Cooperative National Park Resources Studies Unit

ARIZONA

TECHNICAL REPORT NO. 34

FIRE HISTORY AND STAND STRUCTURE OF A PINYON-JUNIPER WOODLAND AT WALNUT CANYON NATIONAL MONUMENT, ARIZONA

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University of Arizona/Tucson - National Park Service

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Del W. Despain and Jeffrey C. Mosley

Final Report
Project PX8601-7-0105

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August 1990

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ACKNOWLEDGEMENTS

Authors wish to thank Roy Keys, Ramzi Touchan, Peter Gilruth, Kate Dixon, Mary Ann Botergan and personnel from the Laboratory of Tree Ring Research at the University of Arizona for technical assistance.

ABSTRACT

This study examined the historical role of fire and its effects within a pinyon-juniper woodland in northern Arizona. Cross-sections were cut from dead snags, stumps and logs of trees evidently killed by past fires. Tree cores were extracted from living trees exhibiting fire scars and from living trees rooted near dead, burned trees. Samples were cross-dated to estimate when trees were killed or scarred by fire. Stand structure was also examined at 10 sites to assess the apparent impacts of past fires. Few cross-sections were datable, but small fires probably occurred within the woodland in 1804, 1832, 1862 and shortly after 1880. The oldest trees sampled were 300-400 years old, and some may have exceeded 500 years of age. Stand structures suggest tree density has increased significantly, probably within the last 200 years, but the rate of increase has slowed in recent decades. Fires probably occurred periodically throughout the woodland in the past, but these fires were not usually stand replacing fires as might be expected to occur under present tree and understory conditions.

INTRODUCTION

Pinyon-juniper woodlands are a significant ecosystem type in western North America. These woodlands increased greatly in extent and density following European settlement (Arnold et al. 1984; Barney and Frischknecht 1974; Blackburn and Tueller 1970; Brotherson et al. 1983; Burkhardt and Tisdale 1976; Christenson and Johnson 1964; Cottom and Stewart 1940; Ellis and Schuster 1968; Johnsen 1962; Tausch et al. 1981; West et al. 1975; West et al. 1979; West 1984; Woodbury 1947; Young and Evans 1981) and now occupy more than 19 million hectares in the western United States (Buckman and Wolters 1987).

Decreased frequency of fires due to fire suppression and reduced understory fuels is believed to have contributed to the increase in extent and density of pinyon-juniper woodlands (Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Evans 1988; Johnsen 1962; Rand 1965; Springfield 1975; West et al. 1975; West 1984), but the long-term historical role of fire in shaping these woodlands is not well understood. Several studies have examined plant successional changes following known individual fires (Arnold et al. 1964; Barney and Frischknecht 1974; Despain 1987; Koniak 1985; Tausch and West 1988), but little is known about historical fire frequency and its effect upon stand structure within pinyon-juniper woodlands. Young and Evans (1981) examined western juniper (*Juniperus occidentalis*) in California and determined that at least three large fires occurred in their study area between 1600 and 1860 A.D., with the possibility of additional small fires or surface fires that had negligible impact on most larger trees in the stands. Young and Evans found no evidence of fire after about 1860.

The purpose of this study was to evaluate the history and impact of past fires on a pinyon-juniper woodland within Walnut Canyon National Monument (WACA) in north-central Arizona.

STUDY AREA

WACA, located about 11 km east of Flagstaff, Arizona, was established in 1915 to preserve a collection of Sinagua Indian dwellings and archaeological sites dating from about 1000 to 1200 A.D. WACA consists of 815 ha including about 300 ha of pinyon-juniper woodland that were evaluated in this study. The study area is bounded by the monument entrance road on the west, the monument boundary on the north, and by Walnut Canyon to the south and east (Figure 1).

The study area is situated on a limestone plateau at an elevation of 2040 m. Topography is gentle with slopes generally less than 5%. Precipitation averages 45 cm annually with 12% received from April through June, 26% received as July and August thunder storms and the remaining 62% distributed rather evenly from September through March. The woodland studied occurs near the ecotone with ponderosa pine (*Pinus ponderosa*).

Vegetation of the study area is dominated by pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) with occasional occurrences of one-seed juniper (*Juniperus monosperma*) and, rarely, Rocky Mountain juniper (*Juniperus scopulorum*). Understory species include blue grama (*Bouteloua gracilis*), mutton grass (*Poa fendleriana*) and cliffrose (*Cowania mexicana*).

Although woodlands north of the study area were burned intentionally in the 1960's, there is no physical evidence of a significant fire within the study area since WACA was established. Prior use of the area for firewood, livestock grazing, recreation, etc. was heavy due to its close proximity to the city of Flagstaff which was settled in the early 1870's. Evidence of such use remains today in the form of axe cut stumps, old equipment parts, and litter.

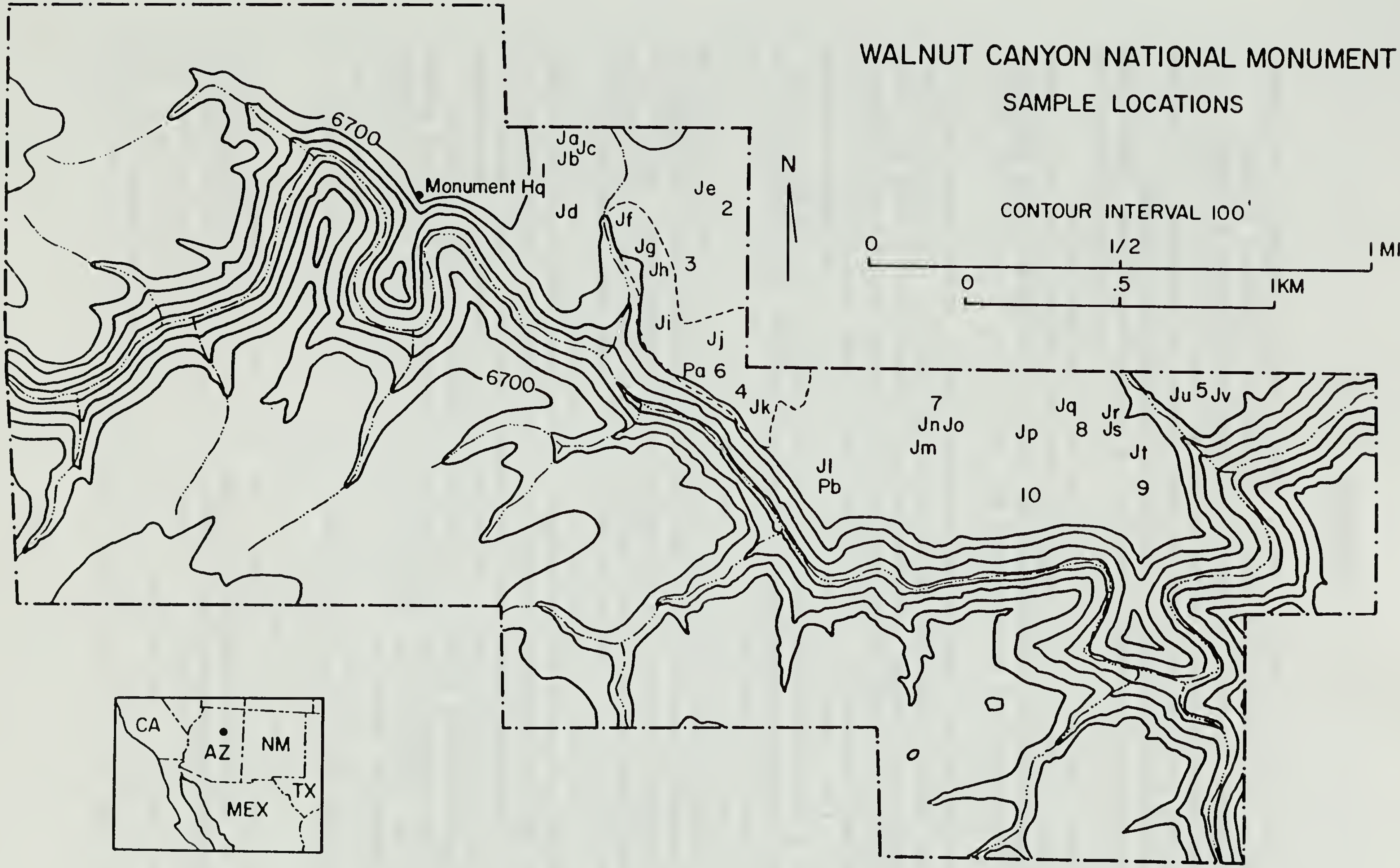


Figure 1. Walnut Canyon National Monument and location of study macroplots (numbers) and burned juniper (J_x) and pinyon (P_x) remnants sampled.

METHODS

The study area was searched for evidence of past fires. Cross-sections were cut from dead snags, stumps or logs of trees evidently killed by past fires. In locations where several burned trees were present, samples were collected from only a portion of the burned material in the area. A total of 24 dead, burned trees were evaluated including two pinyons (Figure 1). Also, cores were extracted from living ponderosa pines with fire scars and from pinyons or ponderosa pines rooted within about one meter of dead, burned trees. Samples were cross-dated (Schweingruber 1988) at the University of Arizona Laboratory of Tree-Ring Research to determine the year or estimate the period when trees were killed or scarred by fire.

In anticipation of difficulty dating junipers, stand structure at 10 locations throughout the study area (Figure 1) was evaluated to assess apparent impact of historical fires and to aid our interpretations of past fire activity. The 10 locations selected represented major strata within the study area based on topography, site conditions and stand structure. Stands on steep slopes along drainages leading to Walnut Canyon and stands with significant numbers of ponderosa pine or gambel oak (*Quercus gambelii*) were not sampled.

A 0.4-ha circular macroplot was established within each of the 10 stands selected for sampling. Macroplots were located within stands of uniform structure and site characteristics. All junipers and pinyons in each macroplot were measured for diameter at stump height (20 cm above ground) and total tree height. Equivalent diameters (Chojnacky 1988) were computed for the few multi-stemmed junipers encountered. Cores were extracted as near to stump height as possible from 20 to 40 pinyons in each macroplot. Trees of various sizes were included among cored samples. Approximate age at stump height of the cored trees was estimated by counting rings. Junipers were not cored because complete cores are difficult to extract from large junipers and because it is difficult to date or accurately count rings in Utah junipers (Despain 1989).

Non-linear regressions of the form:

$$\text{Estimated age} = (a)*(\text{diameter})^{b}$$

were used to estimate general age characteristics of pinyons in the stands (Brotherson et al. 1983).

RESULTS

DIRECT EVIDENCE OF FIRES

Only three of the 22 burned juniper snags sampled were datable (J_a, J_b and J_t). An outside ring or bark date was found only on sample J_a. Samples J_b and J_t had an unknown number of outer rings missing. Both pinyon samples (P_a and P_b) were datable, but they were highly weathered with an unknown number of outer rings missing from each.

Several burned juniper stumps were present in the immediate vicinity of samples J_a, J_b and J_c (Figure 1). Sample J_a died during the growing season of 1862 (assumed to have been killed by the fire). Sample J_b was located within a few meters of sample J_a. The outer ring of J_b dated to 1834, but the sample was highly weathered and was assumed to have also burned in 1862. Other burned stumps nearby were probably killed by the same fire. The extent of this fire within the boundaries of WACA is unknown, but appears to have been limited to 3 or 4 ha near the monument's northern boundary.

Little additional evidence of past fires was found in the western portion of the study area and no evidence was found within Plot 1. Similarly, little evidence of past fires was found in the vicinity of Plots 2 and 3. However, a non-datable, burned juniper remnant (sample J_e) was found in a dense, mature stand similar to stands sampled by Plots 2 and 3. The presence of mature trees suggests the fire which killed the juniper was not an extensive crown fire in that vicinity.

Considerable evidence of fire was found in the area delineated by the dashed line in Figure 1. One pinyon remnant (sample P_a) and six juniper remnants were sampled from throughout the area (samples J_{f-k}). The pinyon remnant was weathered considerably, but the most recent annual growth ring found on the sample dated 1826. None of the juniper samples (J_{f-k}) were datable. However, samples J_i, J_j, and J_k cross-dated among themselves. This indicates that each was burned by the same fire, apparently the same fire which killed the pinyon (P_a). Juniper samples J_g and J_h cross-dated with each other, but it is uncertain whether these two trees were killed by the same fire as trees J_i, J_j, and J_k.

A living ponderosa pine tree near sample J_f was scarred by fire shortly before 1840. The exact year of the fire was indeterminable from cores bisecting the interface between the scar and subsequent growth. However, it appears the entire area within the dashed lines of Figure 1 was burned by the same fire, probably sometime between 1826 and 1840. Swetnam et al. (1990) determined that much of the ponderosa pine type in WACA was burned in 1832 including just across Walnut Canyon to the south of the study area. The pinyon-juniper woodland delineated by the dashed lines in Figure 1 probably burned also in 1832. All trees within the area were not burned, but the southeastern portion (where Plots 4 and 6 were located) appeared to have burned more completely than the northwestern portion, based on relative densities of remaining mature trees and younger, reestablished trees.

A considerably weathered pinyon remnant east of Plot 4 (sample P_b) had an outer ring from 1794 with an unknown number of later rings missing. Although stand structure was not evaluated at this location, the stand was more dense and apparently more mature than stands in Plots 4 and 6. If this tree was burned by the same fire that burned Plots 4 and 6, most of the surrounding trees were apparently unaffected. A non-datable, burned juniper stump was sampled near the same location (sample J_l), but other evidence of fire was uncommon.

Burned remnants of juniper throughout most of the eastern half of the study area were less common than to the west, except in the northeastern corner of the study area near Plots 8 and 5. Although non-datable, juniper snags within Plot 8 and the surrounding vicinity appeared to have burned relatively recently, as evidenced by several standing snags with many remaining branches. However, the fire's impact upon the overstory was apparently spotty based on age structure of the present stand. A similarly spotty fire in and around Plot 5 occurred sometime after 1880 (sample J_t). It is possible that burned snags near Plots 8 and 5 were killed by the same fire. However, any such assumption must be tentative, especially because of the presence of a deep, steep-sided draw separating the two sites.

Remnants of past fires were not found in or near Plots 9 or 10. However, a few burned, but highly weathered and apparently old remnants were found widely scattered throughout the vicinity of Plot 7. None of the juniper remnants sampled (J_m through J_p) were datable. One large, highly decayed ponderosa pine stump near sample J_p had two fire scars which dated to 1796 and 1804 respectively. Whether these scars were caused by lightning strikes to the tree or by general surface fires is unknown, but several ponderosa pines elsewhere in WACA burned in 1804 (Swetnam et al. 1990). Regardless of how the ponderosa pine tree was burned, the fires apparently had little effect on the surrounding woodland as evidenced by mature stands throughout the area. If burned juniper remnants in the vicinity were killed by these fires, the fires were not extensive, stand replacing crown fires.

STAND STRUCTURES

Regressions of the relationship between tree age and stem diameter were generally weak for each of the 10 plots sampled (Appendix). Furthermore, a recent study by McClaran and Bartolome (1990) demonstrated the inappropriateness of using size/age relations for predicting stand age-class structures and drawing conclusions about tree establishment histories therefrom. Accordingly, only general assumptions about the role of past fires will be drawn from stand age-class structures estimated in this study.

The oldest pinyons found were about 300-400 years of age at stump height (Table 1). The largest junipers, although generally larger in diameter than the pinyons, may or may not be older. The largest trees in a pinyon-juniper stand generally reflect faster growth and are not necessarily the oldest trees in the stand. Although ring counts of Utah junipers are inconclusive and possibly misleading (Despain 1989), ring counts of a few moderately sized junipers on the study area suggest some may exceed 500 years of age. Diameter growth of junipers in this region tends to be similar to or slightly slower than that of pinyons (Brotherson et al. 1983; Despain D.W., unpublished data), which suggests that many junipers on the study area are as old as or perhaps older than the oldest pinyons sampled.

All stands sampled for size and age structure were dense and mature except Plots 4 and 6. Size (especially diameter) characteristics varied among the 10 stands sampled (Tables 2 and 3), but appeared to depend more on site productivity and stand density than on differences in stand age (Table 1). This is consistent with suggestions by Meeuwig (1979) that diameter growth rates on a stand basis are governed primarily by competition rather than by age. Despain (1989) also found competition to be an overriding influence on diameter growth rates in dense pinyon-juniper stands.

Median diameter and median height were generally similar regardless of density or age, including the least mature stands (Plots 4 and 6). The tallest trees were usually pinyons, but the largest diameter trees were always junipers (Table 2). Stands with the shortest maximum heights (Plots 4, 5, 6 and 8) displayed the most evidence of recent fires, although Plots 4, 5 and 6 also were located near the canyon rim on relatively dry sites with shallow soils.

Although Plots 1, 2 and 3 on the west side of the study area had the highest density of trees, Plots 7, 9 and 10 had the greatest total basal area. Junipers accounted for only 16% to 36% of the number of trees in all plots except Plot 1. However, junipers comprised more than 35% of the basal area of all stands and more than 50% of the basal area of six of the ten stands sampled (Table 3).

Table 1. Summary of estimated age characteristics of pinyons ≥5cm in diameter.

Plot	No. of pinyons cored	Estimated age (at stump height)		
		Oldest cored	Largest diameter	Stand average
01	39	316	264	155
02	32	262	265	123
03	35	283	291	136
04	21	74	72	53
05	33	223	221	93
06	20	125	123	66
07	34	392	388	160
08	38	307	220	86
09	28	292	224	175
10	28	286	312	131

All stands exhibited a class structure that suggests a relatively recent increase in tree density, probably within the last 200 years (Figure 2). A paucity of dead and downed trees other than those killed by fire supports findings of research cited earlier that tree density within pinyon-juniper woodlands has increased dramatically over the past one to two centuries. Most of the increase was pinyons while juniper densities remained more constant in many of the stands sampled (Figure 2). This was similar to findings of Tausch and West (1988). Although some of the smaller trees may be old trees, the overall trend in size/age relations strongly suggests that tree density has increased on WACA during the past two centuries.

It appears that the rate of increase in density of established trees has slowed in the past few decades, as evidenced by the presence of fewer 5 to 10-cm diameter trees (Figure 2). The large number of saplings presently found in most stands may represent a recent influx of trees due to a favorable combination of climatic events which will eventually contribute to the density of the overstory. Alternatively, these saplings may represent a stagnant component of the understory which acts largely as a replacement pool for the overstory. The reduced numbers of 5-10-cm trees suggests the latter scenario, though a combination of both factors is possible.

Table 2. Summary of size characteristics of sample stands for trees ≥5cm in diameter.

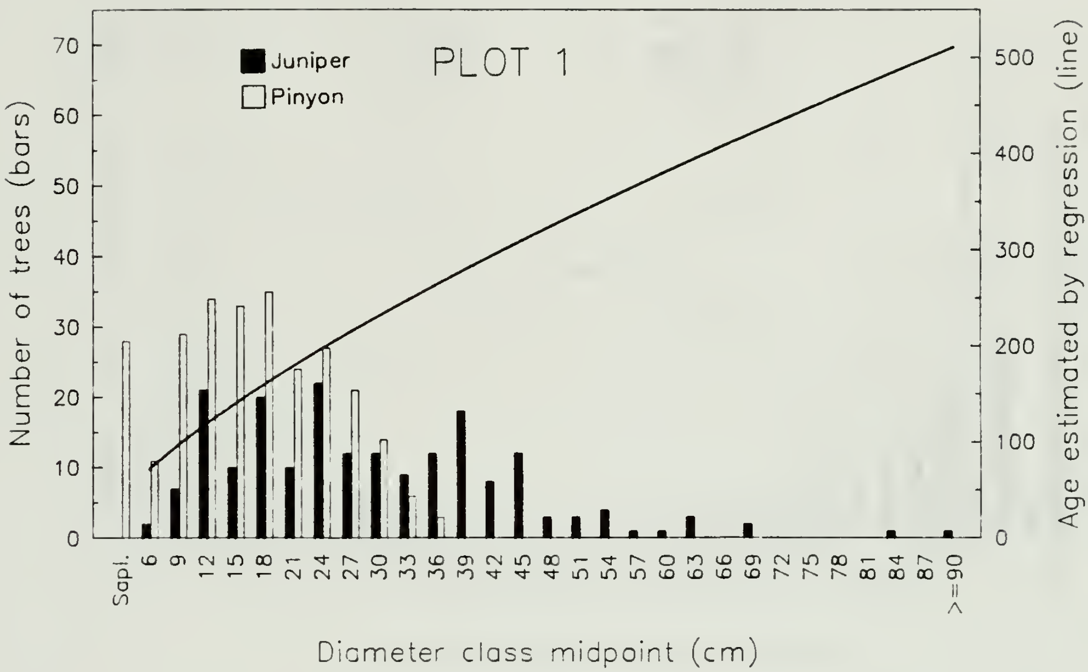
	Tree diameter(cm)								
	Stand			Junipers			Pinyons		
Plot	Max.	Med.	Mean	Max.	Med.	Mean	Max.	Med.	Mean
01	99	19.0	22.2	99	12.0	28.6	36	14.0	17.2
02	65	16.0	18.4	65	9.5	30.2	49	13.0	16.2
03	106	15.0	17.5	106	8.0	20.6	58	13.0	16.4
04	71	18.0	21.7	71	9.0	29.1	42	12.0	17.4
05	101	15.0	19.0	101	8.0	31.8	40	12.0	14.4
06	90	17.0	21.4	90	8.0	28.1	50	13.0	18.4
07	102	19.0	22.3	102	10.5	27.0	60	14.0	19.8
08	88	14.0	17.8	88	7.5	27.3	46	12.0	15.1
09	120	36.0	35.6	120	13.0	51.3	77	27.0	32.0
10	111	47.5	51.0	111	40.0	57.3	79	44.0	48.5

	Tree height (m)								
	Stand			Junipers			Pinyons		
Plot	Max.	Med.	Mean	Max.	Med.	Mean	Max.	Med.	Mean
01	11.3	4.5	5.1	9.0	3.4	4.8	11.3	3.4	5.2
02	11.1	4.9	5.4	8.6	2.5	5.4	11.1	4.9	5.3
03	12.3	4.9	5.3	9.8	2.5	4.1	12.3	4.9	5.7
04	8.6	4.9	4.3	8.6	2.5	4.4	7.4	3.7	4.3
05	8.6	3.7	4.0	7.4	2.5	4.5	8.6	3.7	3.8
06	7.4	4.9	4.6	6.2	2.5	4.1	7.4	3.7	4.7
07	12.3	4.9	5.4	8.6	2.5	4.6	12.3	3.7	5.8
08	9.8	4.9	4.8	9.8	2.5	5.0	9.8	4.9	4.7
09	11.1	4.9	4.9	9.8	2.5	5.2	11.1	3.7	4.8
10	12.3	4.9	5.2	12.3	2.5	4.9	12.3	3.7	5.3

Table 3. Summary of stand density, basal area and composition.

	Density (no./ha)				Basal Area (m^2/ha)	
	Saplings		Trees≥5cm diameter		Trees≥5cm diameter	
Plot	Total	% Junipers	Total	% Junipers	Total	% Junipers
01	70	0	1043	44	53.3	70
02	188	11	918	16	32.5	40
03	160	55	1158	26	37.7	42
04	345	28	248	36	13.2	63
05	220	16	718	26	30.5	65
06	265	23	353	31	19.0	57
07	198	11	833	35	45.7	54
08	268	6	878	23	31.0	51
09	210	0	625	18	83.3	35
10	113	7	773	28	167.8	37

Stand structure in Plots 9 and 10 was dissimilar to other stands sampled (Figure 2). Diameter size structure of Plot 9 was rather uniform with apparent recruitment relatively constant during the past 200 years. Plot 10 showed the same apparent increase in density during the past century as occurred in other stands, but there was an abrupt termination of recruitment during this century. No trees smaller than 35 cm in diameter were found in the stand except for a moderate number of saplings. Although trees were large in Plot 10, they were not older than trees in other plots. Plot 10 was located in a concave topographical position where water drained through the plot and where soils were deeper than at most other sites.



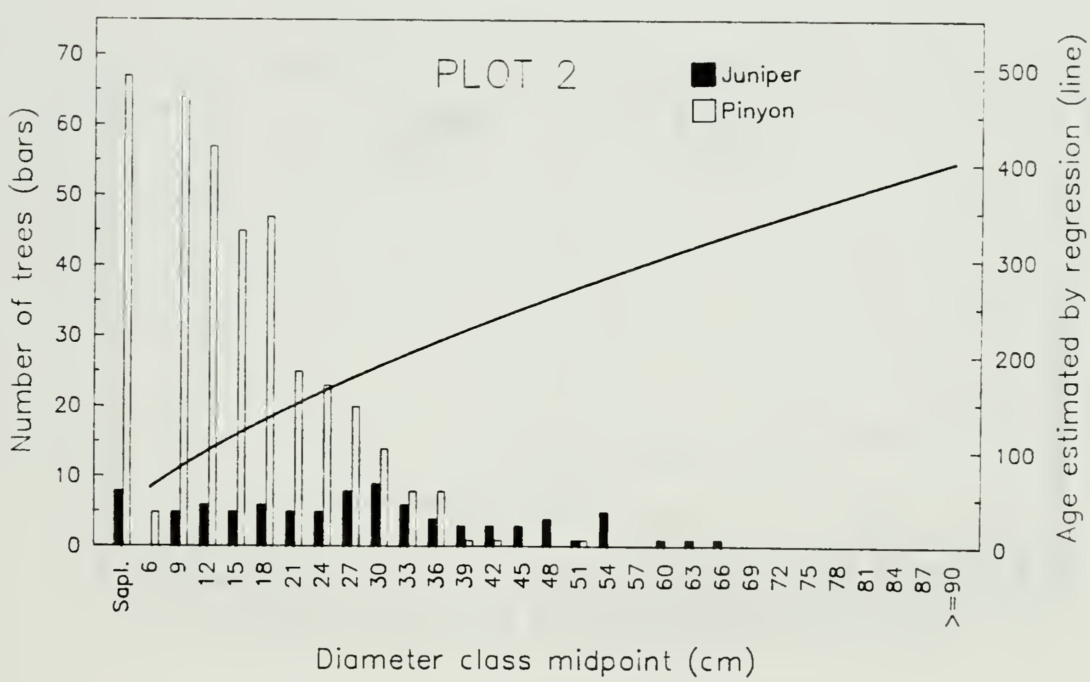
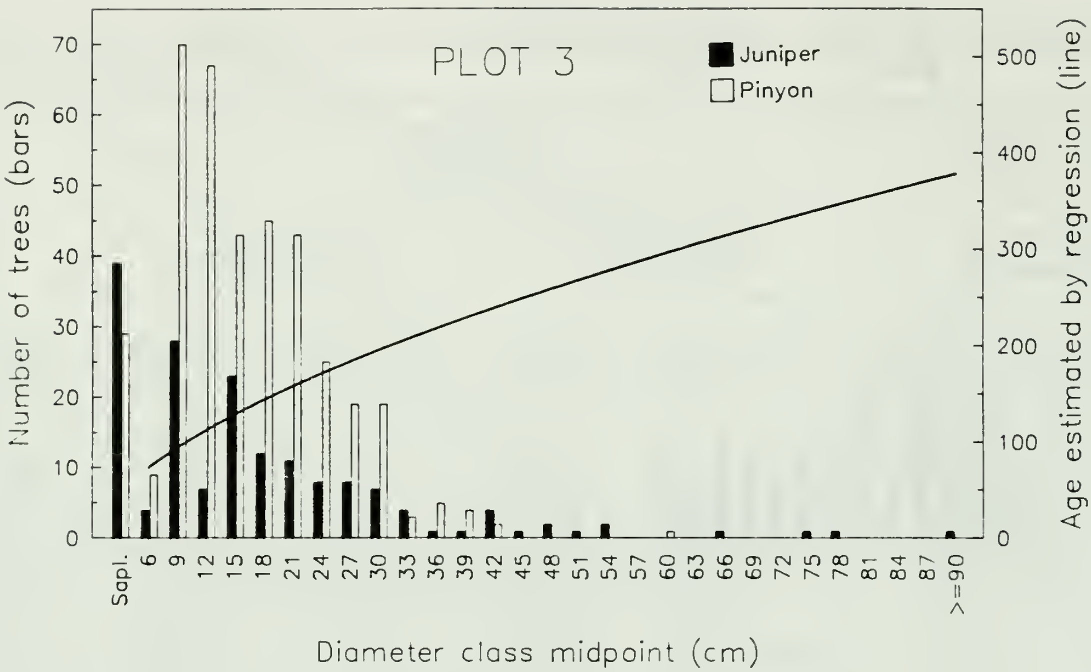
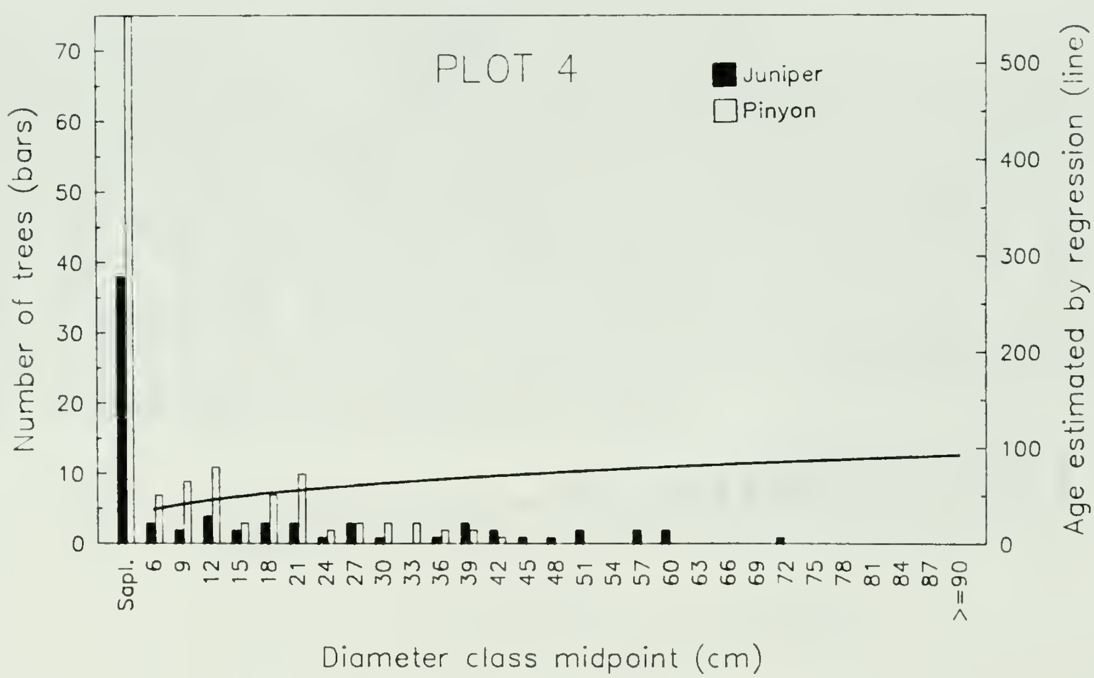


Figure 2. Diameter size class structure of stands sampled in WACA with regression estimates of corresponding age structure.





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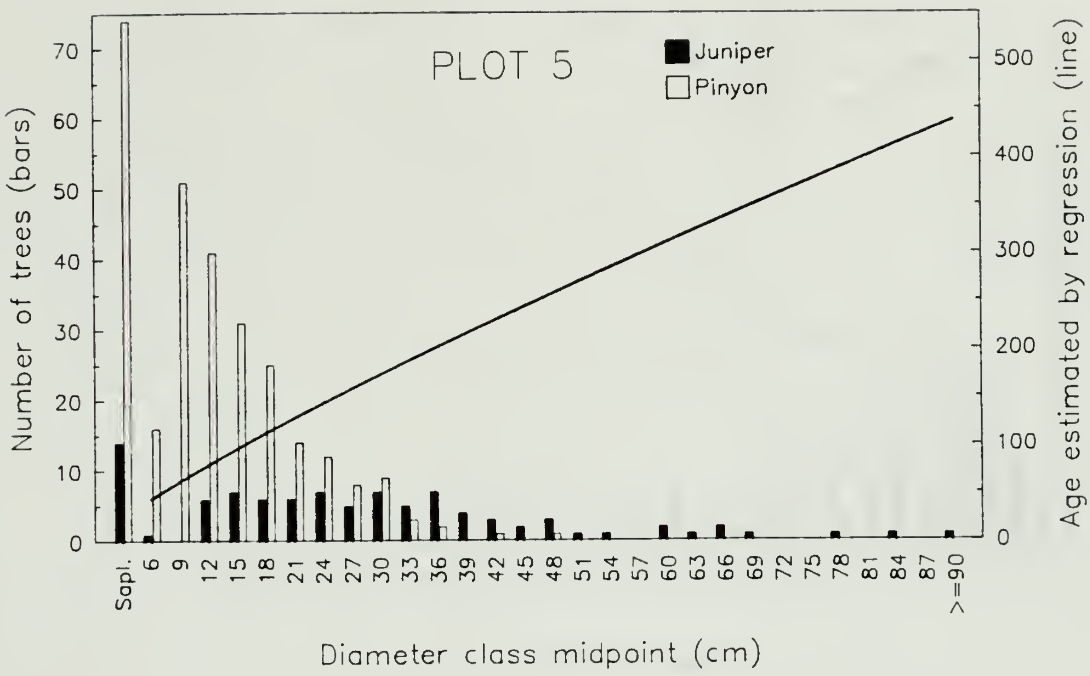

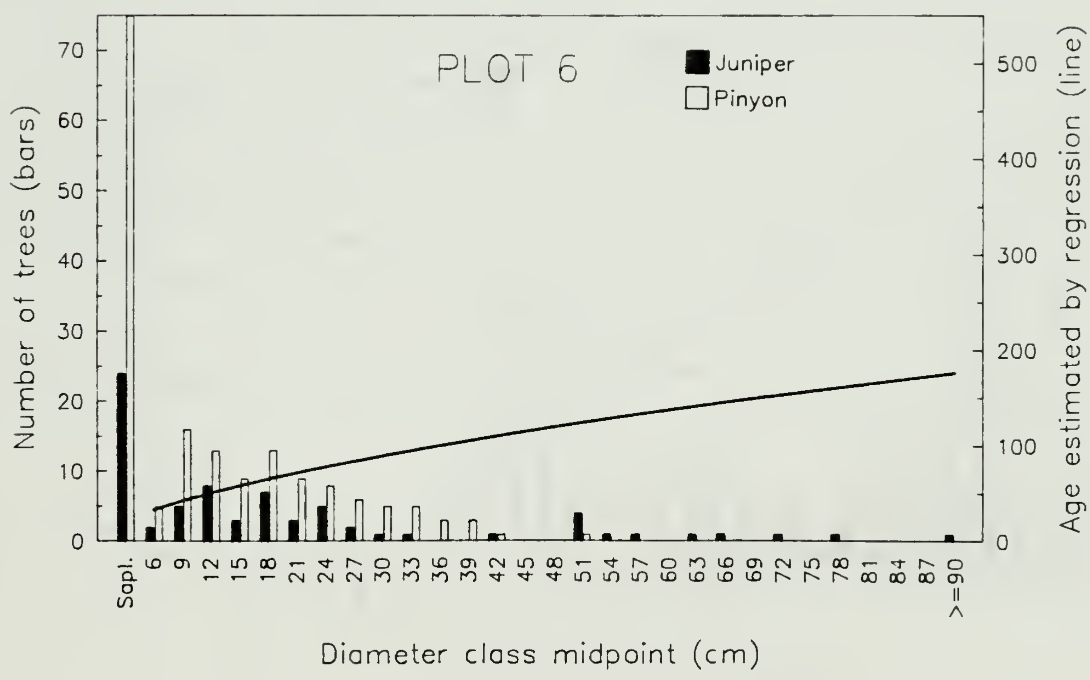

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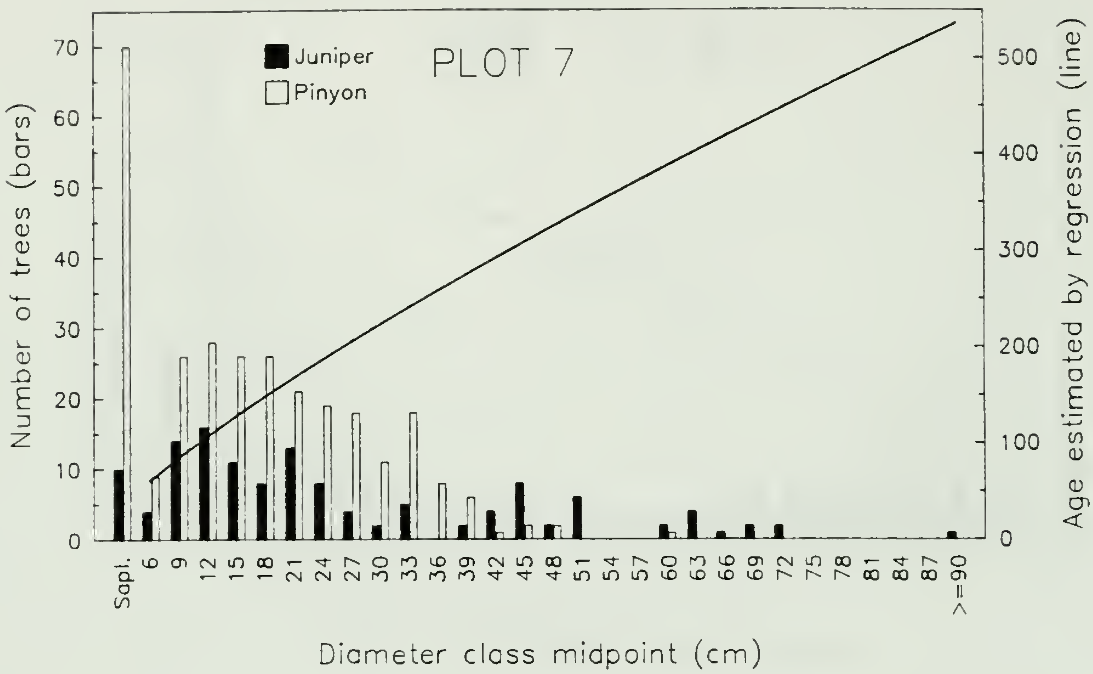

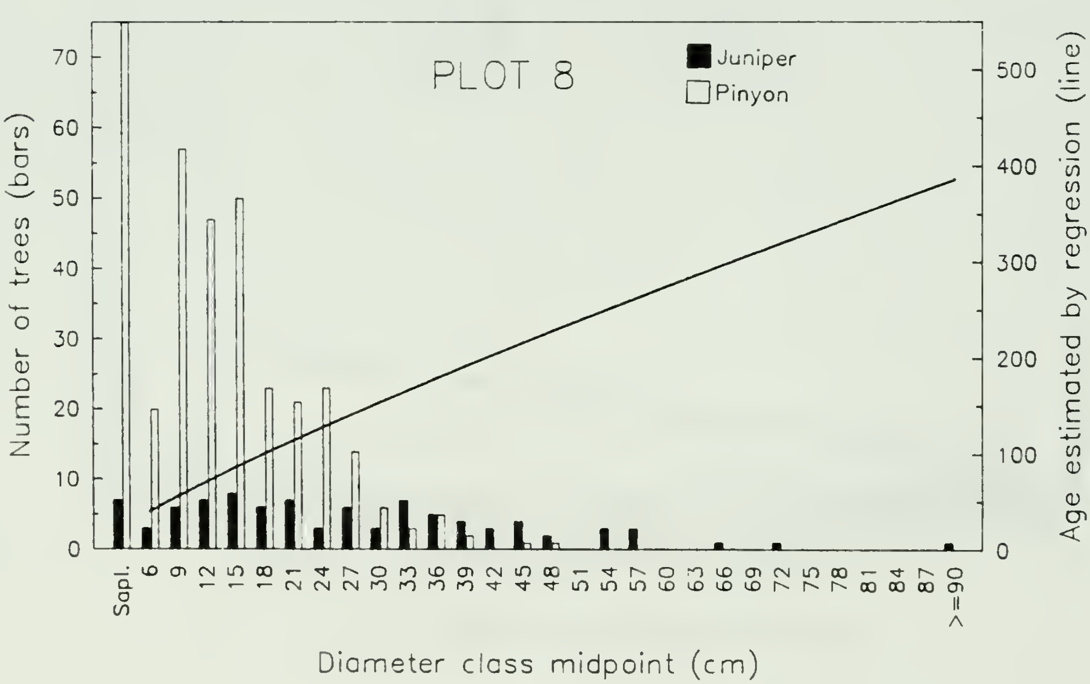

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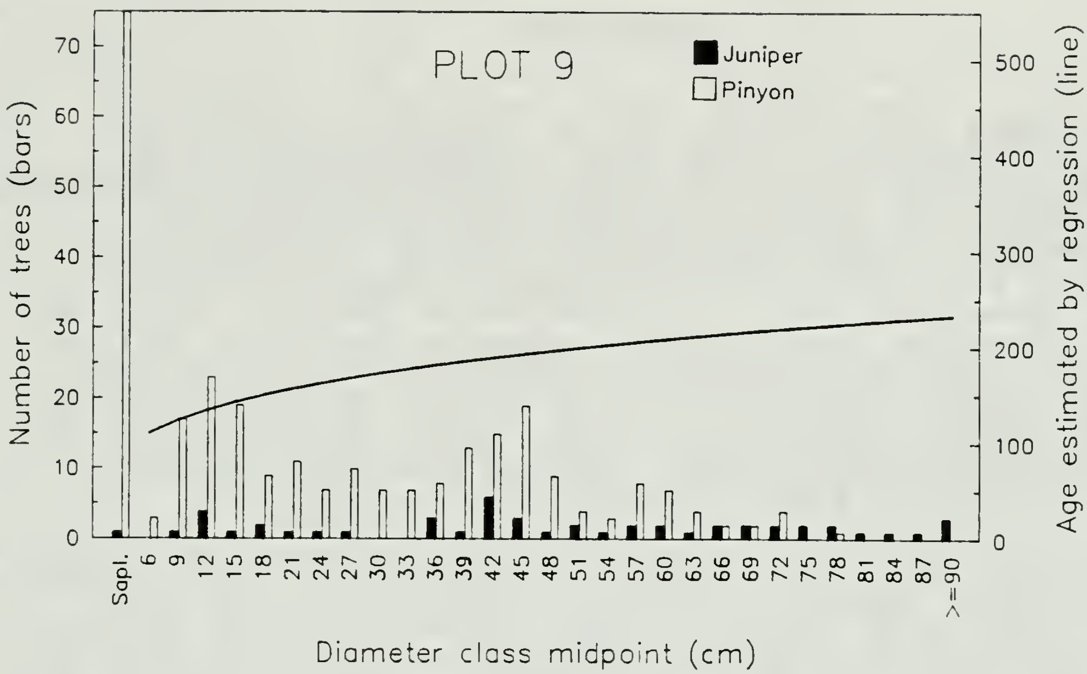


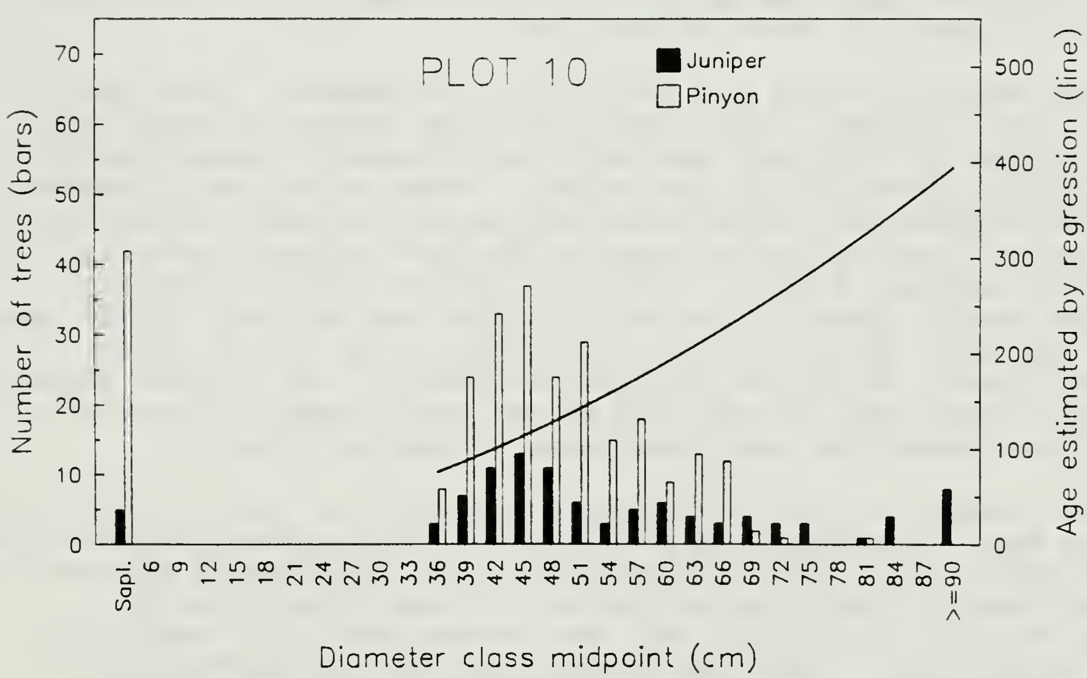


Figure 2 (continued).

DISCUSSION

Too few burned junipers were datable to rigidly define the pattern and frequency of past fires within pinyon-juniper woodlands at WACA. Also, stand size structure does not describe age structure with sufficient accuracy to develop a clear understanding of stand establishment history. However, two assumptions are tenable from this study. First, fire has occurred throughout most of the study area, probably within the past two centuries in all cases. Probable fire dates include 1804, 1832, 1862 and sometime following 1880. Only in the immediate vicinity of Plot 1 and in the area of Plots 9 and 10 was no evidence of past fires found. Second, fires generally were not stand replacing crown fires as might be expected to occur under present stand and understory conditions.

Fires may have been more frequent than dead snags alone suggest if ground fires occurred with little impact on the overstory. Although fires were not as frequent in the study area as they were in ponderosa pine stands elsewhere in WACA (Swetnam et al. 1990), fire apparently played a significant role in the pinyon-juniper woodlands based on the ubiquity of burned remnants. We speculate that the close proximity of the study area to frequently burned ponderosa pine stands may have made the woodland studied more susceptible to fire than similar pinyon-juniper woodlands at lower elevations.

Size class structure and the scarcity of senescent trees and decaying logs suggests that pinyon-juniper stands in WACA were much more open in the past and have only recently developed to their current dense and closed state. Under more open canopies, understory vegetation would have been more abundant, which may have allowed fires to carry through the area without greatly affecting overstory trees. Such a situation would plausibly agree with early observations by Phillips and Mulford (1912) who stated, "Surface fires are the most common, but crown fires sometimes occur" in pinyon-juniper woodlands. We suspect these fires would have been patchy and would have created a mosaic of varying tree densities and herbaceous understory yields.

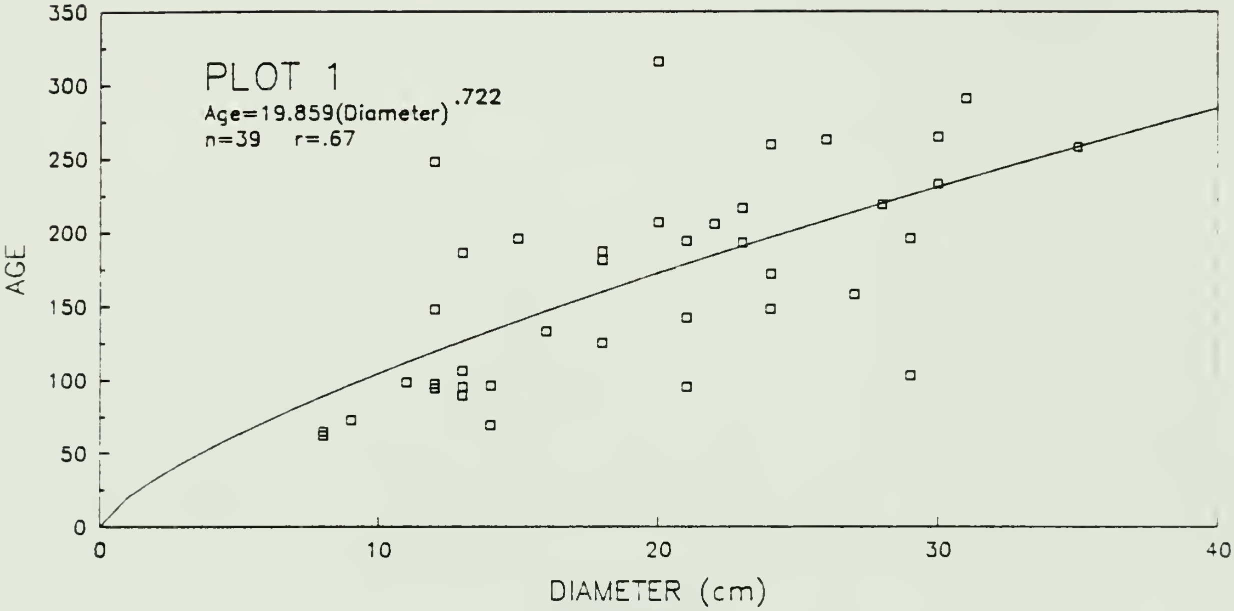
The oldest trees on the study area originated at least more than 400 years ago. Assuming the woodland was much more open when the area was inhabited by the Sinaguas (if not practically denuded by the significant population estimated to have lived there), woodland stands in the area may have never been in a condition similar to today's. Although present stands may be "natural" under current conditions, these woodlands do not appear to represent historical conditions.

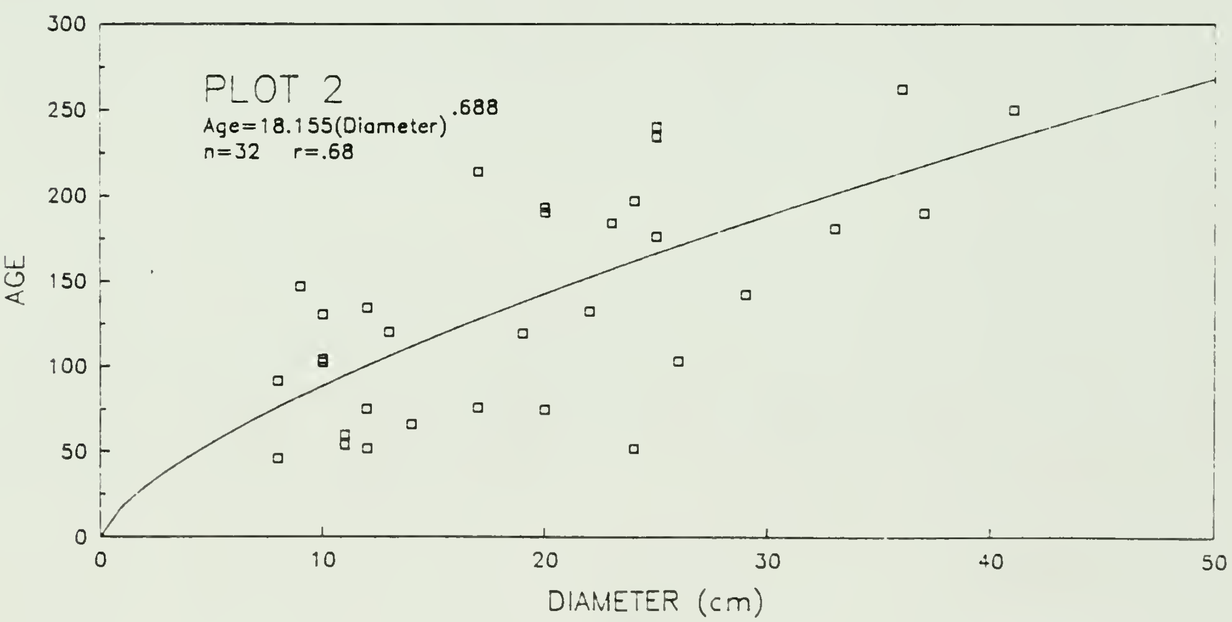
An active program of prescribed fire management is not feasible in pinyon-juniper stands in WACA because of the relatively small size of the stands and the lack of understory fuels to carry small, manageable fires (Arnold 1964; Despain 1987). Any significant fire would likely be an intensive crown fire which would endanger other aspects of WACA as well as adjacent lands. Physical management of stands through selective cutting may be a potential alternative for recreating woodland conditions under which prescribed fire would be practicable in the future, if this is desired as a management objective.

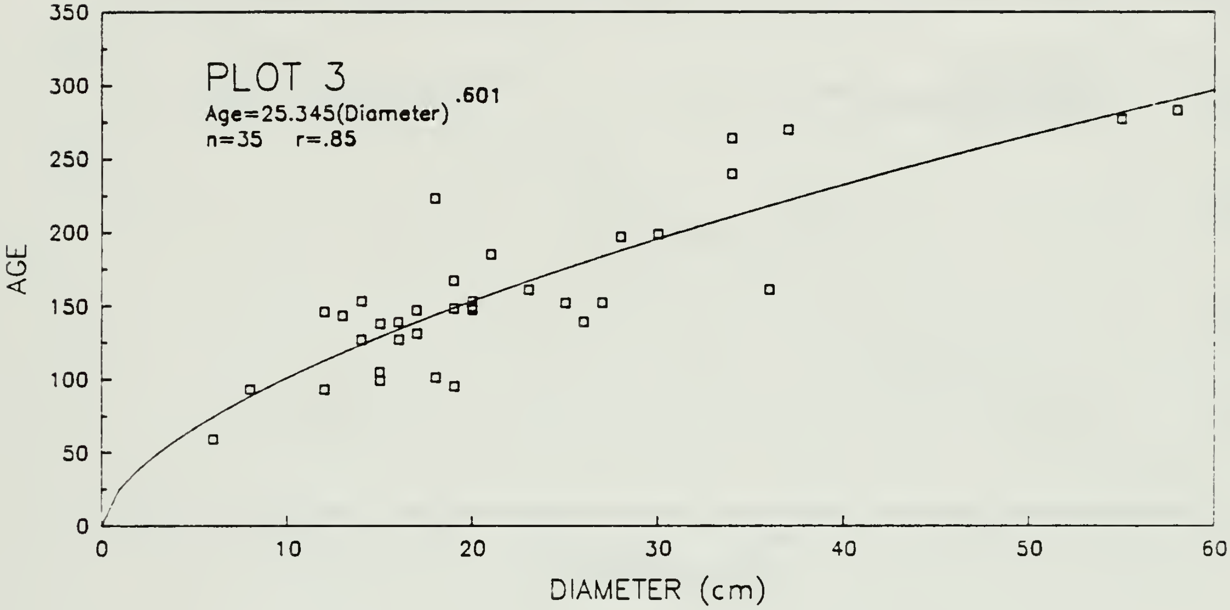
We suggest that future research to clarify the historical role of fire in pinyon-juniper woodlands in the Southwest should concentrate along two lines. First, areas where juniper is cross-dated more readily should be studied using traditional techniques of matching fire dates among burned samples. For example, Utah junipers in the Four Corners region are more successfully cross-dated than in other areas of the Southwest. Second, for those areas where juniper is not readily datable, we suggest approaching fire history of woodlands on a regional basis, such as along the Grand Canyon corridor of woodlands across northern Arizona. Burned samples could be collected from throughout the region until sufficient datable samples were found to develop probability estimates of past fire frequency. Those years during which past fires in the pinyon-juniper type were common throughout the region could also be identified.

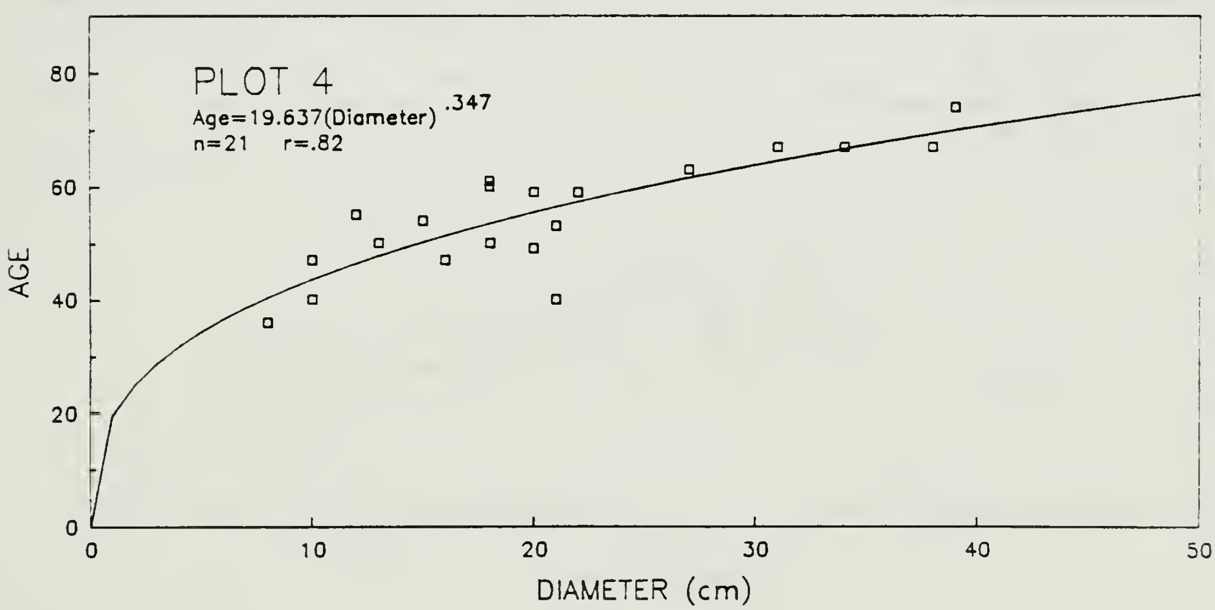
APPENDIX

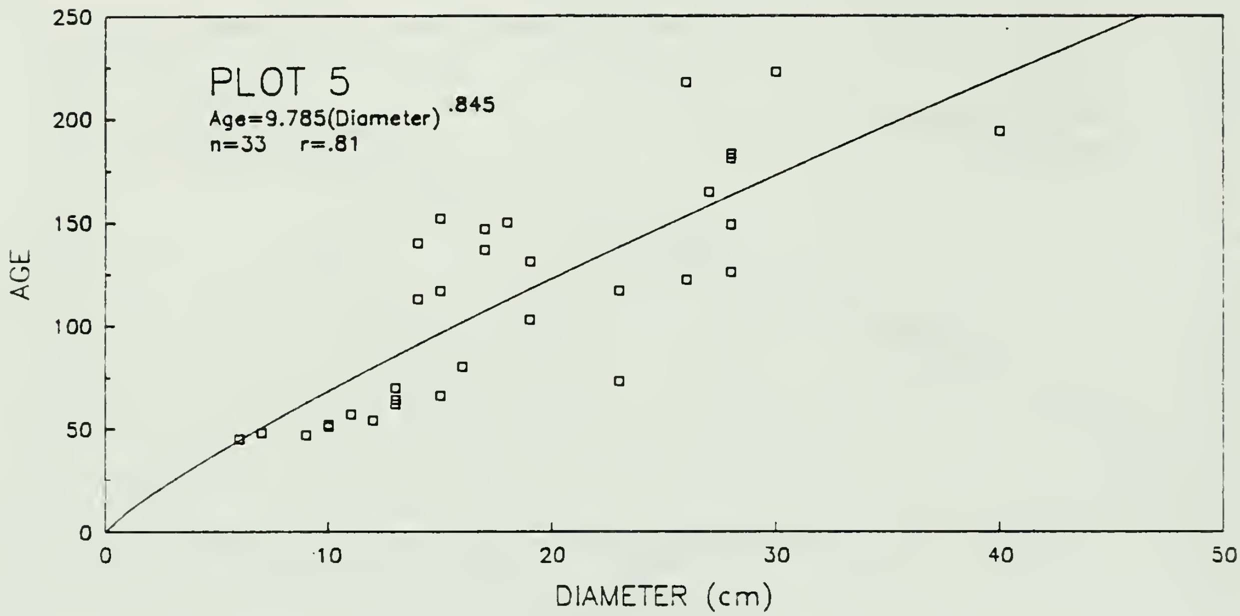
Regressions of age with diameter of pinyons at 10 locations in WACA

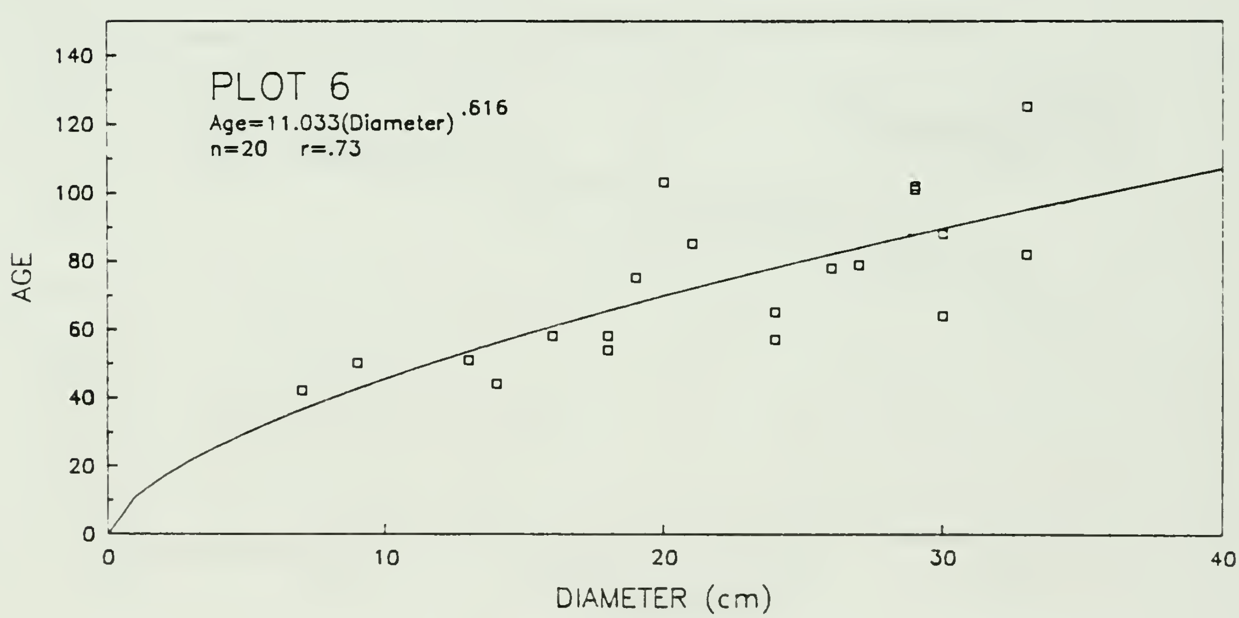

PLOT 1
Age=19.859(Diameter)^.722
n=39 r=.67
AGE
DIAMETER (cm)

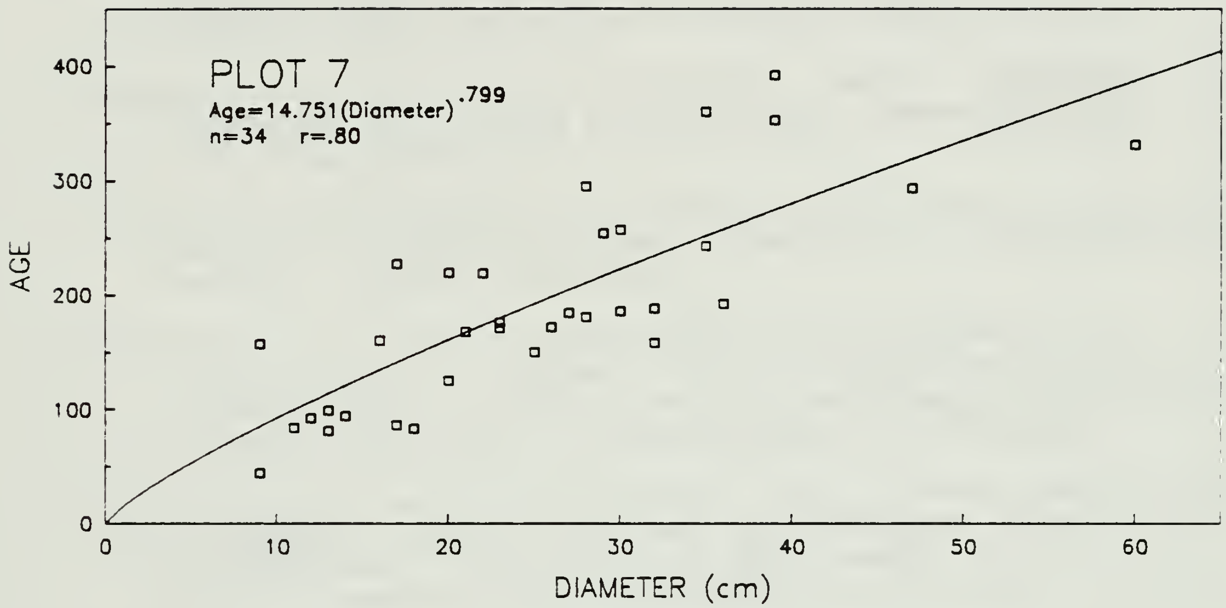

PLOT 2
Age=18.155(Diameter)^.688
n=32 r=.68
AGE
DIAMETER (cm)

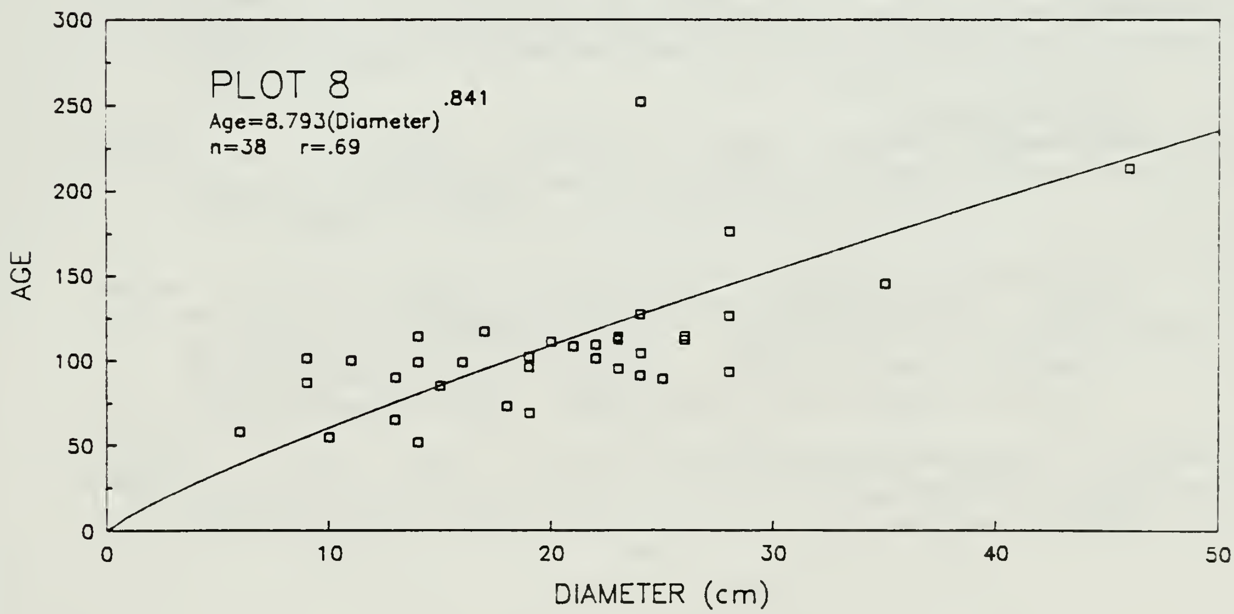

PLOT 3
Age=25.345(Diameter) .601
n=35 r=.85
AGE
DIAMETER (cm)
0
50
100
150
200
250
300
350
0
10
20
30
40
50
60

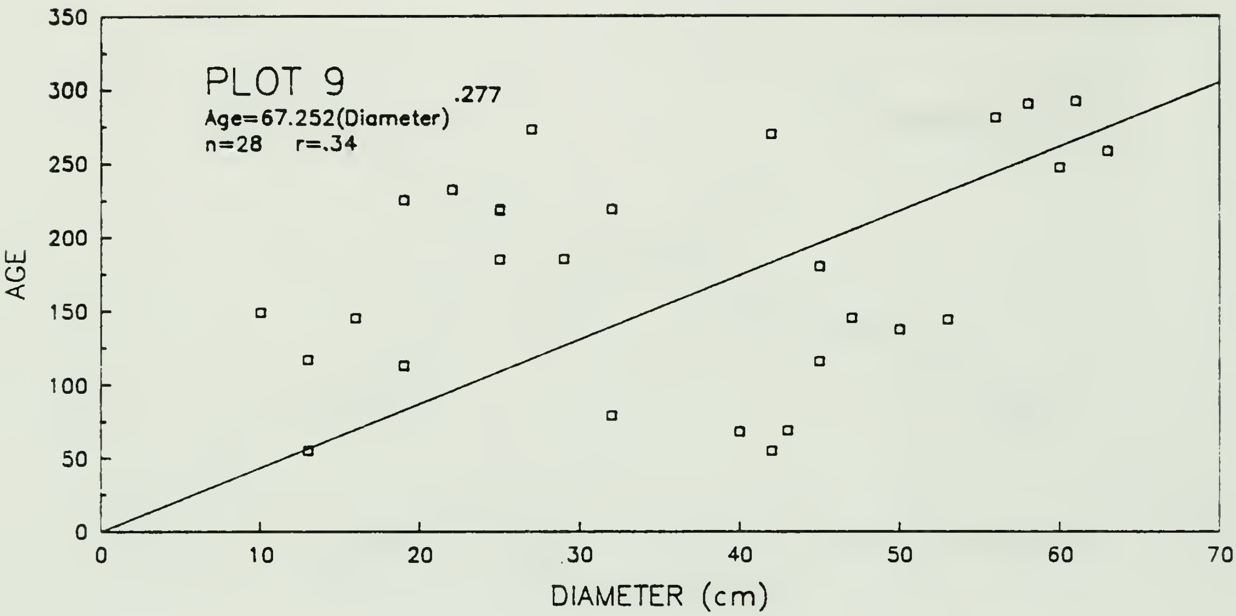

PLOT 4
Age=19.637(Diameter) .347
n=21 r=.82
AGE
DIAMETER (cm)
0
20
40
60
80
0
10
20
30
40
50

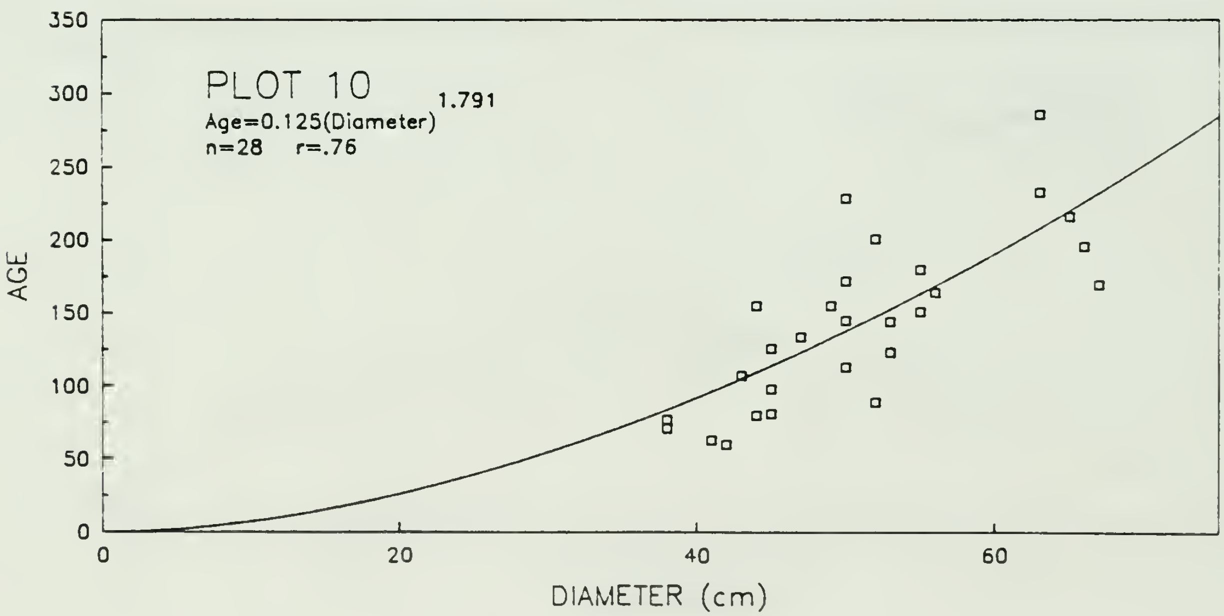

PLOT 5
Age=9.785(Diameter)^.845
n=33 r=.81
AGE
DIAMETER (cm)
0
50
100
150
200
250
0
10
20
30
40
50


PLOT 6
Age=11.033(Diameter)^.616
n=20 r=.73
AGE
DIAMETER (cm)
0
20
40
60
80
100
120
140
0
10
20
30
40


PLOT 7
Age=14.751(Diameter)
.799
n=34 r=.80
AGE
DIAMETER (cm)
400
300
200
100
0
0
10
20
30
40
50
60


PLOT 8
Age=8.793(Diameter)
.841
n=38 r=.69
AGE
DIAMETER (cm)
300
250
200
150
100
50
0
0
10
20
30
40
50


PLOT 9
Age=67.252(Diameter).277
n=28 r=.34
AGE
DIAMETER (cm)
0
50
100
150
200
250
300
350
0
10
20
30
40
50
60
70


PLOT 10
Age=0.125(Diameter)1.791
n=28 r=.76
AGE
DIAMETER (cm)
0
50
100
150
200
250
300
350
0
20
40
60

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