.2	3605	5
8	10	635	116	4	3507	5
Midflame Windspeed = 20 mph						
2	139	884	2249	15.7	4886	20
3	123	813	1835	14.3	4494	20
4	110	756	1532	13.1	4179	20
5	100	712	1311	12.2	3932	20
6	93	678	1150	11.5	3744	20
7	86	653	1033	11	3605	20
8	81	635	948	10.5	3507	20
Midflame Windspeed = 40 mph						
2	412	884	6672	25.8	4886	40
3	365	813	5443	23.5	4494	40
4	328	756	4545	21.7	4179	40
5	298	712	3889	20.2	3932	40
6	256	678	3185	18.4	3744	38.3*
7	225	653	2696	17	3605	36.9*
8	204	635	2368	16	3507	35.9*
Worst Case Scenario including data on tree species						
Midflame Windspeed = 5 mph						
2	39	1088	781	9.6	5269	5
3	36	1020	677	9	4943	5
4	34	966	597	8.5	4679	5
5	32	923	537	8.1	4469	5
6	30	889	491	7.8	4307	5
7	29	864	457	7.5	4184	5
8	28	845	430	7.3	4092	5
Midflame Windspeed = 20 mph						
2	285	1088	5689	24	5269	20
3	263	1020	4928	22.5	4943	20
4	246	966	4348	21.2	4679	20
5	231	923	3908	20.2	4469	20
6	219	889	3575	19.4	4307	20
7	210	864	3324	18.8	4184	20
8	202	845	3134	18.3	4092	20
Midflame Windspeed = 40 mph						
2	787	1088	15700	38.3	5269	40
3	727	1020	13599	35.9	4943	40
4	678	966	11998	33.9	4679	40
5	638	923	10784	32.2	4469	40
6	605	889	9866	30.9	4307	40
7	579	864	9174	29.9	4184	40
8	558	845	8648	29.1	4092	40

* MEANS YOU HIT THE WIND LIMIT.

CHAPTER 4

STAND STRUCTURE OF MESA VERDE'S PINON JUNIPER WOODLANDS

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INTRODUCTION

An extensive fire history has recently been completed for the oak/piñon-juniper woodlands of Mesa Verde National Park, MVNP (Chapter 1). However, where Oak (*Quercus gambelii*) is absent, we cannot determine fire frequencies in the piñon-juniper zones. For example, the southern end of Chapin and Wetherill Mesas do not support extensive oak stands, therefore other methods must be developed to date the possible fire history. In an initial effort to determine past fire history in piñon-juniper woodlands, we developed stand structures for three woodlands in Mesa Verde National Park.

Interpretation of stand ages of piñon and junipers is hampered by our lack of precise knowledge of the time between disturbance and invasion of the woodland successional series. However, a complete stand structural analysis, documenting the size and age class distributions of the piñon and juniper trees, will be useful in determining patterns of woodland invasion. We also seek knowledge of the extent of timing of tree invasion--was this spread over a long period, or did the trees invade in a narrow time period? If the latter is documented, we will have evidence that catastrophic events, such as fire, created conditions for woodland invasion and possibly determine the approximate year of the last stand-replacing disturbance.

To our knowledge, prehistoric fire history has never been successfully determined in piñon-juniper woodlands like those of MVNP. This is primarily because none of the common species in this vegetation type form good fire scars. There is a need for better information on past fire occurrence and intensity in the southern woodlands of MVNP, for two major reasons. First, past fire dates are needed to estimate fire probabilities in our fire risk model (Chapter 5). This information is essential for the development of the model since many of the most important archaeological sites are located in the piñon-juniper woodlands of MVNP, and the potential is high for very intense burning. Secondly, the dense piñon-juniper woodlands, which so strongly influence the visitor's experience of the southern ends of the mesas, are a poorly understood and possibly non-renewable resource -- at least within the time scale of the area's history as a national park.

We make this last admittedly alarmist suggestion because the piñon-juniper woodlands in MVNP that have burned during the twentieth century (in 1934, 1959, 1972, and 1989) are not presently becoming reforested with piñon and juniper. On the contrary, a preliminary but systematic search for young piñons in these areas in 1993 (unpublished data) revealed that tree regeneration is almost nonexistent within the twentieth century burns. Instead, the former woodland has been replaced by shrublands or swards of exotic grasses, e.g., smooth brome *Bromus inermis*. This suggests that either (1) post-fire reforestation is extremely slow, and trees only begin to become re-established after many decades; or (2) the forests cannot recover from the kinds of high-intensity fires that have occurred in this century. If the latter is true, then either the extant woodlands did not burn prior to this century or prehistoric fires were different in some important way. For instance, prehistoric fires may have occurred more frequently and maintained a more open woodland structure with lighter fuels that would burn with lower intensity. Soil texture and nutrient conditions may have been different when the woodlands originally invaded these mesas. For example, we are gathering evidence that available nitrogen pools vary considerably across microsites on Chapin Mesa of different stand age (Berry and Floyd-Hanna, unpublished data).

All of this is speculative, because we have no specific information on prehistoric fire

history in piñon-juniper woodlands of MVNP. However, the current lack of regeneration in historic burns suggests a possibly serious problem for management of fire, vegetation, and biological diversity in the Park. We suggest a series of studies to determine when the last stand-replacing disturbance occurred in representative woodland sites in the southern end of the Park, and to ascertain whether that disturbance was a fire or something else. (For example, fire disturbance would presumably still be evident from charcoal on large remnants, whereas clearing by humans might leave recognizable stumps.) We think that this will be possible by investigating four different aspects of the problem: (a) size and age class structure of piñon and juniper woodlands, a study initiated in 1994, (b) spatial patterns of trees within the extant woodlands, (c) detailed description of the few microsites within which piñon and juniper seedlings have become established following historic fires (e.g., the Glade fire from the late 1800's on Chapin Mesa), and (d) transplant experiments to determine whether the lack of trees is because of inadequate dispersal or because of inimical site conditions. As a pilot to this study, Part (a) was begun in 1994. It may be possible to determine the approximate year of the last stand-replacing disturbance by carefully documenting current stand age structure, but if that disturbance occurred long before the extant trees became established, then it may not be possible to ascertain the time of the disturbance with any precision. Nevertheless, even this kind of information would be better than what we have at present.

Our recently completed vegetation study (Floyd-Hanna et al., 1994) suggested an unusually high density of piñon and juniper trees on the southern end of Mesa Verde. Stands of such density are rarely encountered, even when compared with 15 sites in a demographic study of these woodlands across the southwestern United States and northern Mexico (Floyd 1986). High stand density and recent mortality add significantly to the fuel capacity of Chapin Mesa. Also, observations made through the years by Marilyn Colyer, MVNP Resource Manager, include the presence of very large diameter stumps or downed piñon and juniper logs. This suggests that the woodland once may have consisted of a mature canopy with sizes (and possibly ages) exceeding those typical in the canopy today. Both live and dead piñon and juniper trees will be tallied in an effort to reconstruct the possible changes in woodland structure on Chapin Mesa and Wetherill Mesas.

A similar method of sampling was employed by one of the PIs (Floyd 1986) in stands across the southwestern U.S and in Chihuahua, Mexico, and will allow us a valuable comparison with existing demographic data. The geographically close but structurally different piñon-juniper woodlands near Dolores, Colorado (several km north of Mesa Verde), were well-sampled in Floyd's (1986) study and will provide a useful comparative base.

A pilot project was carried out in 1994 to determine sizes, ages, and density of piñon and juniper trees in representative stands on southern Chapin Mesa and Wetherill Mesas. The Chapin Mesa sites are either in dense, old-growth piñon-juniper or in a relatively open area, the Glade burn, which probably occurred in the late 1800's. A preliminary set of data on the stand structure of piñon-juniper woodlands was completed and in several plots, stumps were aged. Age-diameter regressions were developed which can be used to determine the ages of trees in other nearby site. This chapter outlines our results of the 1994 pilot study.

METHODS

STAND AGE

The Chapin Mesa plot included a fuel-reduction site (set out with the help of Tim Oliverias and the fuel reduction crew) where, in 1993/1994 trees had been removed through thinning. We obtained sections of tree stumps at ground level for age determination. The piñon and juniper seedlings, samplings, and trees which remained in these study plots were measured as above in order to determine a composite stand structure of the plots. In one additional site on Chapin Mesa and in the Wetherill study plot, increment cores were taken for

a subset of adult trees to determine age-diameter relationship for the site, although we could age only a few trees because of technical difficulties with increment borers. Saplings were aged directly by counting whorls of annual growth. These data and the age/diameter regression relationship determined in the fuel-reduction sites allowed a preliminary evaluation of piñon-juniper stand structure.

STAND STRUCTURE

In 1994, as a pilot study, a belt transect was established in two areas of dense piñon-juniper woodland on Chapin Mesa and one stand on Wetherill Mesa. On either side of a central transect, two 15 by 15 meter plots were established and the belt was run until increasing the sampled area no longer altered the measured size class distribution (approximately 6 plots per site). The size (dbh and diameter at root collar), height, canopy diameter, and status (live or dead) was recorded for all piñon and juniper of all size classes that are rooted within the plot.

RESULTS

STAND AGE

Using the ages obtained from stumps within the fuel-reduction area of Chapin Mesa, we performed a regression of age with diameter of each species. A quadratic model showed the best fit to predict age from diameter of each species (Figures 4-1 and 4-2) since a linear model would over estimate the ages of the largest diameter trees, whose incremental growth slows as the tree senesces. This relationship was used on unaged trees to predict age from the mean of two root collar diameters. Therefore, the results are presented both as size structures and age structures of the two sample populations.

STAND STRUCTURE

The stand structures are represented by size class distributions of live piñon and juniper on Chapin and Wetherill Mesas as well as in the Glade Fire which occurred in the south Chapin Mesa area in the late 1800's.

Figure 4-3 graphically compares the size structures of the sampled *Pinus edulis* populations in three sites. A high percentage population consists of small trees with diameters less than 10 cm (87.8% of the population in Chapin site; 79.9% of population in Glade site; 84.3% of population in Wetherill site), demonstrating effective recruitment in the recent past. On Wetherill Mesa, piñon has an almost identical distribution to that on Chapin Mesa with the exception of density--it is nearly twice as dense on Chapin Mesa. Pinon trees rarely reach 30 cm diameters in the Glade burn because of its relatively young stand age (although records are lacking, indications are that the Glade burn occurred before 1900). A Chi-square Goodness of Fit Test indicates that there is a significant difference in these three size class distributions ($\chi^2=196$, $p<.05$).

Figure 4-4 graphically compares the size structures of sampled *Juniperus osteosperma* populations. Juniper trees are larger on Wetherill Mesa than on Chapin Mesa. Apparently, most of the mature conifers were killed by the Glade fire in the late 1800's, although a few juniper are so large, greater than 40 cm, that we must infer that they were established prior to the burn, possibly surviving in unburned patches.

The density of piñon trees of all size classes combined, exceeded that of juniper, primarily because of high piñon seedling density (Table 4-1).

Figure 4-1. Regression model predicting age from diameter in *Pinus edulis*

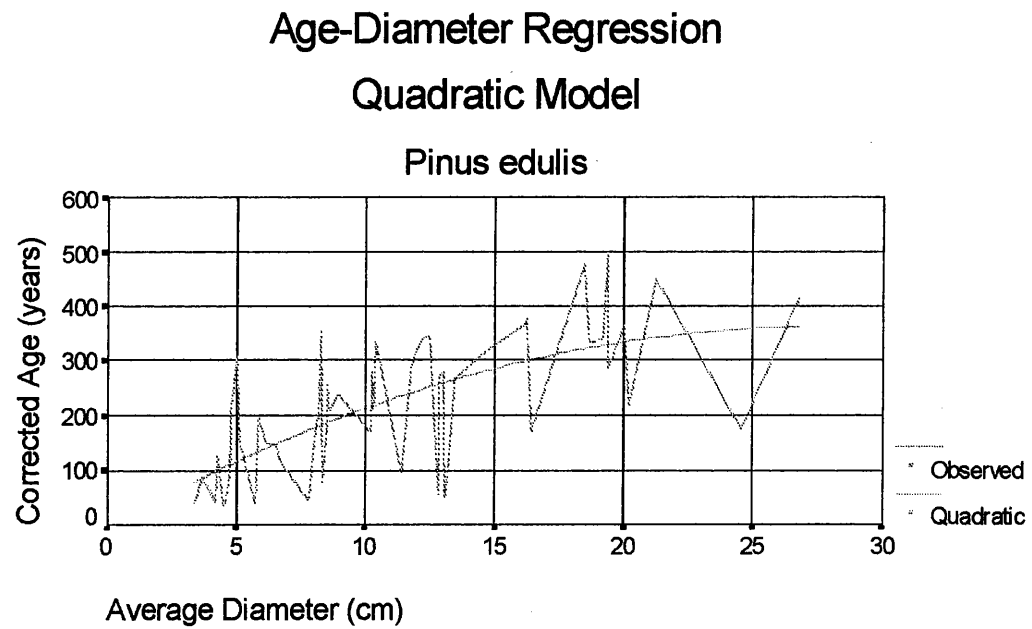


**Figure 4-2. Regression model predicting age from diameter in
*Juniperus osteosperma***

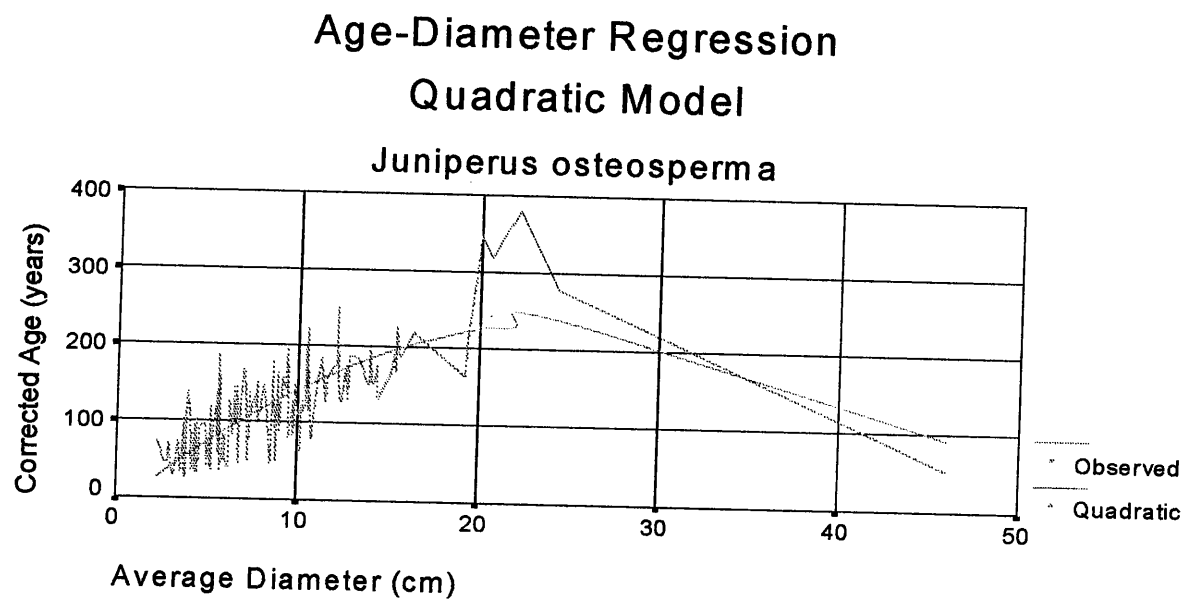


**Figure 4-3. Comparative Stand Structures of Pinon Pines
Populations
Mesa Verde National Park**

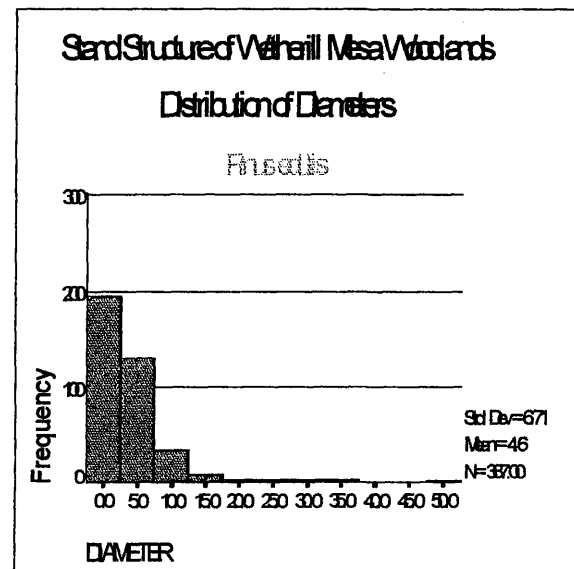
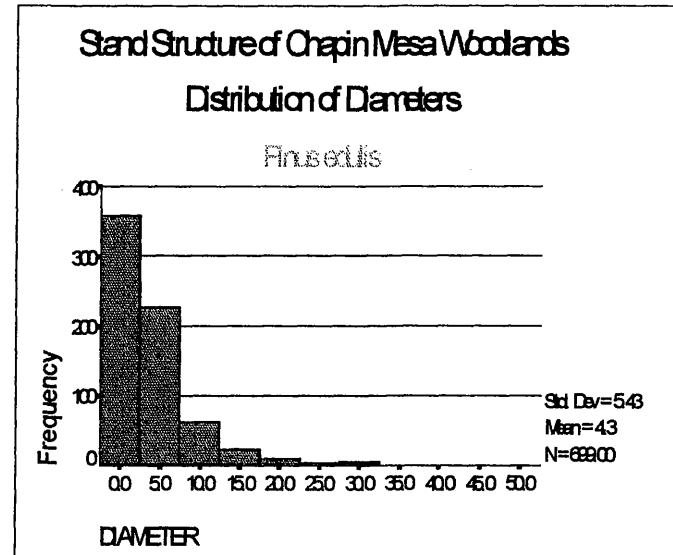
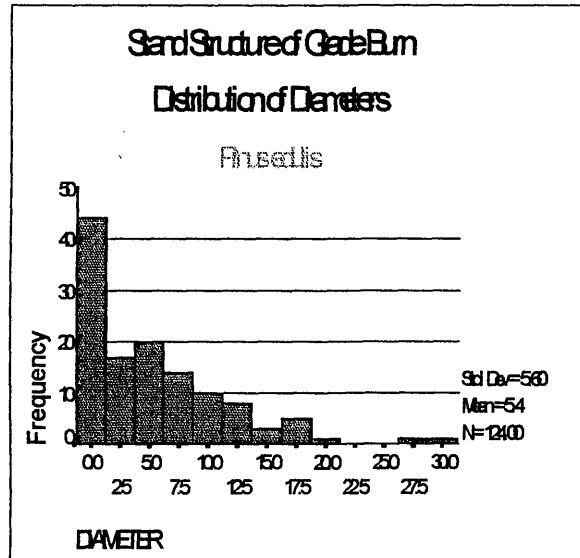


**Figure 4-4. Comparative Stand Structures of Juniper Populations
Mesa Verde National Park**

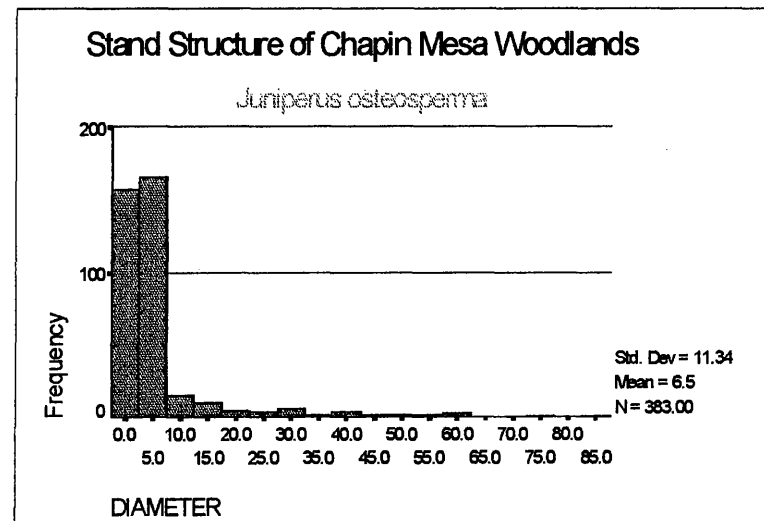
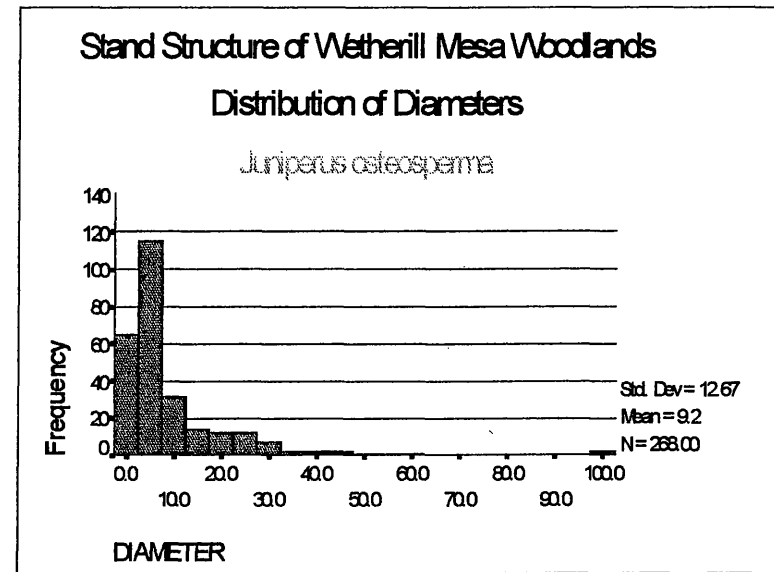
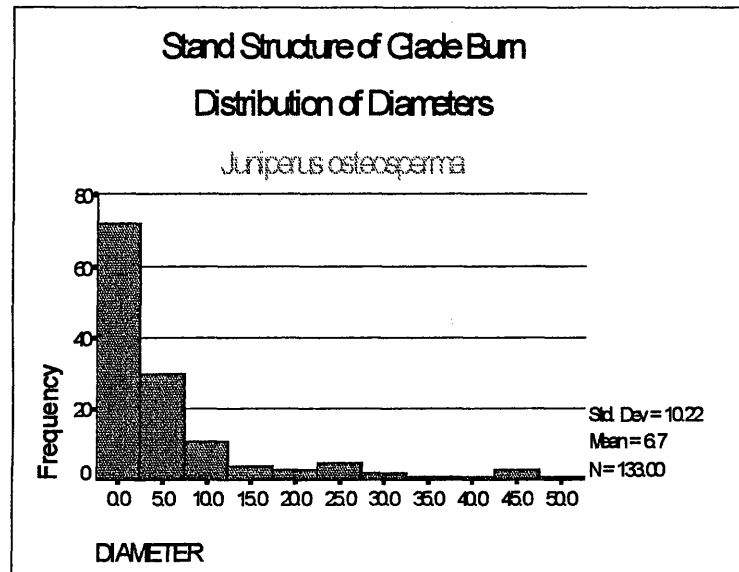


Table 4-1. The density (number of trees per hectare) of piñon and junipers in three study areas on Chapin and Wetherill Mesas.

	Wetherill	Glade	Chapin
Piñon	2864	918	5173
Juniper	1983	984	2834

In mature piñon canopy, piñon density is nearly twice juniper density, yet in the earlier successional sere represented by the Glade burn, piñon and juniper are present in equal density. One possible interpretation of these trends is that while juniper is successful in early successional seres, the conditions created by a closed canopy favor the establishment of piñon in later stages. The ages of piñon and juniper stumps that were sampled by fuel reduction personnel on Chapin Mesa are summarized in Figures 4-5 and 4-6. The most common ages for piñon is between 80-180 years, while the age distribution of juniper is more evenly dispersed over the 50-375 year classes. Junipers reached 500 years of age, while the oldest piñon tree was only 380 years.

Finally, the distributions of age and diameter are combined across the three sampling areas and converted to cumulative frequency diagrams to study mortality patterns (Figures 4-7 and 4-8). Piñon and juniper show an almost identical pattern in the cumulative proportion of diameter classes, although the slope of the piñon curve is steeper, indicating higher mortality between two size classes than is evident in the more gradual slope in juniper. However, the age structures are markedly different. Juniper has a consistent transition from one class to the next, while piñon shows an abrupt inflection point at 150 years of age. Once this age is reached, mortality slows in piñon populations. Knowles and Grant (1983) describe this structure as typical of climax stands of the Rocky Mountains, although this interpretation has been disputed in other geographic areas. As stated above, the oldest piñon is about a century and a half younger than the oldest juniper, indicating either that the sites were invaded by juniper first, or that mature piñon trees have been killed selectively.

DISCUSSION

These data indicate an uneven-sized, and infer an uneven-aged, distribution of conifers in Mesa Verde National Park. There is no clear indication that they became established following a catastrophic disturbance, e.g., high-intensity fire or anthropogenic harvesting. Because these limited data indicate that the largest trees do not compose a clear even-aged cohort, we must conclude that the last stand-replacing disturbance occurred long before the extant trees became established. A gradual conifer invasion, initiated by junipers, into previously burned areas could result in a stand structure resembling the Glade fire. This is an important area in Mesa Verde, because few of the known historic burns occurred on the southern, low elevation, sections of the park. Our observations indicate that conifer regeneration has not occurred in the other historic burns, but these have the added dimensions of distance from seed sources (mature piñon-juniper woodlands), high elevations, and soils which do not necessarily support piñon-juniper elsewhere in the park. Microclimatic characteristics must be considered when determining the suitability of the area for piñon and juniper invasion.

Further study is required to verify these trends and to address more fully the fire history of piñon-juniper woodlands. In addition to the preliminary data on the size and age

Figure: 4-8

Mesa Verde National Park
Pinon-Juniper Structural Analysis

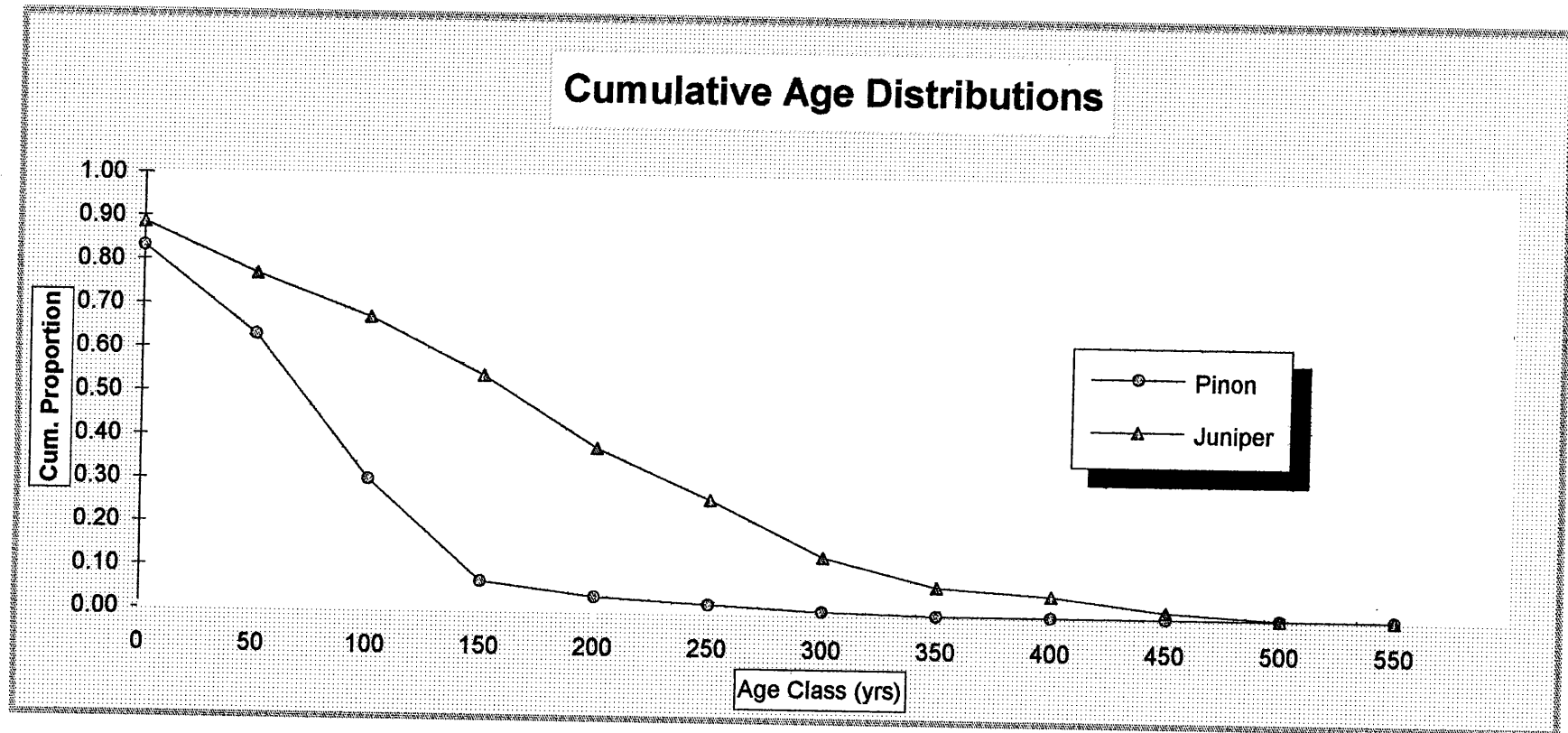
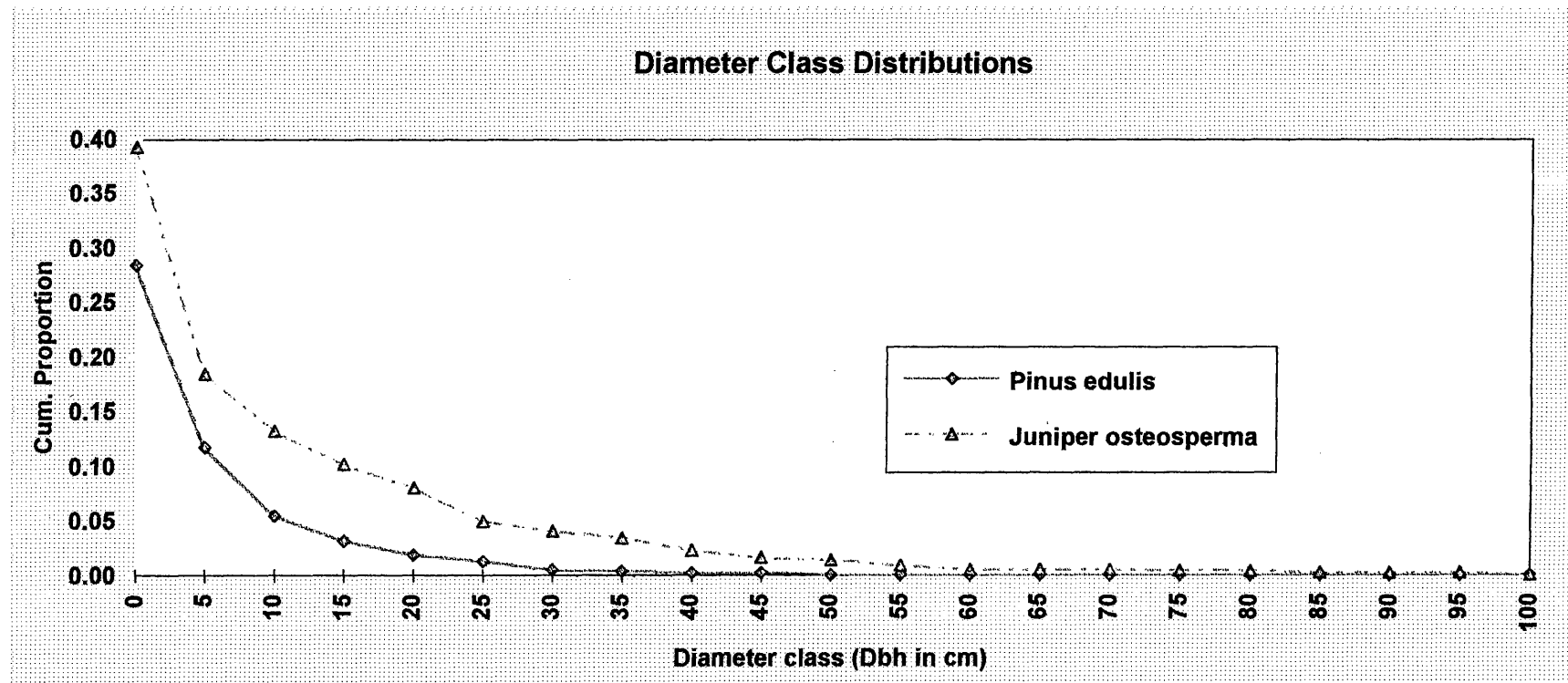


Figure: 4-7

5/10/95

Mesa Verde National Park Pinon-Juniper Stand Structure



class structure of live piñon and juniper woodlands, we require similar information on stumps, snags, and downed logs. The spatial patterns of trees within the extant woodlands must be determined, and detailed description of the few microsites within which piñon and juniper seedlings have become established following historic fires (e.g., the Glade fire from the late 1800's on Chapin Mesa). Transplant experiments and extensive studies of avian behaviors in various stand ages will determine whether the lack of trees is because of inadequate dispersal or because of inimical site conditions.

In a future study, we will test for significant differences in the statistical distribution of diameters of living and dead trees (perhaps for the largest size classes only, since these are best preserved in the population of long-dead trees). If the mean/median diameter of the dead trees is significantly greater than that of the living trees, then we will conclude that directional changes are still occurring the structure of the woodlands. Alternatively, if the differences are not significant, then we will conclude that the woodlands have been stable in structure for at least the last century or so. If the spatial maps indicate that older trees are surrounded by more or less concentric rings of progressively younger trees, then we will conclude that the present stands became established first as scattered individuals (perhaps in special microhabitats) that then served as nuclei for further tree establishment.

CHAPTER 5

DEVELOPING A FIRE RISK MODEL FOR MESA VERDE NATIONAL PARK

Our research outlined in the previous chapters provides much of the necessary background information from which we can predict specific fire effects on cultural sites. In addition we have completed a map of the vegetation communities (Floyd-Hanna and Romme, 1994). A digital map was compiled to define the vegetation of Mesa Verde so that the fire potential of each plant community could be accurately predicted. This was the first step of modeling the fire effects on cultural resources that occur in a variety of fuel types. Landsat TM and SPOT panchromatic data from May and June 1990 were used as a spatial and spectral base. An unsupervised classification of the image data was performed, and in conjunction with initial field surveys showed that 17% of the image was classed as shadow. Since a large portion of the image was classed as shadow, important vegetation characteristics were obscured. To mitigate the topographic effects in the image data, a transformation was used to separate the spectral and illumination information (Pouch and Campagna 1990). The transformed image was then reclassified. Ground truth efforts were guided by this reclassification were made with releve stand analyses (Mueller-Dombois and Ellenburg 1974) of over 300 sites, each located with a Trimble Pathfinder Basic⁺ Global Positioning System (GPS). Species cover and abundance ratings were clustered with TWINSpan, a multivariate clustering program (Gauch 1982). This ordination was used to guide the final supervised classification of the image data with training signatures from the mean spectral signatures of the clustered sample points. In this way, the spectral and field information were related to one another.

These data sets, the fire studies outlined in Chapters 1-4 and the vegetation study of MVNP, incorporated into spatially explicit layers in the Mesa Verde's Geographic Information System, will be used to model the risk and specific effects of fire on particular classes of cultural resources.

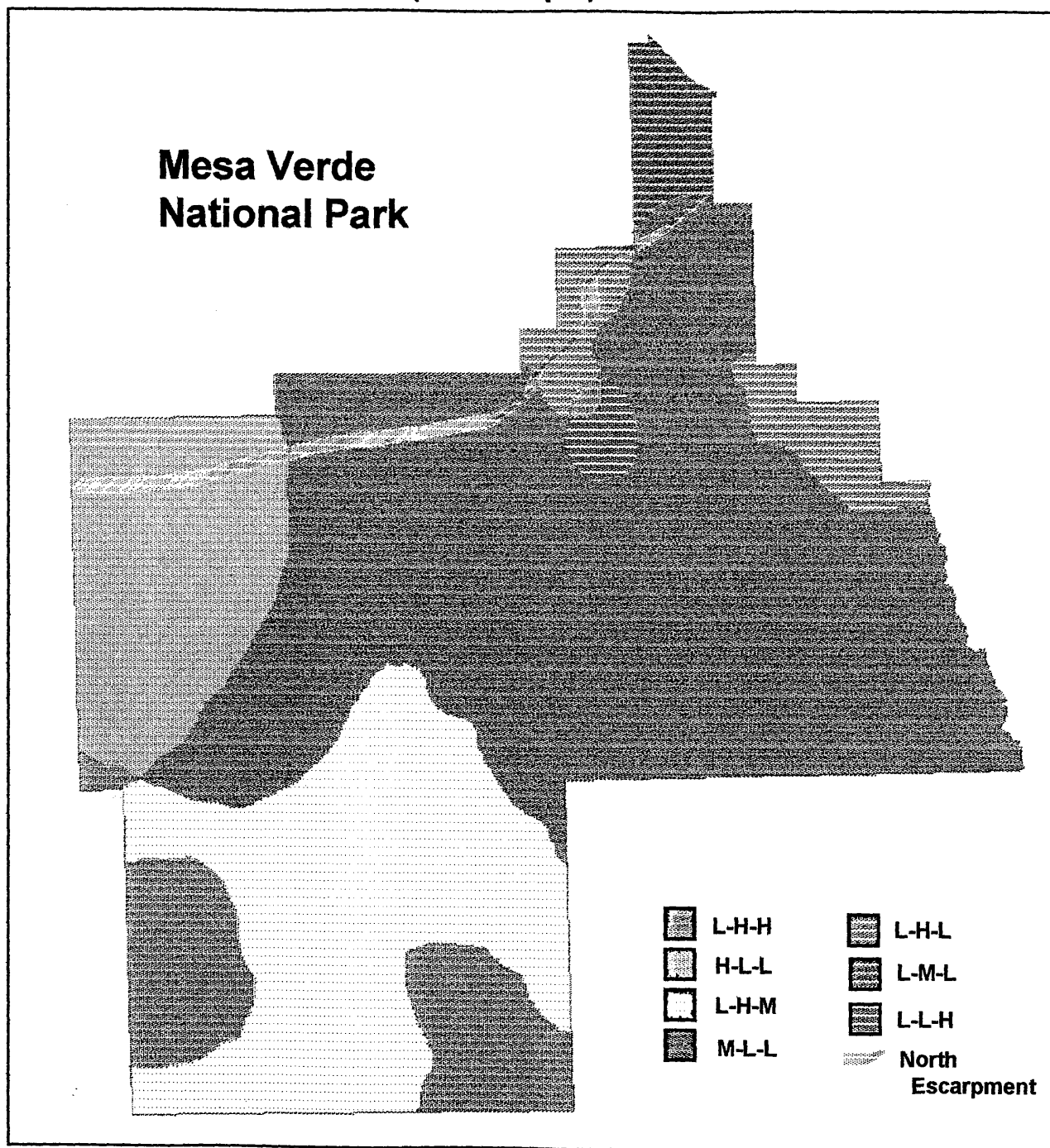
EFFECTS OF FIRE ON CULTURAL RESOURCES

These data will allow us to predict the probability of occurrence and the effect which a fire might have on a given type of archeological site, depending on its location in the landscape. Data layers, each of which is spatially defined as points or areas, will be as follows:

1. *Median fire interval*--expressed as a probability of occurrence, High=0.02 (from a 50 year fire return interval), Medium=0.01 (from a 100-year fire return interval), and Low <0.01 (for fire return intervals greater than 100 years).
2. *Vegetation/fuels and fire intensity potential*--expressed as high, medium, or low intensity. "High" potential occurs in Douglas fir forests or pinon/juniper woodlands, "Medium" potential occurs in sparse piñon-juniper woodlands, and "Low" potential occurs in mountain shrublands and meadows.
3. *Significant and vulnerable cultural resources*-- Although all cultural resources at Mesa Verde have intrinsic value, some are more vulnerable to fires than others. The following classification was developed by a group of archeologists, ecologists and fire behavior specialists (Romme et al. 1993):
 - A. Sites with high vulnerability of fire damage:
 1. Native American historic structure, e. g. sweat lodges and corrals

Figure 5-1:

Fire Risk Summary (an example)



Letter designations:

1st = Fire probability (Low, Medium, High)

2nd = Fire intensity (Low, Medium, High)

3rd = Vulnerability of Cultural Resources (Low, Medium, High)

2. Alcoves and cliff dwellings containing organic materials, e. g. , packet rat middens, wooden beams, corn cobs
 3. Rock art panels
 4. Culturally scarred trees
- B. Sites with moderate vulnerability to fire damage:
1. Euro-American historic structures, e. g. museum and administration buildings
 2. Lithic scatter and shallow hearth
- C. Sites with low vulnerability to fire damage
1. Deeply buried, unexcavated pueblos
 2. Lithic scatter
 3. Check dams

A Risk Model is currently being developed by the authors and other National Park Service personnel in which these three categories of risk overlap each other (Fig. 5-1 is a simplified example of this for illustrative purposes). Although each data layer is not yet complete, we begin to see the pattern of fire risk at Mesa Verde National Park as a mosaic of superimposed risk probabilities. For example, an area with dense fuels and highly valued cultural sites such as Chapin mesa is at higher risk than an area which has burned frequently, preventing heavy fuel build-up, and which has few archeological resources as found on the north end of the park. Many of the most vulnerable sites--and perhaps those upon which fire fighting efforts and pre-suppression activities such as fuel reduction should focus-- are not surprisingly on the southern ends of Chapin and Wetherill mesas. This is because of a High risk rating in two categories. Another High risk area occurs at the head of Prater Canyon, where culturally scarred trees occur in a site of dangerous fuels.

We will continue to improve on the risk assessment for Mesa Verde National Park and to develop a model based on the probability of fire, fire intensity, and location of archeological sites. As the inventory of cultural sites is completed in the near future and the locations of cultural resources are mapped, we will be able to accurately predict fire effects on cultural resources in Mesa Verde National Park.

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