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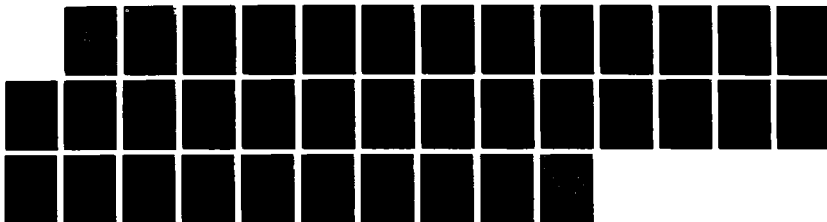
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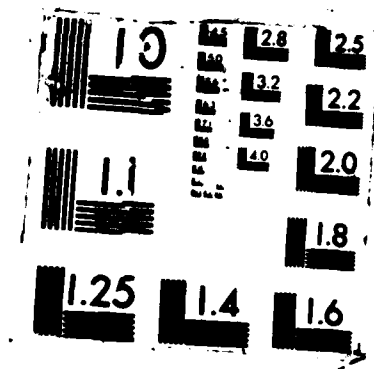
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June 1987

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Growth Rate of Pinyon Pine (Pinus Edulis) on Fort Carson and Piñon Canyon Maneuver Site, Colorado

by
Victor E. Diersing
David J. Tazik
Edward W. Novak

Pinyon Pine trees are extremely important as a concealment resource for military training exercises on Fort Carson and Piñon Canyon Maneuver Site, Colorado. However, during extensive and continued maneuver training, many of these trees are severely damaged or destroyed to the point where the woodlands may not be self-sustaining.

As a first step in determining the need for a reforestation program, this study was done to determine the time required to grow replacement trees to the height necessary to provide concealment for tracked vehicles. Age-growth prediction equations were developed and the age structure of the current Pinyon Pine population was determined.

Results from three sample sites on the training lands indicated that the trees take an average of 42, 73, and 87 years, respectively, to grow to the height of an M60 tank. The age structure analysis indicated that few replacement trees are established naturally. Due to the slow growth rate and low natural regeneration capability of Pinyon Pine, it is recommended that means for minimizing tree losses should be fully exercised and that changes in population density, foliar cover, and age composition should be monitored.

This study design may be useful in solving similar problems on other installations.

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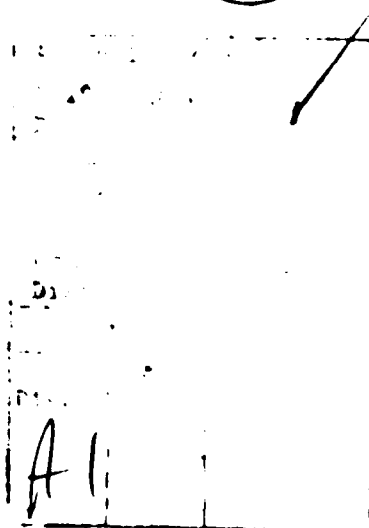
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FOREWORD

This project was conducted for the Office of the Assistant Chief of Engineers (OACE) Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project (OMA funds) FAD No. 001126 dated 25 June 1985, "Condition and Trend Analyses." The work was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (USA-CERL). The HQUSACE Technical Monitor was Mr. Donald Bandel, DAEN-ZCF-B.

The tree age, tree height and bole diameter data were collected by Marvin Stokes and other staff of the Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona, under contract DACA88-85-M-0480. Appreciation is extended to Thomas Warren and David Thomas (Director and Range Conservationist, respectively, of Environment, Energy and Natural Resources, Fort Carson Directorate of Engineering and Housing) for allowing all field personnel access to the training lands they manage. We thank Robert Hill for his valuable assistance during the field data collection on the Piñon Canyon Maneuver Site.

Dr. R. E. Jain is Chief of USA-CERL-EN, COL Norman C. Hintz is the Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.



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GROWTH RATE OF PINYON PINE (PINUS EDULIS) ON FORT CARSON AND PINON CANYON MANEUVER SITE, COLORADO

1 INTRODUCTION

Background

U.S. Army troops training in semiarid regions of the western United States require concealment as part of a realistic training program. Much of the concealment in this region is provided by vegetative cover, particularly trees. On Fort Carson and the Piñon Canyon Maneuver Site in Colorado, this concealment is provided largely by pinyon pine (Pinus edulis). During extensive and continued tracked vehicle maneuver training, many of these trees are inadvertently run over and crushed. Others are cut for camouflage. Under these conditions, the woodlands may not be self-sustaining, and a supplemental reforestation program may have to be initiated. However, before such a program can be planned, the time required to grow replacement trees must be documented.

Objective

The objectives of this study were to: (1) develop growth rate prediction equations for pinyon trees growing on Fort Carson and the Piñon Canyon Maneuver Site (PCMS); (2) calculate the number of years required to produce trees of the minimum height necessary to provide useful concealment for tracked vehicles; and (3) present data on the age structure of the current population.

Approach

Study plots were established within two areas on Fort Carson and one on PCMS where pinyon trees were growing. Random sampling (coring) within these plots yielded the age information, and the measurement of tree height and bole diameter yielded the growth rate equations.

Scope

It is not the scope of this report to discuss the rate of loss of pinyon trees due to maneuver damage but only to document their growth rate.

Mode of Technology Transfer

Fort Carson natural resource personnel will use these data to develop procedures for sustaining the availability of pinyon pine woodlands. This study design can be used to solve similar problems on other installations.

2 GENERAL SITE DESCRIPTION

Fort Carson and Piñon Canyon Maneuver Site

Fort Carson is located along the interface of the Great Plains and Rocky Mountains in central Colorado. The installation is largely limited to El Paso County with its southern limits extending slightly into Pueblo and Fremont counties. Fort Carson encompasses about 55,785 ha; its north-south length is nearly 39 km, and its greatest width is about 24 km. The eastern side of the installation is characterized by gently to moderately sloping grasslands with relatively low relief. The western portion of the installation has wooded foothills, steep and rocky slopes, and higher elevations. The highest elevation on the post is 2121 m on a ridge near State Highway 115; its lowest elevation is 1560 m in the Beaver Creek Valley on the southeastern corner. Intermittent streams on Fort Carson generally flow from northwest to southeast. Turkey Creek flows through the center of the installation and enters the Arkansas River south of the post. Rock Creek and Little Fountain Creek flow through the northern part of Fort Carson and enter the south-flowing Fountain Creek just east of the installation. Fort Carson has cool summers and cold winters. The average annual temperature is about 23°C with an average annual humidity of 54 percent. Prevailing winds are from the north. Mean annual precipitation is about 38.0 cm, with slightly higher averages to the west and north and slightly lower averages to the south and east. Slightly more than 80 percent of the total annual precipitation is received from April through September.

Piñon Canyon Maneuver Site, which encompasses about 98,785 ha, is located entirely within Las Animas County in the high plains of southeastern Colorado. Topographically, the parcel slopes gently to the southeast, culminating in the Purgatoire River (Arkansas River drainage), which serves as the parcel's eastern boundary. This slope is interrupted by mesas and deep canyons. Mean annual precipitation is about 33.5 cm, and the elevation varies from about 1311 m to 1800 m. Historically, the parcel has been used for cattle grazing, with military training beginning in 1985. Piñon Canyon contains two major vegetation types: shortgrass prairie interspersed with varying densities of cholla and yucca, and pinyon-juniper woodland.

Study Sites

Random-collection grids were established in two training areas on Fort Carson (Figure 1) and one on Piñon Canyon Maneuver Site (Figure 2). On Fort Carson, one plot was located immediately to the west of Route 11 in the area known as Buffalo Prairie at grid coordinates 095692, at an elevation of about 1939 m (6360 ft). The site, located in rolling hill country with vegetation consisting of grassland interspersed with patches of pinyon-juniper woodland, is here referred to as the Buffalo Prairie Site. Pinyon pine is the dominant tree species of the woodland. The trees are growing on a bright red-colored soil developed from a red sandstone parent material. The area is extensively used for tracked-vehicle training, and the impact of this activity is overwhelmingly obvious on visual inspection. Twenty or more well-used vehicular trackways can be seen on the plot, and a large proportion of the area has little or no herbaceous vegetation cover left. Very few young trees can be seen, and extensive damage to living trees is obvious. Numerous dead trees which have been pushed over are in evidence. Data were collected on 24 May 1985.

The other Fort Carson site was located about 600 m south of the intersection of Routes 7 and 8 (road junction B8), immediately south of the El Paso-Pueblo County line

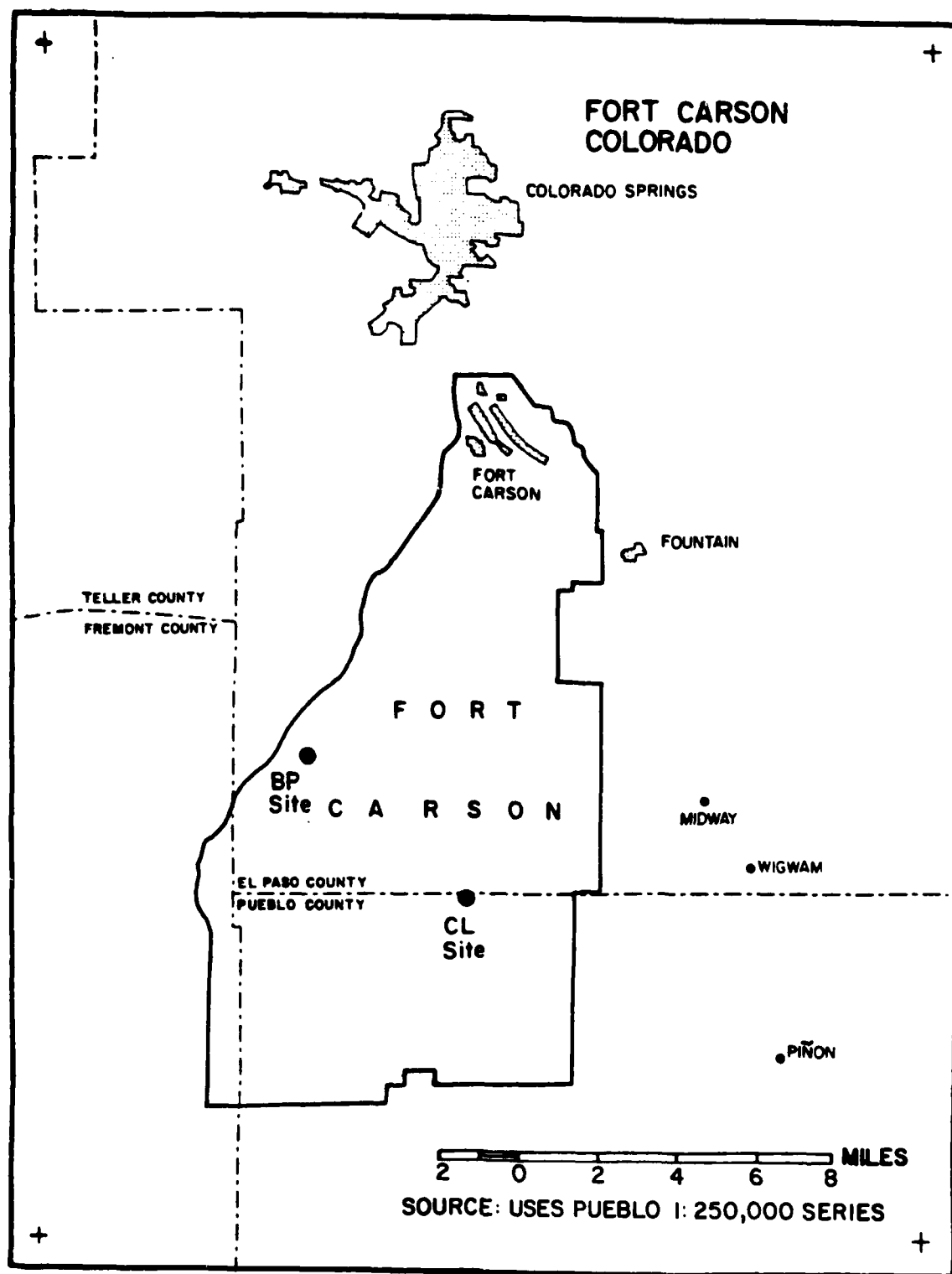


Figure 1. Location of the two study plots on Fort Carson (BP = Buffalo Prairie and CL = County-Line).

in Pueblo County at grid coordinates 176629, at an elevation of 1784 m. It is designated the County-Line Site. This site is in the southeast part of the reservation, also in rolling hill country of grassland interspersed with pinyon-juniper woodland. Pinyon is the dominant tree on the site. The trees are growing on rocky soil developed on light gray sandstone. The general appearance and training impact of this site are very similar to that of the Buffalo Prairie Site. Data were collected on 26 May 1985.

One random-collection site was established at the Piñon Canyon Maneuver Site just south of the radio facility on the pipeline road in the Big Arroyo Hills area. Designated as the Radio Pipeline Site, it is located at grid coordinates 874548, at an elevation of 1683 m. The site is on fairly flat upland and is moderately covered with pinyon-juniper trees and some patches of grassland. Juniper is the dominant tree species, but pinyon is abundant. The trees are growing on a rocky soil developed on light gray limestone. This area has not been used for training and much less human-use impact has occurred here, although wood-cutting activity was noted just off the site. Data were collected on 31 May 1985.

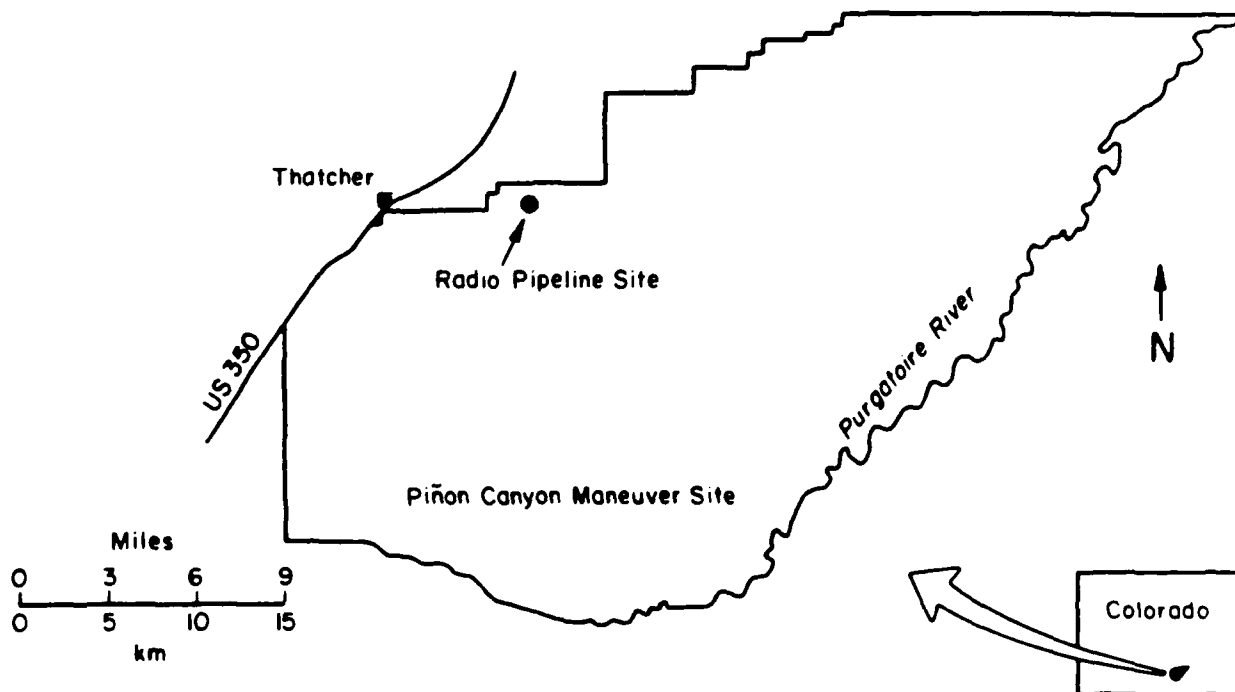


Figure 2. Location of the Radio Pipeline study site on Piñon Canyon Maneuver Site.

3 METHODS

Collection of Increment Cores

Two cores per tree were collected. Ages of the trees were determined by cross dating the tree-ring growth patterns, using the techniques of dendrochronology.¹

Random collection plots (grids) were established at the three sites described in Chapter 2 in order to facilitate population structure analysis by preparation of age-class histograms. Two of these sites were in intensively used areas and one was in an area previously unused for tracked vehicle training.

Cross Dating of Cores

Dendrochronology is the study of variations in the width of tree growth rings in order to establish a precisely dated time series, or chronology, which can be used to date past events or reconstruct environmental conditions which affected tree growth. Precisely dated tree-ring material greatly improves the accuracy of growth rate studies on forest and woodland communities.

The annual rings of trees growing on climatically sensitive sites can be accurately dated by the process of cross dating, or matching the patterns of the sequence of wide and narrow rings from tree to tree.² In semiarid regions, the width of the annual ring is strongly influenced by soil moisture, so that in relatively dry years trees growing on well-drained sites tend to produce a relatively narrow ring. The well-known principle of "limiting factors"³ states that biological processes, like growth, cannot proceed faster than is allowed by the most limiting factor influencing that process.⁴ In semiarid lower forest border sites in the western United States, the factor which is most often limiting to tree growth is precipitation, through its effect on soil moisture availability.⁵ Temperature is sometimes limiting to tree growth, usually through its negative effect on soil moisture. Since all the trees growing on one site experience the same climatic conditions, their relative growth patterns will be similar. It is this climatically controlled growth similarity between trees which makes it possible to accurately cross date the wood, even if the tree is no longer living, and even if some of the trees have missing rings.

Pinyon pine has been shown in previous studies to exhibit excellent cross dating and correlation with climatic variables.⁶ Pinyon often reaches ages of several hundred years

¹A. E. Douglass, "A Method of Estimating Rainfall by the Growth of Trees," *The Climatic Factor*, E. Huntington, Ed., Publ. No. 192 (Carnegie Inst. Wash., 1919); A. E. Douglass, *Climatic Cycles and Tree Growth*, Vols 1 & 2 (Carnegie Inst. Wash., 1919), pp 1-27; M. A. Stokes and T. L. Smiley, *An Introduction to Tree-ring Dating* (University of Chicago Press, Chicago, 1968), pp 1-68.

²M. A. Stokes and T. L. Smiley.

³F. F. Blackman, "Optima and limiting factors," *Ann Botany*, Vol 19 (1905), pp 281-298.

⁴H. C. Fritts, *Tree Rings and Climate* (Academic Press, London, 1976), pp 1-567.

⁵A. E. Douglass, "A Method of Estimating Rainfall by the Growth of Trees"; A. E. Douglass, "Climatic Cycles and Tree Growth"; H. C. Fritts.

⁶E. Schulmen, *Dendroclimatic Changes in Semiarid America* (University of Arizona Press, Tuscon, 1956), pp 1-142.

and is generally datable throughout its range from Utah to Texas, although some of the more arid sites are quite difficult because of the high percentage of missing rings.⁷

Random Sample Plots

Random-collection grids were established in two training areas on Fort Carson (Buffalo Prairie and County-Line). Both grids consisted of 40-m by 100-m plots divided into ten 20-m by 20-m subplots. Three trees from each of the 10 subplots were randomly selected to be sampled, for a total of 30 trees. These trees were sampled near the ground by extraction of a small-diameter core (4.5 mm), using a Swedish increment borer. Tree heights were measured to the nearest decimeter using a stadia rod and diameters were measured at ground level to the nearest 0.1 cm. All 30 cores from the County-Line site, but only 23 of the 30 cores from the Buffalo Prairie Site could be dated.

Due to time and manpower limitations, the grid on the PCMS Radio Pipeline Site was smaller than the Fort Carson grids: 40 m by 40 m, divided into four 20-m by 20-m subplots. Collection was completed essentially the same way as for the Fort Carson sites, except that seven trees from each of the four subplots were selected, giving a sample size of 28 trees. Only 25 of the 28 cores could be dated.

Methods of Data Analyses

Histograms of 20-year age classes were prepared from the tree age data collected from the random samples of trees on the three sites (Figure 3).

Since tree growth typically decreases with age, height-growth relationships are curvilinear. Thus, growth rate regression equations generated from log-transformed data more accurately predict tree growth than straight line regression equations.⁸ Therefore, all age and height data were transformed to their $\log_{10}$ (Tables 1, 2, 3). Height growth rate equations were then generated from the regression of log age vs. log height for trees on each site (Table 4). These equations were used to predict the height of pinyon trees at 50, 75, 100, 125, 150, 175, and 200 years of age (Table 5). The height growth rate equations were then used to compare observed and predicted ages of individual trees on each of the three sites (Table 6).

The relationship between tree age and bole diameter was examined in a similar manner. The bole diameter data were log transformed. Bole diameter growth rate equations were then generated for the trees on each site (Table 7). These equations were used to predict the rate of increase in bole diameter with age for trees on each site (Table 8). The bole diameter growth rate equations were then used to compare observed and predicted ages of trees on each of the three sites (Table 9).

As a final comparison, the trees of all sites ($N = 77$) were pooled and an average height growth rate equation was generated. Pinyon tree growth rate was compared to the known growth rates of other species of common trees in the United States (Figure 4).

The 426-year-old tree from the County-Line Site was omitted from all analyses because its extreme age, short height (5.5 m), and narrow bole (22.8 cm) greatly affected the growth rate equation.

⁷E. Schulmen.

⁸B. Husch, C. I. Miller, and T. W. Beer, *Forest Mensuration* (John Wiley and Sons, New York, 1982), pp 1-289.

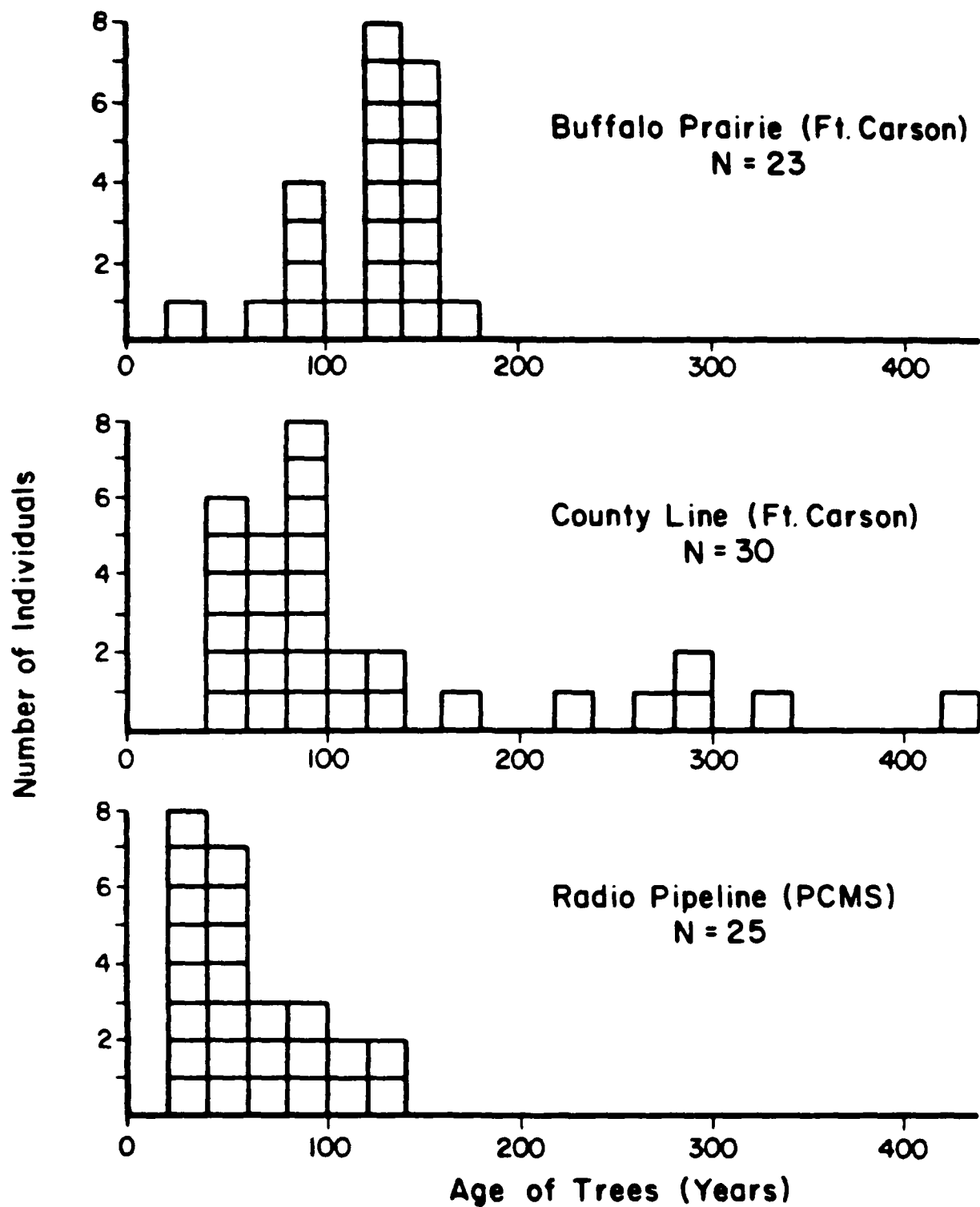


Figure 3. Age class Histogram (20 year intervals) comparing the Age Structure of Pinyon Trees on the Three Study Sites.

Table 1

**Data File for Pinyon Trees on
Buffalo Prairie Site**

Tree Identification Nos.	Tree Height (m)	Tree Diameter (cm)	Tree Age (years)	Log of Tree Height	Log of Tree Diameter	Log of Tree Age
1	6.4	20.9	143	0.806180	1.320146	2.155336
2	5.0	14.9	144	0.698970	1.173186	2.158362
3	5.0	15.1	130	0.698970	1.178976	2.113943
4	6.3	23.4	147	0.799341	1.369215	2.167317
5	5.3	20.5	133	0.724276	1.311753	2.123852
6	5.7	19.4	144	0.755875	1.287801	2.158362
7	5.7	18.6	144	0.755875	1.269512	2.158362
8	6.8	22.5	137	0.832509	1.352182	2.136721
9	5.7	14.4	83	0.755875	1.158362	1.919078
10	6.2	19.6	144	0.792392	1.292256	2.158362
11	2.5	4.5	28	0.397940	0.653212	1.447158
12	4.2	13.6	84	0.623249	1.133538	1.924279
13	4.0	12.2	148	0.602060	1.086359	2.170262
14	4.1	9.5	91	0.612784	0.977723	1.959041
15	4.4	12.2	93	0.643453	1.086359	1.968483
16	5.9	24.7	139	0.770852	1.392696	2.143015
17	5.9	18.1	138	0.770852	1.257678	2.139879
18	5.1	19.5	75	0.707570	1.290034	1.875061
19	6.1	34.7	125	0.785330	1.540329	2.096910
20	6.8	21.5	131	0.832509	1.332438	2.117271
21	6.0	17.6	166	0.778151	1.245512	2.220108
22	5.7	19.2	114	0.755875	1.283301	2.056905
23	7.0	25.3	135	0.845098	1.403120	2.130334

Table 2
Data file for Pinyon Trees on
County-line Site

Tree Identification Nos.	Tree Height (meters)	Tree Diameter (cm)	Tree Age (years)	Log of Tree Height	Log of Tree Diameter	Log of Tree Age
1	3.1	13.5	68	0.491362	1.130333	1.832509
2	6.1	30.3	296	0.785330	1.481442	2.471292
3	7.8	30.9	334	0.892095	1.489958	2.523746
4	7.7	32.7	283	0.886491	1.514547	2.451786
5	2.3	6.9	66	0.361728	0.838849	1.819544
6	4.1	12.1	70	0.612784	1.082785	1.845098
7	4.2	12.3	81	0.623249	1.089905	1.908485
8	5.8	15.3	95	0.763428	1.184691	1.977724
9	4.6	20.8	100	0.662758	1.318063	2.000000
10	4.2	15.7	58	0.623249	1.195899	1.763428
11	3.7	8.5	67	0.568202	0.929418	1.826075
12	6.0	18.4	77	0.778151	1.264817	1.886491
13	2.9	6.5	87	0.462398	0.812913	1.939519
14	5.5	31.6	129	0.740363	1.499687	2.110590
15	1.9	6.9	59	0.278754	0.838849	1.770852
16	4.6	18.3	130	0.662758	1.262451	2.113943
17	1.9	6.2	85	0.278754	0.792391	1.929419
18	3.8	7.2	58	0.579784	0.857332	1.763428
19	3.3	11.2	120	0.518514	1.049218	2.079181
20	4.1	9.3	55	0.612784	0.968482	1.740363
21	1.8	4.0	83	0.255273	0.602059	1.919078
22	1.9	9.0	60	0.278754	0.954242	1.778151
23	2.2	4.5	59	0.342423	0.653212	1.770852
24	4.7	17.3	97	0.672098	1.238046	1.986772
25	5.4	21.6	171	0.732294	1.334453	2.232996
26	5.6	27.8	265	0.748188	1.444044	2.423246
27	4.8	12.8	113	0.681241	1.107209	2.053078
28	3.1	11.4	90	0.491362	1.056904	1.954243
29*	5.5	24.6	426	0.740363	1.390935	2.629410
30	7.4	22.8	239	0.869232	1.357934	2.378398

*Number 29 was omitted from all analyses because of its extreme age.

Table 3
Data File for Pinyon Trees on
Radio Pipeline Site

Tree Identification Nos.	Tree Height (meters)	Tree Diameter (cm)	Tree Age (years)	Log of Tree Height	Log of Tree Diameter	Log of Tree Age
1	1.7	11.9	30	0.230449	1.075546	1.477121
2	2.6	12.6	38	0.414973	1.100370	1.579784
3	3.0	8.3	59	0.477121	0.919078	1.770852
4	3.8	9.9	62	0.579784	0.995635	1.792392
5	0.9	4.7	35	-0.045757	0.672097	1.544068
6	5.9	17.9	127	0.770852	1.252853	2.103804
7	3.4	11.0	135	0.531479	1.041392	2.130334
8	4.3	18.7	115	0.633458	1.271841	2.060698
9	2.4	5.3	42	0.380211	0.724275	1.623249
10	0.5	4.2	34	-0.301030	0.623249	1.531479
11	3.5	12.0	86	0.544068	1.079181	1.934498
12	2.3	3.9	71	0.361728	0.591064	1.851258
13	3.2	12.6	47	0.505150	1.100370	1.672098
14	2.4	15.7	49	0.380211	1.195899	1.690196
15	2.7	4.3	30	0.431364	0.633468	1.477121
16	1.9	8.7	57	0.278754	0.939519	1.755875
17	1.9	6.3	43	0.278754	0.799340	1.633468
18	4.7	12.9	84	0.672098	1.110589	1.924279
19	2.2	3.4	37	0.342423	0.531478	1.568202
20	1.5	9.3	54	0.176091	0.968482	1.732394
21	2.8	12.0	72	0.447158	1.079181	1.857332
22	1.6	5.1	40	0.204120	0.707570	1.602060
23	3.8	18.4	107	0.579784	1.264817	2.029384
24	2.5	4.9	93	0.397940	0.690196	1.968483
25	2.5	4.9	24	0.397940	0.690196	1.380211

Table 4

**Age-Height Growth Rate Equations Generated from Trees
Sampled on the Three Study Sites (Tables 1, 2, 3)**

Site	Sample Size	Growth Rate Equation	R ² *	Significance
Buffalo Prairie Equation	23	Log height = -0.249 + (0.473) (Log age)	0.59	0.001
County-Line Equation	29	Log height = -0.523 + (0.556) (Log age)	0.47	0.001
Radio Pipeline Equation	25	Log height = -0.779 + (0.667) (Log age)	0.37	0.001

*Coefficient of Determination (R²) corrected for degrees of freedom.

Table 5

**Predicted Height of Pinyon Trees on
the Three Study Sites**

Site	Tree Height (Meters) at Ages . . .						
	50 yrs	75 yrs	100 yrs	125 yrs	150 yrs	175 yrs	200 yrs
Buffalo Prairie	3.59	4.34	4.98	5.53	6.03	6.49	6.91
County-Line	2.64	3.32	3.89	4.40	4.86	5.30	5.72
Radio Pipeline	2.26	2.96	3.59	4.17	4.71	5.21	5.70

Table 6

Comparison of Observed and Predicted Ages of Individual
Trees Based on Tree Height Equations in Table 4

Buffalo Prairie			County-Line			Radio Pipeline		
Height (m)	Observed Age	Predicted Age	Height (m)	Observed Age	Predicted Age	Height (m)	Observed Age	Predicted Age
2.5	28	24	4.1	55	108	2.5	24	58
5.1	75	107	4.2	58	110	2.7	30	65
5.7	83	137	3.8	58	96	1.7	30	33
4.2	84	69	2.2	59	36	0.5	34	5
4.1	91	65	1.9	59	28	0.9	35	13
4.4	93	76	1.9	60	28	2.2	37	48
5.7	114	137	2.3	66	39	2.6	38	62
6.1	125	154	3.7	67	92	1.6	40	30
5.0	130	102	3.1	68	67	2.4	42	55
6.8	131	191	4.1	70	108	1.9	43	39
5.3	133	112	6.0	77	219	3.2	47	84
7.0	135	211	4.2	81	110	2.4	49	55
6.8	137	191	1.8	83	25	1.5	54	27
5.9	138	143	1.9	85	28	1.9	57	55
5.9	139	143	2.9	87	59	3.0	59	76
6.4	143	173	3.1	90	67	3.8	62	109
5.0	144	102	5.8	95	206	2.3	71	51
5.7	144	137	4.7	97	141	2.8	72	69
5.7	144	137	4.6	100	136	4.7	84	150
6.2	144	158	4.8	113	147	3.5	86	96
6.3	147	166	3.3	120	75	2.5	93	58
4.0	148	62	5.5	129	187	3.8	107	109
6.0	166	148	4.6	130	136	4.3	115	131
			5.4	171	181	5.9	127	211
			7.4	239	319	3.4	135	92
			5.6	265	193			
			7.7	283	343			
			6.1	296	225			
			7.8	334	351			

Table 7

**Age-Bole Diameter Growth Equations Generated from the Trees
Sampled on the Three Study Sites (Tables 1, 2, 3)**

Site	Sample Size	Growth Equation	R²*	Significance
Buffalo Prairie	23	Log diameter = -0.424 + (0.803) (Log age)	0.54	0.001
County-Line	29	Log diameter = -0.547 + (0.828) (Log age)	0.56	0.001
Radio Pipeline	25	Log diameter = -0.186 + (0.634) (Log age)	0.30	0.01

*Coefficient of Determination (R²) corrected for degrees of freedom.

Table 8

**Predicted Bole Diameter of Pinyon Trees on the
Three Study Sites**

Tree Bole Diameter (cm) at Ages . . .							
Site	50 yrs	75 yrs	100 yrs	125 yrs	150 yrs	175 yrs	200 yrs
Buffalo Prairie	8.7	12.2	15.2	18.1	21.0	23.8	26.5
County-Line	7.2	10.2	12.8	15.5	18.0	20.4	22.8
Radio Pipeline	7.9	10.0	12.0	13.9	15.7	17.3	18.7

Table 9

Comparison of Observed and Predicted Ages of Individual Trees Based on the
Bole Diameter Equations in Table 7 for Each of the Three Sites

Buffalo Prairie				County-Line				Radio Pipeline			
Diameter (cm)	Observed Age	Predicted Age	Diameter (cm)	Observed Age	Predicted Age	Diameter (cm)	Observed Age	Diameter (cm)	Observed Age	Predicted Age	Diameter (cm)
4.5	28	22	9.3	55	68	4.9	24	4.9	24	24	4.9
19.5	75	136	7.2	58	50	4.3	30	4.3	30	20	4.3
14.4	83	93	15.7	58	127	11.9	30	11.9	30	98	11.9
13.6	84	87	6.9	59	47	4.2	34	4.2	34	19	4.2
9.5	91	56	4.5	59	28	4.7	35	4.7	35	23	4.7
12.2	93	76	9.0	60	65	3.4	37	3.4	37	14	3.4
19.2	114	134	6.9	66	47	12.6	38	12.6	38	107	12.6
34.7	125	279	8.5	67	61	5.1	40	5.1	40	26	5.1
15.1	130	99	13.5	68	106	5.3	42	5.3	42	27	5.3
21.5	131	154	12.1	70	93	6.3	43	6.3	43	36	6.3
20.5	133	145	18.4	77	154	12.6	47	12.6	47	107	12.6
25.3	135	189	12.3	81	95	15.7	49	15.7	49	151	15.7
22.5	137	163	4.0	83	24	9.3	54	9.3	54	66	9.3
18.1	138	124	6.2	85	41	8.7	57	8.7	57	60	8.7
24.7	139	183	6.5	87	44	8.3	59	8.3	59	55	8.3
20.9	143	149	11.4	90	87	9.9	62	9.9	62	73	9.9
19.6	144	137	15.3	95	123	3.9	71	3.9	71	17	3.9
18.6	144	129	17.3	97	143	12.0	72	12.0	72	99	12.0
19.4	144	135	20.8	100	179	12.9	84	12.9	84	111	12.9
14.9	144	98	12.8	113	100	12.0	86	12.0	86	99	12.0
23.4	147	171	11.2	120	85	4.9	93	4.9	93	24	4.9
12.2	148	76	31.6	129	296	18.4	107	18.4	107	194	18.4
17.6	166	120	18.3	130	153	18.7	115	18.7	115	199	18.7
			21.6	171	187	17.9	127	17.9	127	186	17.9
			22.8	239	200	11.0	135	11.0	135	86	11.0
			27.8	265	254						
			32.7	283	309						
			30.3	296	282						
			30.9	334	288						

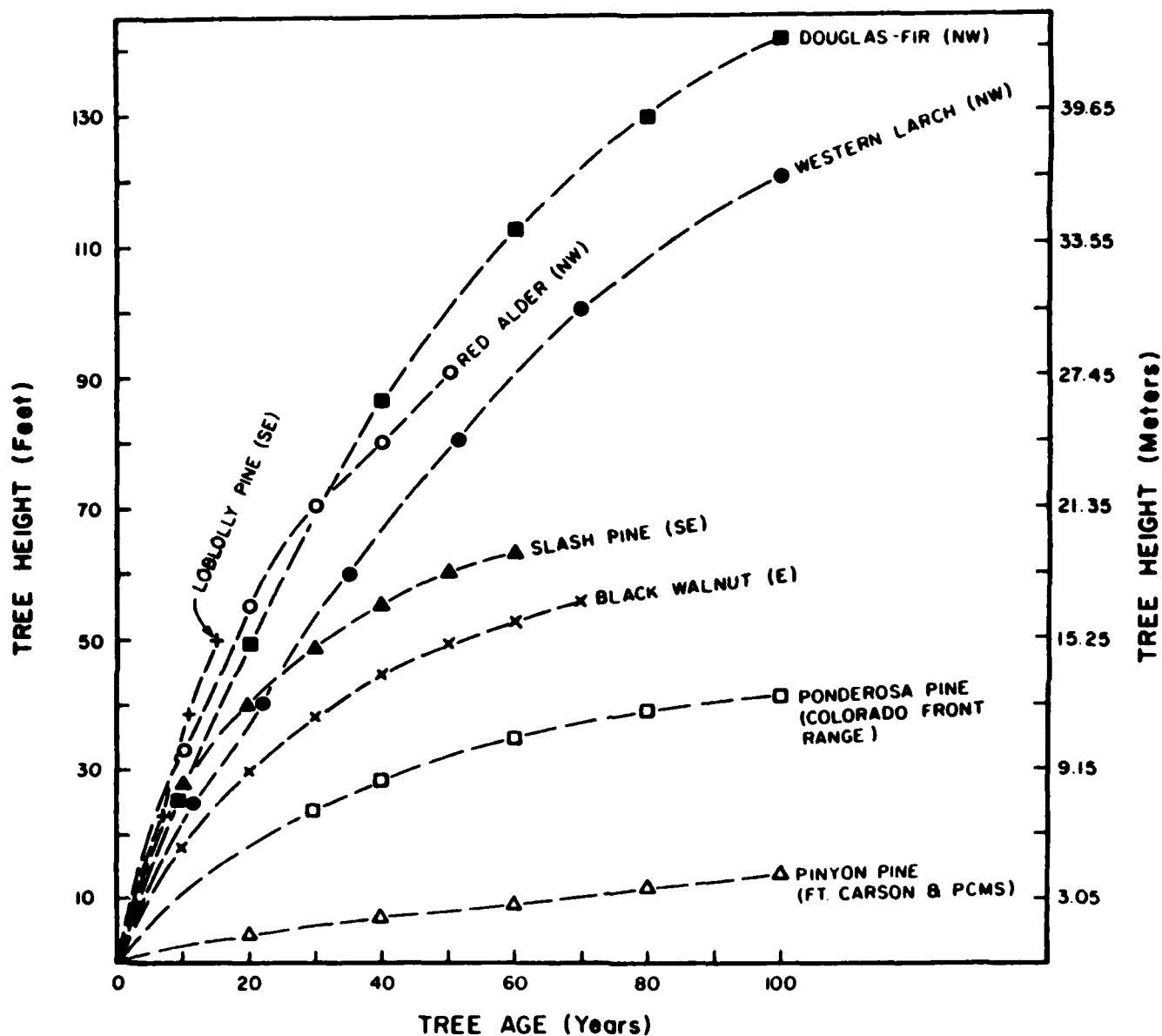


Figure 4. Average growth rates of eight species of common trees (hardwoods and softwoods) illustrating the slow growth of pinyon pine. The abbreviations SE, E, and NW denote the general region of the United States where a particular tree grows.

4 RESULTS

Population Structure

Trees on the Buffalo Prairie Site averaged the tallest (5.5 m), those on the County-Line Site were of medium height (4.3 m), and those on the Radio Pipeline Site were the shortest (2.7 m). Trees averaged the oldest on the County-Line Site (131 years); those on the Buffalo Prairie Site averaged 122 years, and those on the Radio Pipeline Site 63 years.

Age class histograms for trees on the three sites are shown in Figure 3. Most of the trees colonized each site over a period of about 50 to 70 years. The main colonizing period for the Buffalo Prairie Site was about 1820 to 1870, for the County-Line Site about 1880 to 1940, and for the Radio Pipeline Site about 1880 to 1950. Only the County-Line Site shows evidence of an earlier secondary period of pinyon colonization. Six of the 30 trees surveyed on this site (20 per cent) became established between 1560 and 1747. Samples from all sites showed a distinct absence of young trees 1 to 20 years of age.

Age-Height Equations

The relationship of tree height to tree age was analyzed by regression analysis for each of the three study sites. The growth rate equations for trees on each site are given in Table 4. Each site showed a significant relationship ($P < 0.001$) between tree height and tree age.

Using these equations, change in tree height with age on each site is predicted at 50, 75, 100, 125, 150, 175, and 200 years of age in Table 5. Trees on the Buffalo Prairie Site are the tallest at all ages, those on the County-Line Site the second tallest, and those on the Radio Pipeline Site the shortest.

To determine the accuracy of the height equations for predicting tree age, they were used to compare observed and predicted ages of the trees on each of the sites. The predicted age of 31 of the 77 trees (40 percent) was within 25 percent of the observed (actual) age.

Age-Diameter Equations

The relationship of tree bole diameter to tree age was analyzed by regression analysis. The tree age-bole diameter equation for each site is presented in Table 7. There was a significant relationship between tree bole diameter and age for each site: $P < 0.01$ for Radio Pipeline and $P < 0.001$ for other sites.

Using these equations, change in bole diameter with age on each site is predicted at 50, 75, 100, 125, 150, 175, and 200 years of age (Table 8). In agreement with the height-age data, trees on the Buffalo Prairie Site have the widest boles at all ages, those on the County-Line Site the second widest (except at 50 years of age), and those on the Radio Pipeline Site the narrowest (except at 50 years of age).

To determine the accuracy of the bole diameter equations for predicting tree age, the equations were used to compare observed and predicted ages of the trees on each of the sites (Table 9). The predicted age of 38 of the 77 trees (49 per cent) was within 25 percent of the observed (actual) age.

5 DISCUSSION

Population Structure

The age class histograms (Figure 3) show that young trees (0 to 20 years) are absent from each of the three samples. This absence could be attributed to several causes such as (1) insufficient sampling, (2) lack of reproductive success, (3) stands fully stocked, or (4) preferential destruction of younger trees by inadvertent crushing during tracked vehicle maneuvering. Since training had not started on PCMS (Radio Pipeline Site) at the time of this survey, an absence of young trees probably indicates that this stand is nearly fully stocked. On Fort Carson (Buffalo Prairie and County-Line sites), the absence of young trees in the samples is probably because the stands were fully stocked before tracked vehicle maneuvers began and because replacement trees (young trees growing in the place of killed larger trees) have a short life expectancy while the lands are used for maneuver exercises.

Age-Height Equations

The three height prediction equations (Table 4) yielded different growth rates for pinyon pine on the three sites studied. It appears, however, that much of this difference can be attributed to the effect of elevation. Trees from the higher elevations (Buffalo Prairie Site at 1939 m), where rainfall is higher and evapotranspiration rates are lower, take an average of 42 years to grow to the height of an M60 tank. Trees from lower elevations (County-Line at 1784 m and Radio Pipeline at 1683 m) take 73 and 87 years to grow to this height, respectively.

Age-Diameter Equations

As with the age-height relationship, bole diameter of equal age trees is largest at higher elevations (Buffalo Prairie Site) and smallest at the lowest elevations (Radio Pipeline Site). Those from the County-Line Site, at an intermediate elevation, have medium diameter boles.

Pinyon Tree Growth Compared to Other Tree Species

The log-transformed data of the trees on all sites ($N = 77$) were pooled and an average height growth rate equation generated. The equation, $\log \text{ height} = -0.787 + (0.698) (\log \text{ age})$, was used to compare the growth rate of pinyon pine to that of some other common species of the United States (Figure 4). The growth rates of the following species of trees were compared to pinyon pine: loblolly pine (*Pinus taeda*),⁹ Douglas-fir

⁹W. E. Balmer, *Effects of Various Spacings on Loblolly Pine Growth 15 Years After Planting*, USDA Forest Service Res. Note SE-211 (U.S. Department of Agriculture [USDA], Southeastern Forest Exp. Station, 1975), pp 1-6.

(*Pseudotsuga taxifolia*),¹⁰ western larch (*Larix occidentalis*),¹¹ red alder (*Alnus rubra*),¹² slash pine (*Pinus elliottii*),¹³ black walnut (*Juglans nigra*),¹⁴ and ponderosa pine (*Pinus ponderosa*).¹⁵ The growth rate of ponderosa pine is that of trees from the Colorado Front Range in north-central Colorado. For those species where growth rates for various sites (site index curves) were given, the average rate of growth is presented here.

As can be seen in Figure 4, pinyon pine has a much slower growth rate than the other seven species. At 50 years of age red alder, western larch, and Douglas-fir are about 10 times the height of pinyon pine, while slash pine and black walnut are about 6 times taller. Ponderosa pine, which also occurs in limited numbers on Fort Carson, has a slower growth rate than all the other species, except pinyon pine. In regions other than the Front Range, ponderosa pine has a much more rapid growth rate.¹⁶ The most important feature to note from Figure 4, is that it takes less than 15 years for all species other than pinyon pine to grow over 4.5 m (15 ft) in height, whereas pinyon pine takes about 75 to 100 years to grow to this height.

Figure 5 compares the growth rates of three common western conifer trees, illustrating the slow growth rate of pinyon pine. For example, at 60 years of age pinyon pine averages nearly 0.5 m shorter than an M60 tank (3.3 m). At the same age, ponderosa pine is about 11 m tall and Douglas-fir is about 34 m tall.

¹⁰J. E. King, "Site Index Curves for Douglas-fir in the Pacific Northwest," *Weyerhaeuser Forestry Paper*, No. 8 (Weyerhaeuser Forestry Research Center, Centralia, WA, 1966), pp 1-49.

¹¹P. H. Cochran, *Site Index, Height Growth, Normal Yields, and Stocking Levels for Larch in Oregon and Washington*, USDA Forest Service Res. Note PNW-424 (USDA, Pacific Northwest Forest and Range Exp. Station, 1985), pp 1-22.

¹²C. A. Harrington and R. O. Curtis, *Height Growth and Site Index Curves for Red Alder*, USDA Forest Service Res. Pap. PNW-358 (USDA, Pacific Northwest Research Station, 1986), pp 1-11.

¹³F. A. Bennett, *Cubic Yields for Slash Pine in Soil Bank Plantings*, USDA Forest Service Res. Note SE-182 (USDA, Southeastern Forest Exp. Station, 1972), pp 1-5; F. A. Bennett, *Variable-Density Yield Tables for Managed Stands of Natural Slash Pine*, USDA Forest Service Res. Note SE-141 (USDA, Southeastern Forest Exp. Station, 1970), pp 1-4.

¹⁴R. C. Schlesinger and D. T. Funk, *Manager's Hand for Black Walnut*, USDA Forest Service General Tech. Report NC-38 (USDA, North Central Forest Exp. Station, 1976), pp 1-22.

¹⁵G. H. Schubert, *Silviculture of Southwestern Ponderosa Pine: The Status of Our Knowledge*, (USDA, Rocky Mountain Forest and Range Exp. Station, 1974), pp 1-66; E. W. Mogren, "A Site Index Classification for Ponderosa Pine in Northern Colorado," Res. Note 5 (Colorado A&M College, School of Forestry and Range Management, Fort Collins, Colorado, 1956), pp 1-2.

¹⁶G. H. Schubert, pp 1-66.

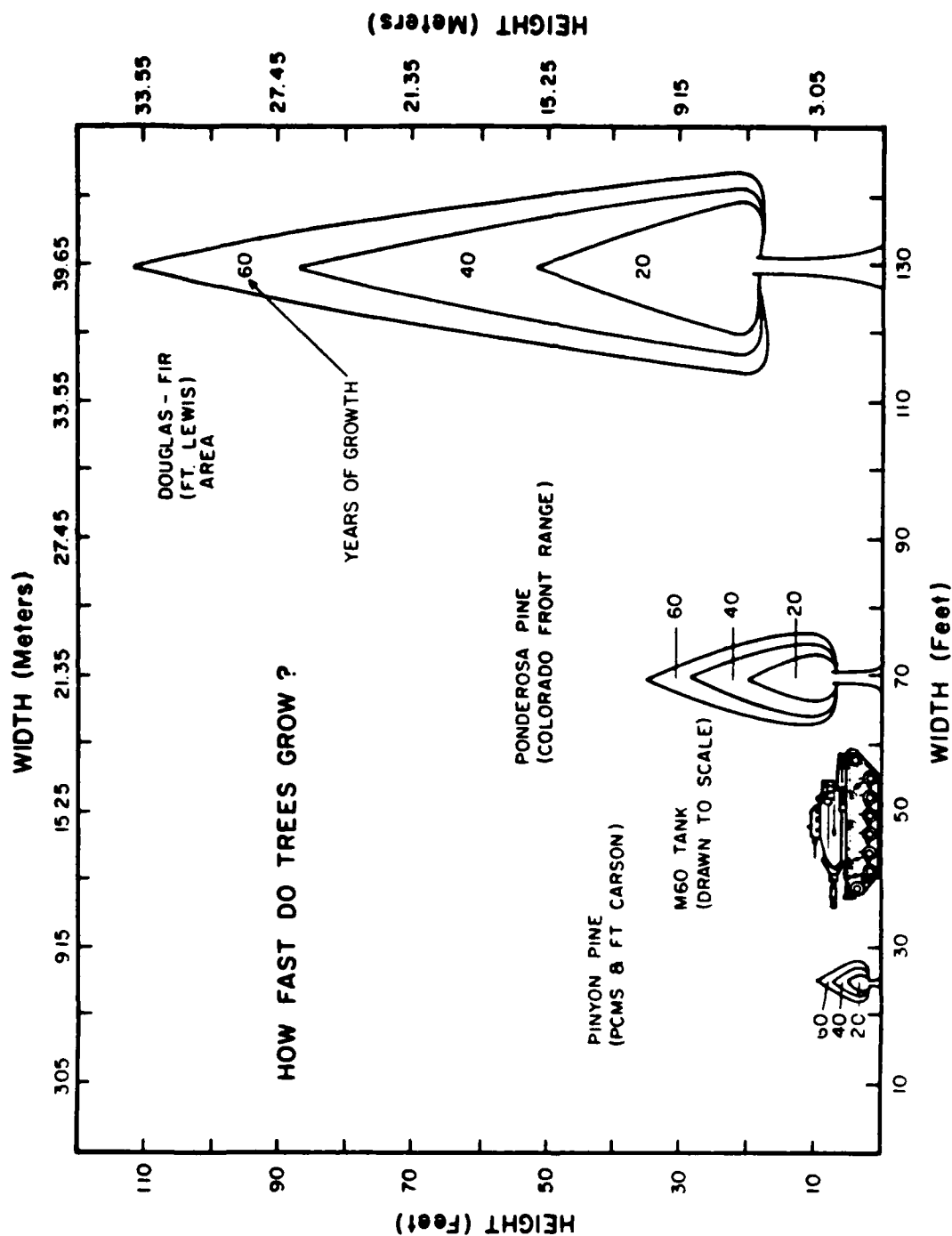


Figure 5. Comparative growth rates of three common conifer trees illustrating the slow growth rate of pinyon pine. Numbers within the figure (20, 40, 60) are years of growth. For example, at 60 years of age pinyon pine averages about one ft shorter than an M60 tank. Width of the trees is approximated and diagrammatic. The main gun of the M60 tank was shortened in the figure.

6 CONCLUSIONS AND RECOMMENDATIONS

Age-growth prediction equations for pinyon pine on Fort Carson and the Piñon Canyon Maneuver Site were developed from trees of known age, height, and bole diameter. Samples of cores collected from trees on three sites yielded an average of 42 years (Buffalo Prairie Site), 73 years (County-Line Site), and 87 years (Radio Pipeline Site) for pinyon pine to grow to the height of an M60 tank (3.3 m). Trees at higher elevations apparently grow faster (taller with wider boles) than those at lower elevations, which is likely in response to increased precipitation and decreased evapotranspiration rates. The age structure of the current population of pinyon pine indicates that few replacement trees are established naturally. Compared to several other species of common trees in the United States (hardwoods and softwoods), pinyon pine is among the slowest growing.

Pinyon pine is unquestionably an integral part of the "realistic" training scenario, providing for tactical concealment as well as stabilizing the soils in training areas. The slow growth of this species, coupled with evidence that natural regeneration is low, places a high premium on maintaining the trees making up the present stand. If means are available for minimizing tree losses, they should be fully exercised. Monitoring of rates of changes in population density, foliar cover, and age composition should be initiated.

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APPENDIX:

HOW TO ESTIMATE THE AGE OF A PINYON TREE OF KNOWN HEIGHT OR BOLE DIAMETER

Equations are provided to estimate the age of pinyon trees when either tree height or bole diameter is known. Estimation of tree age is often necessary to assess damage, interpret stand composition, or identify historically important trees. The three equations provided for calculating tree age generally reflect the regional effect of climate on growth. Tree height is the tallest part of the tree measured in meters, bole diameter is measured at ground level in centimeters.

Trees growing in El Paso County on Fort Carson	use Equation 1
Trees growing in Fremont and Pueblo counties on Fort Carson	use Equation 2
Trees growing on the Piñon Canyon Maneuver Site	use Equation 3

Equation 1a -- Tree height is known. . .

The formula is: $\text{Log age} = \frac{\text{Log height} + 0.249}{0.473}$

Find the log of tree height in Table A1

Add 0.249 to the log of tree height and divide by 0.473

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Equation 1b -- Tree bole diameter is known. . .

The formula is: $\text{Log age} = \frac{\text{Log bole dia.} + 0.424}{0.803}$

Find the log of tree bole diameter in Table A2

Add 0.424 to the log of tree bole diameter and divide by 0.803

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Equation 2a -- Tree height is known. . .

The formula is: $\text{Log age} = \frac{\text{Log height} + 0.523}{0.556}$

Find the log of tree height in Table A1

Add 0.523 to the log of tree height and divide by 0.556

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Equation 2b -- Tree bole diameter is known. . .

The formula is: $\text{Log age} = \frac{\text{Log bole dia.} + 0.547}{0.828}$

Find the log of tree bole diameter in Table A2

Add 0.547 to the log of tree bole diameter and divide by 0.828

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Equation 3a -- Tree height is known. . .

The formula is: $\text{Log age} = \frac{\text{Log height} + 0.779}{0.667}$

Find the log of tree height in Table A1

Add 0.779 to the log of tree height and divide by 0.667

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Equation 3b -- Tree bole diameter is known. . .

The formula is: $\text{Log age} = \frac{\text{Log bole dia} + 0.186}{0.634}$

Find the log of tree bole diameter in Table A2

Add 0.186 to the log of tree bole diameter and divide by 0.634

The product is the log of tree age

Find the log of tree age in Table A3 and read across (left) for tree age

Table A1

**Find Height of Tree in Question and
Read Across (Right) to Determine Log**

Tree Height (m)	Log of Tree Height	Tree Height (m)	Log of Tree Height
1.0	0.000	5.0	0.699
1.1	0.041	5.1	0.708
1.2	0.079	5.2	0.716
1.3	0.114	5.3	0.724
1.4	0.146	5.4	0.732
1.5	0.176	5.5	0.740
1.6	0.204	5.6	0.748
1.7	0.230	5.7	0.756
1.8	0.255	5.8	0.763
1.9	0.279	5.9	0.771
2.0	0.301	6.0	0.778
2.1	0.322	6.1	0.785
2.2	0.342	6.2	0.792
2.3	0.362	6.3	0.799
2.4	0.380	6.4	0.806
2.5	0.398	6.5	0.813
2.6	0.415	6.6	0.820
2.7	0.431	6.7	0.826
2.8	0.447	6.8	0.833
2.9	0.462	6.9	0.839
3.0	0.477	7.0	0.845
3.1	0.491	7.1	0.851
3.2	0.505	7.2	0.857
3.3	0.519	7.3	0.863
3.4	0.531	7.4	0.869
3.5	0.544	7.5	0.875
3.6	0.556	7.6	0.881
3.7	0.568	7.7	0.886
3.8	0.580	7.8	0.892
3.9	0.591	7.9	0.898
4.0	0.602	8.0	0.903
4.1	0.613	8.1	0.908
4.2	0.623	8.2	0.914
4.3	0.633	8.3	0.919
4.4	0.643	8.4	0.924
4.5	0.653	8.5	0.929
4.6	0.663	8.6	0.935
4.7	0.672	8.7	0.940
4.8	0.681	8.8	0.944
4.9	0.690	8.9	0.949
		9.0	0.954

Table A2

**Find bole diameter of tree in question and
read across (right) to determine log**

Tree bole Diameter (cm)	Log of Tree Bole Diameter	Tree Bole Diameter (cm)	Log of Tree Bole Diameter	Tree Bole Diameter (cm)	Log of Tree Bole Diameter
1.0	0.000	14.5	1.161	28.0	1.447
1.5	0.176	15.0	1.176	28.5	1.455
2.0	0.301	15.5	1.190	29.0	1.462
2.5	0.398	16.0	1.204	29.5	1.470
3.0	0.477	16.5	1.217	30.0	1.477
3.5	0.544	17.0	1.230	30.5	1.484
4.0	0.602	17.5	1.243	31.0	1.491
4.5	0.653	18.0	1.255	31.5	1.498
5.0	0.699	18.5	1.267	32.0	1.505
5.5	0.740	19.0	1.279	32.5	1.512
6.0	0.778	19.5	1.290	33.0	1.519
6.5	0.813	20.0	1.301	33.5	1.525
7.0	0.845	20.5	1.312	34.0	1.531
7.5	0.875	21.0	1.322	34.5	1.538
8.0	0.903	21.5	1.332	35.0	1.544
8.5	0.929	22.0	1.342	35.5	1.550
9.0	0.954	22.5	1.352	36.0	1.556
9.5	0.978	23.0	1.362	36.5	1.562
10.0	1.000	23.5	1.371	37.0	1.568
10.5	1.021	24.0	1.380	37.5	1.574
11.0	1.041	24.5	1.389	38.0	1.580
11.5	1.061	25.0	1.398	38.5	1.585
12.0	1.079	25.5	1.407	39.0	1.591
12.5	1.097	26.0	1.415	39.5	1.597
13.0	1.114	26.5	1.423	40.0	1.602
13.5	1.130	27.0	1.431	40.5	1.607
14.0	1.146	27.5	1.439	41.0	1.613

Table A3

Find log of tree age (closest value) and read
across (left) to determine tree age

Tree Age (years)	Log of Tree Age	Tree Age (years)	Log of Tree Age	Tree Age (years)	Log of Tree Age
5	0.699	145	2.161	285	2.455
10	1.000	150	2.176	290	2.462
15	1.176	155	2.190	295	2.470
20	1.301	160	2.204	300	2.477
25	1.398	165	2.217	305	2.484
30	1.477	170	2.230	310	2.491
35	1.544	175	2.243	315	2.498
40	1.602	180	2.255	320	2.505
45	1.653	185	2.267	325	2.512
50	1.699	190	2.279	330	2.519
55	1.740	195	2.290	335	2.525
60	1.778	200	2.301	340	2.531
65	1.812	205	2.312	345	2.538
70	1.845	210	2.322	350	2.544
75	1.875	215	2.332	355	2.550
80	1.903	220	2.342	360	2.556
85	1.929	225	2.352	365	2.562
90	1.954	230	2.362	370	2.568
95	1.978	235	2.371	375	2.574
100	2.000	240	2.380	380	2.580
105	2.021	245	2.389	385	2.585
110	2.041	250	2.398	390	2.591
115	2.061	255	2.407	395	2.597
120	2.079	260	2.415	400	2.602
125	2.097	265	2.423	405	2.607
130	2.114	270	2.431	410	2.613
135	2.130	275	2.439	415	2.618
140	2.146	280	2.447	420	2.623

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