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by

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The author acknowledges the valuable contribution of Robert S. Embry during the establishment and field phases of this study. Embry was formerly assigned to the Station's Research Work Unit at Flagstaff, in cooperation with Northern Arizona University; he is currently Forester, Idaho Panhandle National Forests, Coeur d'Alene, Idaho.

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Contents

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Introduction

Southwestern mixed conifer stands occupy approximately 2.5 million acres in Arizona, New Mexico and southwestern Colorado. About 300,000 acres are in Arizona, which constitute 8% of the commercial forest land in the State (Spencer 1966). Mixed conifer forests are important for water, recreation, wildlife and timber production. Most of the Arizona stands have only recently come under management.

A knowledge of stand growth is vital to forest management. It provides the manager with a measure of past performance, and a tool for designing and planning activities. Davis (1966) states: "Without consideration of growth, a plan of management becomes merely a guide to the installment liquidation of an existing forest crop."

Growth information for virgin southwestern mixed conifer stands and for the component tree species is limited. Greenamyre (1913) conducted an early study of growth-age relationships of ponderosa pine,[2] Douglas-fir and blue spruce in a composite type on the Apache National Forest. Embry and Gottfried (1971b) studied basal growth based on increment cores, in a virgin Arizona stand. Growth data are also scarce for managed stands. Krauch (1945, 1956) working at Cloudcroft, N. Mex., evaluated growth of residual overstory trees on plots harvested by various silvicultural methods. Miller[3] reported residual growth of important tree species in northern New Mexico.

The objective of this study was to provide stand and tree growth, as well as stand structure information from a virgin Arizona mixed conifer stand. The data, although for only a 5-year period, provide an ecological and historical record, especially since most accessible mixed conifer stands have been harvested at least once. The information also provides a basis for comparison with growth changes resulting from various silvicultural treatments in similar stands. The data can also be used to estimate future growth in the preparation of management plans. While the data are most applicable to similar virgin mixed conifer stands (as determined by stand structure, composition, stocking), the lack of any growth data for southwestern mixed conifer forests encourages the use of the information as a "best guess" for managed stands or for stands which have slightly different characteristics. Forest managers have requested such information and can evaluate the local usefulness of this report by comparing our basic stand data with conditions in stands under their management.

The mixed conifer data can be used to develop or validate computer stand simulation models. Avery et al. (1976) published a long-term historical record of growth and stand development in a virgin southwestern ponderosa pine stand designed to provide data for validation of both ecological and management modeling.

Study Area

The study was conducted on the Willow-Thomas Creek area of eastern Arizona, on the Apache-Sitgreaves National Forests, about 20 miles south of Alpine. The two Willow Creek and two Thomas Creek experimental watersheds encompass 1,800 acres of virgin mixed conifer forest. The major species in the uneven-aged stand are: Douglas-fir, ponderosa pine,

[2]Scientific names of trees mentioned are listed in the appendix.

[3]Miller, F. H. 1923. Growth and yield for the important timber species in northern New Mexico. (Unpublished report in the files of the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Ariz.)

Engelmann spruce, blue spruce, white fir, corkbark fir, southwestern white pine and quaking aspen. Douglas-fir is the most common species, while ponderosa pine is the most commercially valuable species.

The undisturbed stand has not had a major forest fire in more than 90 years. Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) and the ponderosa pine dwarf mistletoe (*A. vaginatum* subsp. *cryptopodum* (Engelm.) Hawks. and Wiens) are common in the stand, but most infections tend to be light (Gottfried and Embry 1977). Hawksworth (1961) found no significant differences in radial growth between uninfected and lightly infected trees in a merchantable ponderosa pine stand. We have not studied this relationship in mixed conifer stands.

Average annual precipitation is approximately 29 inches, about 50% of which falls from October through May. An analysis of long-term annual precipitation records from Alpine and Blue, Ariz. (Green and Sellers 1964; Sellers and Hill 1974) indicated that precipitation during the study period was normal.

Elevations on Willow-Thomas Creek range from 8,400 to 9,300 feet; slopes are most frequently 20% but vary from almost level to more than 60%. Forty-seven percent of the aspects are east and southeast. Soils are a stony silty clay loam derived from basalt parent material.

Study Methods

Field and Office Procedures

All growth data were collected by periodic diameter measurement, at breast height (b.h.), of sample trees. Trees were selected around permanent timber inventory points using standard point sampling techniques. A total of 556 sample points were established. Points represent a wide range of sites, species compositions and stand densities. Because they sample the diverse conditions that must be managed, growth estimates from heterogeneous stands are often more credible to land managers than are estimates derived from small homogeneous stands (Bruce 1977).

All trees were selected using a 25 BAF angle gage. The gage was turned clockwise around the point starting from a position along the centerline going to the next highest numbered inventory point. The first "in-tree" to the right of the centerline was recorded as number one, and so forth until the circle was closed. A number-letter code (e.g., "2A") was used to identify and locate new in-trees (ongrowth) during the second inventory. A computer (Stage 1959) and tape were used to check marginal trees. Breast height was permanently marked on all trees, and the diameter measured to the nearest tenth inch using a diameter tape. Any errors in initial diameter measurements were corrected by using increment core measurements and subtracting the 5-year growth from the second diameter measurement. Bark growth was not measured.

Other data were collected from each tree according to the methods developed by Ffolliott and Worley (1965) and Barger and Ffolliott (1970). No height measurements were taken during the second survey. The height-diameter relationships for the area (Embry and Gottfried 1971a) should still be applicable, since height growth generally is not large during a 5-year period. Husch et al. (1972) indicate that such relationships are relatively stable in uneven-aged stands.

The distribution of initial sample trees by species for the stand is shown below:

Species	Number of trees
Engelmann spruce	534
Blue spruce	67
Douglas-fir	1,248
White fir	575
Corkbark fir	132
Ponderosa pine	553
Southwestern white pine	223
Quaking aspen	628
Total	3,960

Tree data were transferred to computer cards, and growth and stand tables were prepared using standard point sampling calculations. The growth terminology and calculations discussed by Grosenbaugh (1958), Beers (1962), and Beers and Miller (1964) were used. For example, initial diameter measurements were generally used to separate data by diameter breast high (d.b.h.) class, and to perform the calculations. Statistical comparisons made in the paper have significance indicated by values above the 5% level.

Several different diameter size class definitions are currently being used in the Southwest. Our results have been summarized by 2-inch diameter size classes using the mid-point value (e.g., the 20-inch class includes all diameters from 19.0 to 20.9 inches). The fine breakdown should allow potential users to manipulate the data (e.g., to create combined size classes) to fit their specific needs. It should allow users to get a clearer picture of growth changes among size classes and to follow the calculations. The tables are generally in terms of trees per acre or basal area (square feet) per acre for this reason. Volume, as board feet or cubic feet per acre, is considered in less detail. Local volume tables could be used with the enclosed stand tables.

Point Sampling vs Fixed Plot Sampling

There have been numerous studies comparing plot and point sampling (Grosenbaugh and Stover 1957, Barrett and Carter 1968). The studies have not demonstrated significant differences between the two techniques; however, Grosenbaugh and Stover (1957) showed that more point samples were necessary to provide the same accuracy as derived from plots.

Point sampling measurements from permanent points were used in the current study. Some authorities, while recognizing the comparability of the two methods for one-time inventories, prefer that repeated stand and growth data be collected from monareal plots (Beers and Myers 1965) of some standard size (i.e., one-tenth acre) or of several acres (Curtis 1976). Beers and Myers (1965) indicate that some of the objections to permanent points include the low sample in the smaller size classes, accounting problems related to on-growth (non-growth) trees, and the non-additivity of initial inventory data, growth, and second inventory data. Despite these objections, Beers and Miller (1964) indicate that permanent points might be a reasonable alternative for the usual permanent plots. Myers (1966) compared various stand and growth parameters derived from repeated measurements from one-fifth-acre plots, from sample points, using a 10 basal area factor, and from a 100% inventory in several mixed hardwood stands. Myers did not find any significant differences (at the 5% level) between the three inventory procedures for the per acre totals or for the species and diameter class breakdowns in terms of trees or basal area. Although the evaluation of average annual basal area net growth estimates indicated some differences for a few d.b.h. classes and species on one site, Myers concluded that one-fifth-acre plots would not offer a consistent advantage over point sampling for growth estimations.

Curtis (1976) suggests that growth data from heterogeneous, uneven-aged stands be collected on large multi-acre plots. It is felt that a well designed system of plots or points should give comparable results but this has not been tested.

Results and Discussion

Initial Stand

The Willow-Thomas Creek watersheds were typical of an undisturbed, multistoried, southwestern mixed conifer stand (fig. 1). Jones (1974) adequately described such stands as a mosaic of groups and patches varying in size. Patch structure can range from single-storied to multistoried, but the overall effect is of a multistoried stand. Species composition throughout the stand is also quite variable. Some sites will contain pure stands (e.g., of ponderosa pine or aspen), while others will contain four or more different species.

Stand tables.—The stand tables for the initial inventory are presented by species in table 1a and in table 1b, which includes the standard errors of the mean for basal area per acre estimates. For convenience, we limited the tables to trees in or less than the 48-inch

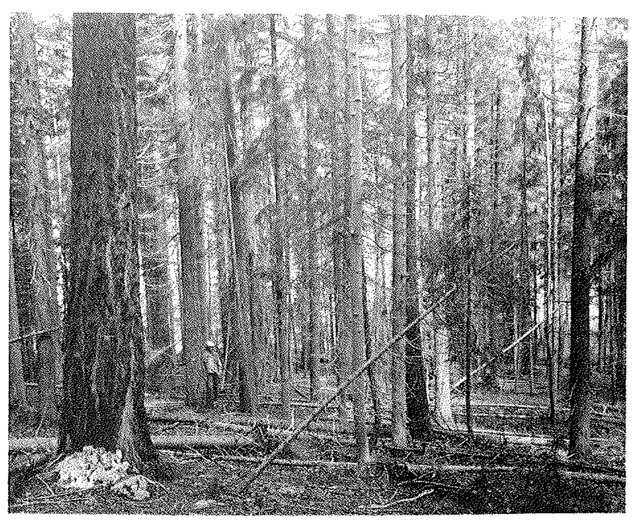

Figure 1.—The Willow-Thomas Creek watersheds contain an undisturbed, multistoried southwestern mixed conifer stand. (Willow Creek East Fork)

Table 1a.—Initial inventory by number of trees per acre.

D.B.H. size class	ES	BS	DF	WF	CF	PP	WP	QA	All species
				Species[1]					
(Inches)									
2	24.73	4.12	63.89	26.79	8.24	18.55	16.49	2.06	164.87
4	11.85	1.55	41.74	17.00	3.61	11.85	6.70	17.52	111.82
6	9.85	0.92	17.40	7.33	2.75	4.81	2.98	27.48	73.52
8	6.31	0.64	9.28	5.28	2.19	1.42	2.06	17.13	44.31
10	5.94	0.74	6.10	1.65	2.06	1.48	1.90	11.71	31.58
12	4.64	0.40	4.69	1.55	1.09	1.43	0.52	3.66	17.98
14	2.65	0.42	3.91	0.88	0.67	1.05	0.88	2.31	12.77
16	1.96	0.19	2.54	1.10	0.42	1.13	0.77	1.29	9.40
18	1.09	0.13	1.86	0.89	0.18	0.97	0.46	0.41	5.99
20	0.64	0.12	1.67	0.70	0.06	1.11	0.23	0.27	4.80
22	0.43	0.10	1.35	0.51	0.07	1.12	0.22	0.14	3.94
24	0.20	0.03	1.25	0.44	0.03	0.72	0.13		2.80
26	0.12	0.01	0.92	0.51	0.01	0.95	0.15	0.01	2.68
28	0.03	0.01	0.64	0.38	0.01	0.32	0.10		1.49
30	0.02		0.41	0.37		0.32	0.06	0.01	1.19
32	0.01		0.33	0.26		0.15	0.06		0.81
34			0.26	0.15	0.01	0.04	0.02		0.48
36	0.01		0.13	0.11		0.04	0.01		0.30
38			0.15	0.10		0.02	0.01		0.28
40			0.07	0.06		[2]T			0.13
42			0.04	0.01			0.01		0.06
44			0.02	0.01			T		0.03
46			0.02						0.02
48			0.01						0.01
Total	70.48	9.38	158.68	66.08	21.40	47.48	33.76	84.00	491.26
%Distrib.	14	2	32	14	4	10	7	17	100

Table 1b.—Initial inventory by basal area (square feet) per acre.

D.B.H. size class	ES	BS	DF	WF	CF	PP	WP	QA	All species
				Species[1]					
(Inches)									
2	0.54	0.09	1.39	0.58	0.18	0.40	0.36	0.04	3.58
4	1.03	0.14	3.64	1.48	0.32	1.03	0.58	1.53	9.75
6	1.93	0.18	3.42	1.44	0.54	0.94	0.58	5.40	14.43
8	2.20	0.22	3.24	1.84	0.76	0.50	0.72	5.98	15.46
10	3.24	0.40	3.33	0.90	1.12	0.81	1.03	6.38	17.21
12	3.64	0.32	3.69	1.21	0.85	1.12	0.40	2.88	14.11
14	2.83	0.45	4.18	0.94	0.72	1.12	0.94	2.47	13.65
16	2.74	0.27	3.55	1.53	0.58	1.57	1.08	1.80	13.12
18	1.93	0.22	3.28	1.57	0.32	1.71	0.81	0.72	10.56
20	1.39	0.27	3.64	1.53	0.14	2.43	0.50	0.58	10.48
22	1.12	0.27	3.55	1.35	0.18	2.97	0.58	0.36	10.38
24	0.63	0.09	3.91	1.39	0.09	2.25	0.40		8.76
26	0.45	0.04	3.37	1.89	0.04	3.51	0.54	0.04	9.88
28	0.14	0.04	2.74	1.62	0.04	1.35	0.45		6.38
30	0.09		2.02	1.80		1.57	0.27	0.04	5.79
32	0.04		1.84	1.44		0.85	0.32		4.49
34			1.66	0.94	0.04	0.22	0.14		3.00
36	0.04		0.90	0.76		0.27	0.09		2.06
38			1.17	0.81		0.18	0.09		2.25
40			0.58	0.50		0.04			1.12
42			0.36	0.14			0.09		0.59
44			0.18	0.14			0.04		0.36
46			0.27						0.27
48			0.09						0.09
Total	23.98	3.00	56.00	25.80	5.92	24.84	10.01	28.22	177.77
Stand. error (±)	1.76	0.61	2.32	1.69	0.83	1.76	0.84	2.19	3.51
%Distrib.	13	2	32	14	3	14	6	16	100

[1]*ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*
[2]*T = Trace*

diameter class, although a few larger Douglas-fir and white fir trees were present. Minor species, such as New Mexican locust, Gambel oak, and willows, were not considered. These trees, generally smaller than 8 inches in diameter, would have added 15.4 trees per acre and 0.7 square foot per acre to the stand table values. Volumes will be discussed later.

Stand structure.—The relationship between number of trees per acre and diameter class for the entire stand (fig. 2) indicates an almost balanced, uneven-aged stand structure (Meyer 1952), when compared to a model using the exponential function:

$$Y = ke^{-ax} \quad a>0 \qquad [1]$$

transformed to the form (Husch et al. 1972):

$$\log Y = \log k - bx \qquad [2]$$

where:

Y = number of trees per diameter class
x = d.b.h. class
b = a $\log_{10} e$
e = base of natural logarithms
a,k = constants

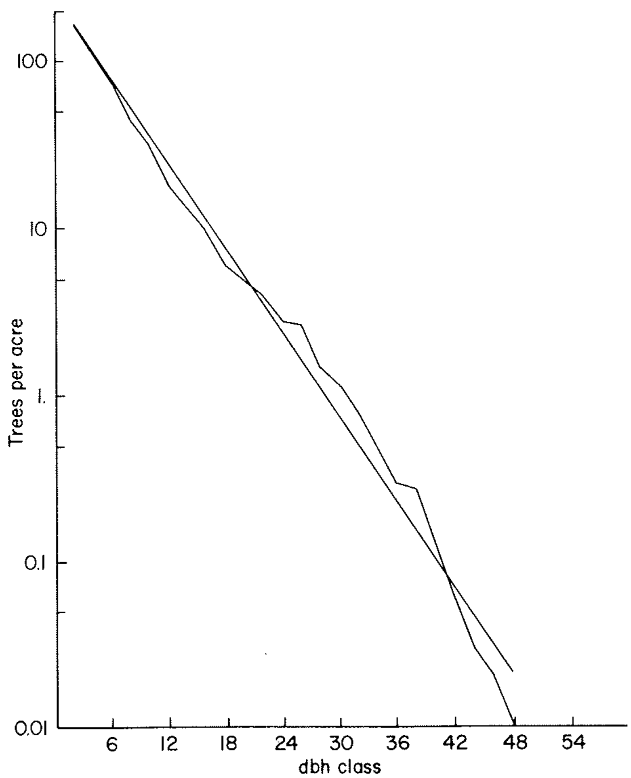

Figure 2.—The distribution of trees per acre by d.b.h. class for the Willow-Thomas Creek area compared to the distribution for the balanced uneven-aged stand.

The regression for the Willow-Thomas stand is:

$$\log Y = 2.400 - 0.084x \qquad [3]$$

The "q" constant, the ratio of number of trees in successive diameter classes for this geometric series is 1.46. The coefficient of determination (r^2) for the regression is 0.98. The high r^2 value tends to confirm a minimum of disturbance in the present stand (Schmelz and Lindsey 1965). Our stand has a deficiency in the smaller size classes and an excess of trees in the 22- through 40-inch diameter classes. The stand does not fit Meyer's (1952) definition of a perfectly balanced virgin forest, because current growth is not equal to the current mortality. It is interesting to note that virgin, uneven-aged Arizona ponderosa pine stands do not conform to this model because of the predominance of large and small size classes and the essential lack of intermediate size classes (Meyer 1952).

Species diameter distributions.—Species in some mixed stands, which exhibit an overall balanced uneven-aged structure, may have either uneven-aged or even-aged diameter distributions. This can be related to ecological succession (Curtis 1976). Species diameter distributions were checked on Willow-Thomas Creek. All regressions of number of trees per acre and d.b.h. class fit the data well, and showed characteristic balanced uneven-aged diameter distributions (fig. 3) with r^2 values ranging from 0.98 (Douglas-fir) to 0.83 (quaking aspen). Tests showed that the regressions for Engelmann spruce and for aspen could be combined, as could those for ponderosa pine and white fir. The species fall into two main groups based on common q value (slope): Engelmann spruce-aspen, corkbark fir, blue spruce with an average q of 1.60, and Douglas-fir, ponderosa pine-white fir with an average q of 1.38. White pine is intermediate (q = 1.43) and could be classed with one species in each group. The higher q represents a larger difference between diameter classes, and indicates a higher percentage of trees in the lower size classes.

It is difficult to draw any ecological conclusions from these data, especially since they are for a composite acre, and for one point in time. The uneven-aged diameter distributions may be the result of the mosaic of species and size classes common to southwestern mixed conifer forests or could indicate successional

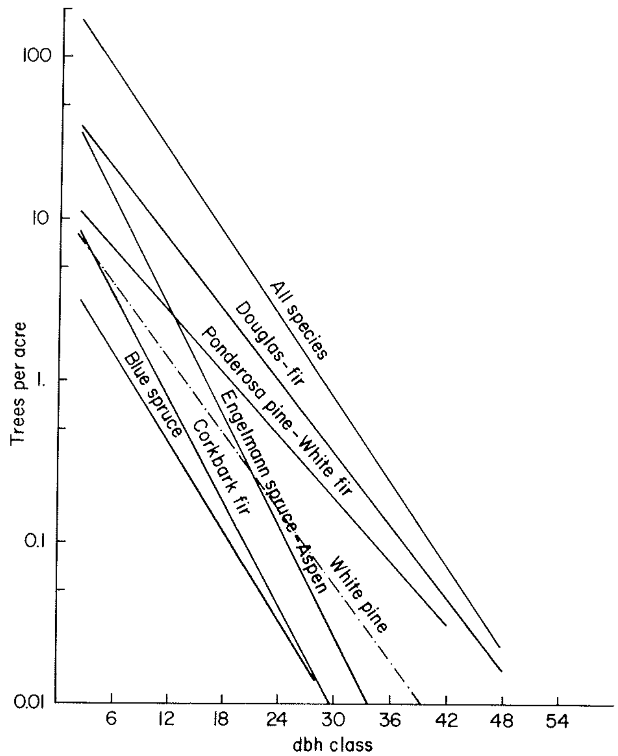

Figure 3.—Comparison of the regressions of trees per acre vs d.b.h. class for the eight mixed conifer species during the initial inventory.

changes on some sites. Engelmann spruce and corkbark fir are the most shade tolerant species, and could replace Douglas-fir and white fir on some areas between 8,500 and 10,000 feet (Jones 1974).

Mortality

Mortality is the number of trees or volume that is lost from the stand generally because of natural causes. A reliable estimate of mortality is necessary if net stand table projection methods are used to predict future stand conditions. We did not consider mortality of potential ingrowth trees.

The number of trees per acre that died during the five years was greatest in the smallest size classes and decreased with increased diameter class (table 2a). A regression of this relationship, using the previous model is:

$$\log Y = 0.906 - 0.080x \quad (r^2=0.91) \qquad [4]$$

The q value is 1.43. The slopes of the stand table and of the mortality table are nearly identical, but the intercepts are different. Other mathematical functions may apply elsewhere.

Five-year basal area per acre losses are presented in table 2b. The amount of mortality can also be illustrated as a percentage of initial stand conditions (tables 3a and 3b). Such data can be useful for models.

It is often difficult to determine the exact cause of death for a tree (table 4) since several factors may have contributed. For example, a minor fire or lightning scar (fig. 4a) may have provided the invasion point for the rot fungi which eventually killed the tree, or dwarf mistletoe may have weakened the tree so that it could not resist an attack of bark beetles. We determined that suppressed trees accounted for 50% of the trees lost. Wind damage was relatively common especially among Engelmann spruce, Douglas-fir, and corkbark fir. Krauch (1956) reported that wind damage was the major cause of mortality among residual sawtimber trees at Cloudcroft. The relatively large amount of wind damage under virgin conditions should serve as a warning that windthrow will be a severe problem if stand

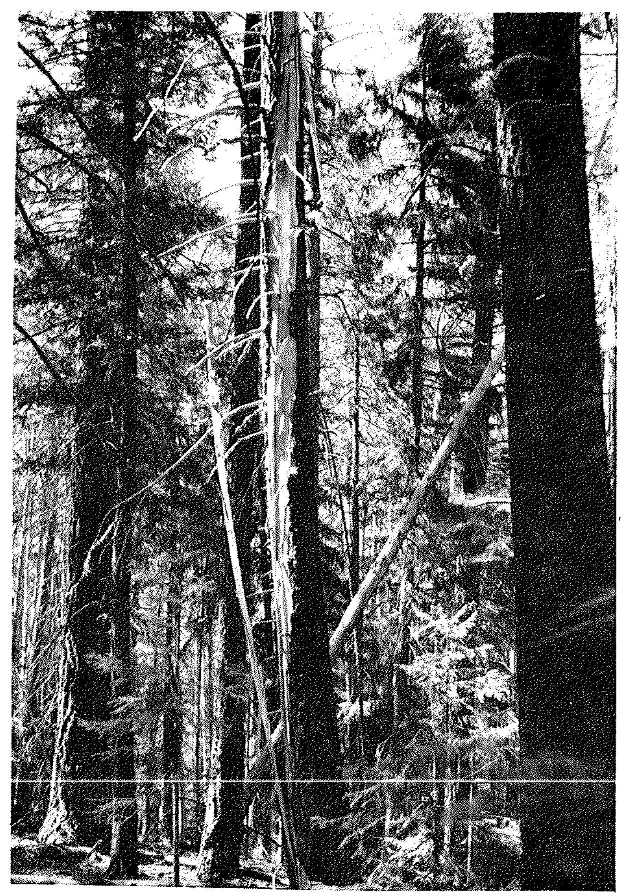

Figure 4a.—Lightning can kill a tree directly or produce a scar which will serve as an invasion point for decay organisms. (Thomas Creek South Fork)

Table 2a—Five-year stand mortality of initial trees by number of trees per acre.

D.B.H. size class	ES	BS	DF	WF	Species[1] CF	PP	WP	QA	All species
(Inches)									
2	2.06		8.24				4.12		14.42
4	1.03		2.58	0.52	0.52	0.52	0.52	3.09	8.78
6	1.14		0.46	0.69	0.23	0.23		1.37	4.12
8	0.39		0.52	0.13	0.13			1.42	2.59
10	0.33		0.58	0.25	0.08			0.33	1.57
12	0.17		0.11			0.06		0.11	0.45
14	0.08		0.04			0.08			0.20
16	0.13		0.06		0.03	0.03			0.25
18			0.02	0.08		0.05			0.15
20	0.02		0.02			0.08		0.02	0.14
22			0.02			0.03	0.02		0.07
24			0.03	0.01		0.06			0.10
26	0.01		0.01	0.04					0.06
28				0.02		0.01			0.03
30			0.02	0.01					0.03
32				0.01		0.01			0.02
34									0.00
36	0.01		0.01	0.01					0.03
38			0.01	0.01					0.02
40				[2]T					T
42			T						T
44			T	T					T
46									
48									
Total	5.37	0.0	12.73	1.78	0.99	1.16	4.66	6.34	33.03
%Distrib.	16	0	39	5	3	4	14	19	100

Table 2b.—Five-year stand mortality of initial trees by basal area (square feet) per acre.

D.B.H. size class	ES	BS	DF	WF	Species[1] CF	PP	WP	QA	All species
(Inches)									
2	0.04		0.18				0.09		0.31
4	0.09		0.22	0.04	0.04	0.04	0.04	0.27	0.74
6	0.22		0.09	0.14	0.04	0.04		0.27	0.80
8	0.14		0.18	0.04	0.04			0.50	0.90
10	0.18		0.32	0.14	0.04			0.18	0.86
12	0.14		0.09			0.04		0.09	0.36
14	0.09		0.04			0.09			0.22
16	0.18		0.09		0.04	0.04			0.35
18			0.04	0.14		0.09			0.27
20	0.04		0.04			0.18		0.04	0.30
22			0.04			0.09	0.04		0.17
24			0.09	0.04		0.18			0.31
26	0.04		0.04	0.14					0.22
28				0.09		0.04			0.13
30			0.09	0.04					0.13
32				0.04		0.04			0.08
34									0.00
36	0.04		0.09	0.04					0.17
38			0.04	0.04					0.08
40				0.04					0.04
42			0.04						0.04
44			0.04	0.04					0.08
46									
48									
Total	1.20	0.0	1.76	1.01	0.20	0.87	0.17	1.35	6.56
%Distrib.	18	0	27	15	3	13	3	21	100

[1] *ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*

[2] *Trace*

Table 3a.—Five-year stand mortality expressed as percent of number of trees per acre in the initial stand.

Size class	ES	BS	DF	WF	CF	PP	WP	QA	All species
	Species[1]								
Saplings-small poles (0.1-6.9 inches)	9.1	0.0	9.2	2.4	5.1	2.1	17.7	9.5	7.8
Poles (7.0-10.9 inches)	5.9	0.0	7.2	5.5	4.9	0.0	0.0	6.1	5.5
Small sawtimber (11.0-16.9 inches)	4.1	0.0	1.9	0.0	1.4	4.7	0.0	1.5	2.2
Medium sawtimber (17.0-22.9 inches)	0.9	0.0	1.2	3.8	0.0	5.0	2.2	2.4	2.4
Large sawtimber (23.0 inches plus)	5.1	0.0	1.9	4.6	0.0	3.1	0.0	0.0	2.8
All size classes	7.6	0.0	8.0	2.7	4.6	2.4	13.8	7.6	6.7

Table 3b.—Five-year stand mortality expressed as percent of basal area per acre in the initial stand.

Size class	ES	BS	DF	WF	CF	PP	WP	QA	All species
	Species[1]								
Saplings-small poles (0.1-6.9 inches)	10.0	0.0	5.8	5.1	7.7	3.4	8.6	7.8	6.7
Poles (7.0-10.9 inches)	5.9	0.0	7.6	6.6	4.3	0.0	0.0	5.5	5.4
Small sawtimber (11.0-16.9 inches)	4.4	0.0	1.9	0.0	1.9	4.5	0.0	1.3	2.3
Medium sawtimber (17.0-22.9 inches)	0.9	0.0	1.2	3.2	0.0	5.1	2.1	2.4	2.4
Large sawtimber (23 inches plus)	5.8	0.0	2.2	4.5	0.0	2.5	0.0	0.0	2.8
All size classes	5.0	0.0	3.1	3.9	3.4	3.5	1.7	4.8	3.7

[1]ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.

density is reduced too quickly. Wind damage included trees which were blown down (fig. 4b), knocked down by blowdowns or were broken off above ground level. Rot was probably a factor in some cases. We did not attempt to determine the type of rot organism responsible; sometimes two organisms attacked the same species (e.g., both *Phellinus tremulae* (Bond.) Bond. et Boris and *Ganoderma applanatum* were found on aspen).

The "miscellaneous" category included several 8- and 10-inch aspen, and several small white pine, ponderosa pine, and Engelmann spruce, which were cut during research and management activities. These losses were not natural but were unplanned and too minor to be considered separately.

"Survivor" Stand

Tables 5a and 5b contain the stand tables for "survivor" trees and basal area. These are the trees which are present for the initial and second inventories (Beers 1962). The tables are derived by subtracting mortality from initial stand values. They will be used in the following calculations and discussions.

Periodic Average Annual Tree Growth

Periodic average annual tree growth by size class in terms of inches of diameter and square feet of basal area, is presented in tables 6a and 6b. Growth differences among the species were not compared statistically; however, it appears

Table 4.—Percent of 5-year mortality by killing agent (on a per acre basis).

Species	Wind	Lightning	Insects	Suppressed	Rot	Dwarf mistletoe	Misc.	Unknown
Engelmann spruce								
Trees	48	0	0	11	0	1	38	2
Basal area	74	0	0	8	0	3	3	12
Douglas-fir								
Trees	11	T[1]	0	80	T	9	0	T
Basal area	40	2	0	25	12	18	0	3
White fir								
Trees	6	2	0	86	4	0	0	2
Basal area	18	18	0	31	24	0	0	9
Corkbark fir								
Trees	31	0	0	53	0	0	0	16
Basal area	41	0	0	18	0	0	0	41
Ponderosa pine								
Trees	9	2	9	46	9	0	20	5
Basal area	15	10	25	5	25	0	5	15
Southwestern white pine								
Trees	0	1	0	0	0	0	99	0
Basal area	0	22	0	0	0	0	78	0
Quaking aspen								
Trees	17	0	0	53	3	0	12	15
Basal area	13	0	0	29	10	0	24	24
All species								
Trees	17	T	T	50	1	4	23	5
Basal area	33	5	3	20	13	5	8	13

[1]*Trace.*

Figure 4b.—Wind damage produced the largest amount of mortality in terms of basal area per acre. (Thomas Creek South Fork)

Table 5a.—Inventory of "survivor" trees by number of trees per acre.

D.B.H. size class	ES	BS	DF	WF	Species[1] CF	PP	WP	QA	All species
(Inches)									
2	22.67	4.12	55.65	26.79	8.24	18.55	12.37	2.06	150.45
4	10.82	1.55	39.16	16.48	3.09	11.33	6.18	14.43	103.04
6	8.71	0.92	16.94	6.64	2.52	4.58	2.98	26.11	69.40
8	5.92	0.64	8.76	5.15	2.06	1.42	2.06	15.71	41.72
10	5.61	0.74	5.52	1.40	1.98	1.48	1.90	11.38	30.01
12	4.47	0.40	4.58	1.55	1.09	1.37	0.52	3.55	17.53
14	2.57	0.42	3.87	0.88	0.67	0.97	0.88	2.31	12.57
16	1.83	0.19	2.48	1.10	0.39	1.10	0.77	1.29	9.15
18	1.09	0.13	1.84	0.81	0.18	0.92	0.46	0.41	5.84
20	0.62	0.12	1.65	0.70	0.06	1.03	0.23	0.25	4.66
22	0.43	0.10	1.33	0.51	0.07	1.09	0.20	0.14	3.87
24	0.20	0.03	1.22	0.43	0.03	0.66	0.13		2.70
26	0.11	0.01	0.91	0.47	0.01	0.95	0.15	0.01	2.62
28	0.03	0.01	0.64	0.36	0.01	0.31	0.10		1.46
30	0.02		0.39	0.36		0.32	0.06	0.01	1.16
32	0.01		0.33	0.25		0.14	0.06		0.79
34			0.26	0.15	0.01	0.04	0.02		0.48
36			0.12	0.10		0.04	0.01		0.27
38			0.14	0.09		0.02	0.01		0.26
40			0.07	0.06		[2]T			0.13
42			0.04	0.01			0.01		0.06
44			0.02	0.01			T		0.03
46			0.02						0.02
48			0.01						0.01
Total	65 11	9.38	145.95	64.30	20.41	46.32	29.10	77.66	458.23
%Distrib.	14	2	32	14	4	10	7	17	100

Table 5b.—Inventory of "survivor" trees by basal area (square feet) per acre.

D.B.H. size class	ES	BS	DF	WF	Species[1] CF	PP	WP	QA	All species
(Inches)									
2	0.50	0.09	1.21	0.58	0.18	0.40	0.27	0.04	3.27
4	0.94	0.14	3.42	1.44	0.28	0.99	0.54	1.26	9.01
6	1.71	0.18	3.33	1.30	0.50	0.90	0.58	5.13	13.63
8	2.06	0.22	3.06	1.80	0.72	0.50	0.72	5.48	14.56
10	3.06	0.40	3.01	0.76	1.08	0.81	1.03	6.20	16.35
12	3.50	0.32	3.60	1.21	0.85	1.08	0.40	2.79	13.75
14	2.74	0.45	4.14	0.94	0.72	1.03	0.94	2.47	13.43
16	2.56	0.27	3.46	1.53	0.54	1.53	1.08	1.80	12.77
18	1.93	0.22	3.24	1.43	0.32	1.62	0.81	0.72	10.29
20	1.35	0.27	3.60	1.53	0.14	2.25	0.50	0.54	10.18
22	1.12	0.27	3.51	1.35	0.18	2.88	0.54	0.36	10.21
24	0.63	0.09	3.82	1.35	0.09	2.07	0.40		8.45
26	0.41	0.04	3.33	1.75	0.04	3.51	0.54	0.04	9.66
28	0.14	0.04	2.74	1.53	0.04	1.31	0.45		6.25
30	0.09		1.93	1.76		1.57	0.27	0.04	5.66
32	0.04		1.84	1.40		0.81	0.32		4.41
34			1.66	0.94	0.04	0.22	0.14		3.00
36			0.81	0.72		0.27	0.09		1.89
38			1.13	0.77		0.18	0.09		2.17
40			0.58	0.46		0.04			1.08
42			0.32	0.14			0.09		0.55
44			0.14	0.10			0.04		0.28
46			0.27						0.27
48			0.09						0.09
Total	22.78	3.00	54.24	24.79	5.72	23.97	9.84	26.87	171.21
%Distrib.	13	2	32	14	3	14	6	16	100

[1]*ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*
[2]*Trace.*

Table 6a.—Periodic average annual diameter (inch) growth by size class for "survivor" sample trees.

D.B.H. size class	ES	BS	DF	WF	CF	PP	WP	QA
				Species[1]				
(Inches)								
2	0.058	0.060	0.054	0.065	0.020	0.042	0.063	0.020
4	.103	.213	.066	.086	.097	.049	.095	.047
6	.119	.100	.081	.081	.064	.085	.077	.055
8	.146	.128	.085	.081	.080	.071	.072	.081
10	.139	.084	.105	.142	.126	.057	.083	.086
12	.153	.086	.113	.123	.135	.082	.120	.090
14	.142	.076	.119	.125	.111	.087	.100	.106
16	.161	.153	.119	.127	.098	.060	.099	.100
18	.151	.080	.117	.117	.097	.084	.064	.095
20	.161	.117	.116	.116	.127	.069	.055	.112
22	.126	.113	.135	.135	.085	.063	.100	.222
24	.151	.040	.142	.123	.120	.048	.067	
26	.111	.100	.112	.119	.140	.074	.057	.140
28	.100	.200	.139	.149	.060	.051	.086	
30	.060		.110	.124		.060	.073	.000
32	.000		.131	.113		.037	.109	
34			.139	.116	.040	.024	.060	
36			.146	.127		.020	.110	
38			.137	.153		.045	.060	
40			.114	.106		.080		
42			.083	.127			.110	
44			.067	.030			.000	
46			.023					
48			.030					

Table 6b.—Periodic average annual basal area (square feet) growth by size class for "survivor" sample trees.

D.B.H. size class	ES	BS	DF	WF	CF	PP	WP	QA
				Species[1]				
(Inches)								
2	0.002	0.002	0.002	0.002	0.001	0.001	0.002	0.001
4	.005	.010	.003	.004	.005	.002	.005	.002
6	.009	.006	.006	.005	.005	.006	.005	.004
8	.014	.012	.008	.007	.007	.006	.006	.007
10	.016	.009	.012	.016	.014	.006	.009	.010
12	.021	.012	.015	.016	.018	.011	.016	.012
14	.022	.012	.019	.019	.018	.013	.015	.016
16	.029	.027	.021	.023	.018	.011	.018	.018
18	.030	.016	.023	.023	.020	.017	.013	.019
20	.036	.026	.026	.026	.028	.015	.012	.025
22	.030	.028	.033	.033	.020	.015	.024	.055
24	.040	.010	.038	.033	.031	.013	.018	
26	.032	.029	.032	.034	.039	.021	.016	.041
28	.030	.062	.043	.046	.018	.015	.027	
30	.020		.037	.041		.020	.024	.000
32	.000		.046	.040		.013	.038	
34			.052	.044	.015	.009	.022	
36			.058	.050		.008	.044	
38			.058	.064		.019	.025	
40			.050	.047		.035		
42			.038	.059			.051	
44			.032	.015			.000	
46			.012					
48			.015					

[1] *ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*

that ponderosa pine is growing less than any other species. Ponderosa pine is near its upper altitudinal limit on Willow-Thomas Creek and is considered a seral species on many sites within southwestern mixed conifer forests. The recent bark beetle outbreaks cannot be discounted either.

Periodic Annual Basal Area Growth Per Acre

Periodic annual basal area growth per acre (table 7) is derived by multiplying average annual basal area growth per tree (table 6b) by the "survivor" number of trees per acre (table 5a). The relationship between gross increment and diameter class is shown in figure 5. The point increment is 3.072 square feet per acre per year with 31% of this value produced by Douglas-fir.

Net periodic annual basal area growth per acre (table 8) is derived by subtracting mortality and adding ingrowth to the information in table 7. However, ingrowth, as will be discussed later, was not a factor in the current calculations. Net periodic annual growth was 1.760 square feet or 57% of the gross value. Douglas-fir contributed 34% of the net growth; however, this was 63% of its gross value. Ponderosa pine lost 81% of its gross growth to mortality. Differences between gross and net basal area growth per acre were significant for all species except for blue spruce (no mortality) and for white pine. Stand mortality was greatest in the 2- to 12-inch diameter classes (fig. 5) and exceeded growth in all classes above 34 inches.

Growth Prediction Tools

Periodic diameter growth and periodic annual basal area growth per acre can be modified to produce growth prediction values.

Growth index ratios.—Periodic diameter growth is used to calculate the growth index ratio (table 9):

$$\text{Annual growth index ratio} = \frac{g}{i} \qquad \text{[5]}$$

$$\text{n-year growth index ratio} = \frac{g}{i} \times n$$

where:

g = diameter growth in inches
i = diameter class interval in inches
n = number of years in projection period.

The growth index ratio is used in stand table projections to estimate future diameter distributions. It assumes that trees in each diameter class are evenly distributed through the class and that upward movement of trees into larger diameter classes is proportional to this ratio. "Survivor" stand table values are multiplied by the ratio for the measurement period to determine the number of trees which will advance to the next one or more d.b.h. classes or will remain stable. For example, it would be expected that 14% of the current survivor Engelmann spruce (table 5a) in the 2-inch class would grow into the 4-inch class, while 86% would remain in the 2-inch class. This stand projection method is covered in more detail in most forest mensuration texts (Avery 1967, Husch et al. 1972). The index ratios in table 9 are for a 5-year period; their precision would decrease as the projection period is extended. It should also be noted that tables 9 and 10 contain actual data. Readers can smooth these to meet their needs.

Basal area growth percentages.—Annual gross basal area growth percentages (table 10) provide a quick and simple method of estimating growth. They can be used to estimate future

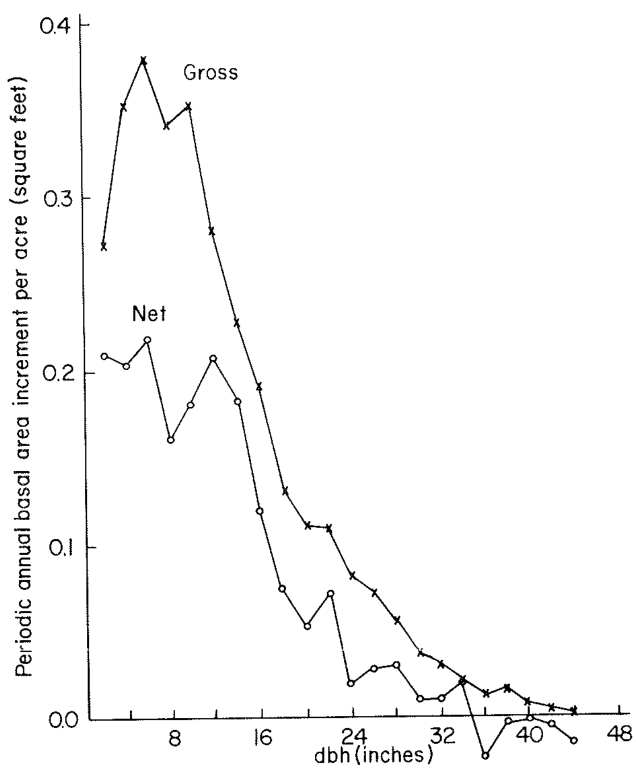

Figure 5.—Gross and net basal area growth per acre by d.b.h. class.

Table 7.—Periodic annual basal area (square feet) growth per acre of "survivor" trees.

D.B.H. size class	Species[1] ES	BS	DF	WF	CF	PP	WP	QA	All species
(Inches)									
2	0.045	0.008	0.111	0.054	0.008	0.019	0.025	0.002	0.272
4	.054	.016	.118	.066	.015	.023	.031	.029	.352
6	.078	.006	.102	.033	.013	.028	.015	.104	.379
8	.083	.008	.070	.036	.014	.008	.012	.110	.341
10	.090	.007	.066	.022	.028	.009	.017	.114	.353
12	.094	.005	.069	.025	.020	.015	.008	.043	.279
14	.056	.005	.074	.017	.012	.013	.013	.037	.227
16	.053	.005	.052	.025	.007	.012	.014	.023	.191
18	.033	.002	.042	.019	.004	.016	.006	.008	.130
20	.022	.003	.043	.018	.002	.015	.003	.006	.112
22	.013	.003	.044	.017	.001	.016	.005	.008	.107
24	.008	[2]T	.046	.014	.001	.009	.002		.080
26	.004	T	.029	.016	T	.020	.002	T	.071
28	.001	.001	.028	.017	T	.005	.003		.055
30	T		.014	.015		.006	.001	.000	.036
32	.000		.015	.010		.002	.002		.029
34			.014	.007	T	T	T		.021
36			.007	.005		T	T		.012
38			.008	.006		T	T		.014
40			.004	.003		T			.007
42			.002	.001			T		.003
44			.001	T			.000		.001
46			T						T
48			T						T
Total	.634	.069	.959	.426	.125	.216	.159	.484	3.072
%Distrib.	21	2	31	14	4	7	5	16	100

Table 8.—Net periodic annual basal area (square feet) growth per acre.

D.B.H. size class	Species[1] ES	BS	DF	WF	CF	PP	WP	QA	All species
(Inches)									
2	.037	.008	.075	.054	.008	.019	.007	.002	.210
4	.036	.016	.074	.058	.007	.015	.023	-.025	.204
6	.034	.006	.084	.005	.005	.020	.015	.050	.219
8	.055	.008	.034	.028	.006	.008	.012	.010	.161
10	.054	.007	.002	-.006	.020	.009	.017	.078	.181
12	.066	.005	.051	.025	.020	.007	.008	.025	.207
14	.038	.005	.066	.017	.012	-.005	.013	.037	.183
16	.017	.005	.034	.025	-.001	.004	.014	.023	.121
18	.033	.002	.034	-.009	.004	-.002	.006	.008	.076
20	.014	.003	.035	.018	.002	-.021	.003	-.002	.052
22	.013	003	.036	.017	.001	-.002	-.003	.008	.073
24	.008	[2]T	.028	.006	.001	-.027	.002		.018
26	-.004	T	.021	-.012	T	.020	.002	T	.027
28	.001	.001	.028	-.001	T	-.003	.003		.029
30	T		-.004	.007		.006	.001	.000	.010
32	.000		.015	.002		-.006	.002		.013
34			.014	.007	T	T	T		.021
36	-.008		-.011	-.003		T	T		-.022
38			.000	-.002		T	T		-.002
40			.004	-.005		T			-.001
42			-.006	.001			T		-.005
44			-.007	-.008			.000		-.015
46			T						T
48			T						T
Total	.394	.069	.607	.224	.085	.042	.125	.214	1.760
% of gross growth	62	100	63	52	68	19	79	44	57

[1]*ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*

[2]*Trace*

Table 9.—Five-year gross growth index ratios.[1]

D.B.H. size class	ES	BS	DF	Species[2] WF	CF	PP	WP	QA
(Inches)								
2	0.14	0.15	0.14	0.16	0.05	0.10	0.16	0.05
4	.26	.53	.16	.22	.24	.12	.24	.12
6	.30	.25	.20	.20	.16	.21	.19	.14
8	.36	.32	.21	.20	.20	.18	.18	.20
10	.35	.21	.26	.36	.32	.14	.21	.22
12	.38	.22	.28	.31	.34	.20	.30	.22
14	.36	.19	.30	.31	.28	.22	.25	.26
16	.40	.38	.30	.32	.24	.15	.25	.25
18	.38	.20	.29	.29	.24	.21	.16	.24
20	.40	.29	.29	.29	.32	.17	.14	.28
22	.32	.28	.34	.34	.21	.16	.25	.56
24	.38	.10	.36	.31	.30	.12	.17	
26	.28	.25	.28	.30	.35	.18	.14	.35
28	.25	.50	.35	.37	.15	.13	.22	
30	.15		.28	.31		.15	.18	.00
32	.00		.33	.28		.09	.27	
34			.35	.29	.10	.06	.15	
36			.36	.32		.05	.28	
38			.34	.38		.11	.15	
40			.28	.26		.20		
42			.21	.32			.28	
44			.17	.08			.00	
46			.06					
48			.08					
Aver. for all size classes	.29	.28	.26	.28	.23	.15	.20	.25

Table 10.—Annual gross basal area growth percentages.

D.B.H. size class	ES	BS	DF	Species[2] WF	CF	PP	WP	QA
(Inches)								
2	9.0	8.9	9.2	9.3	4.4	4.8	9.3	5.0
4	5.7	11.4	3.4	4.6	5.4	2.3	5.7	2.3
6	4.6	3.3	3.1	2.5	2.6	3.1	2.6	2.0
8	4.0	3.6	2.3	2.0	1.9	1.6	1.7	2.0
10	2.9	1.8	2.2	2.9	2.6	1.1	1.6	1.8
12	2.7	1.6	1.9	2.1	2.4	1.4	2.0	1.5
14	2.0	1.1	1.8	1.8	1.7	1.3	1.4	1.5
16	2.1	1.8	1.5	1.6	1.3	0.8	1.3	1.3
18	1.7	0.9	1.3	1.3	1.2	1.0	0.7	1.1
20	1.6	1.1	1.2	1.2	1.4	0.7	0.6	1.1
22	1.2	1.1	1.2	1.3	0.6	0.6	0.9	2.2
24	1.3	0.3	1.2	1.0	1.1	0.4	0.5	
26	1.0	0.7	0.9	0.9	1.0	0.6	0.4	1.0
28	0.7	2.5	1.0	1.1	0.4	0.4	0.7	
30	0.4		0.7	0.8		0.4	0.4	0.0
32	0.0		0.8	0.7		0.2	0.6	
34			0.8	0.7	0.4	0.2	0.3	
36			0.9	0.7		0.1	0.5	
38			0.7	0.8		0.2	0.3	
40			0.7	0.6		0.4		
42			0.6	0.7			0.6	
44			0.7	0.2			0.0	
46			0.1					
48			0.2					
All size classes	2.8	2.3	1.8	1.7	2.2	0.9	1.6	1.8

[1] *Growth index ratio* $= \dfrac{\textit{Diameter Growth in Inches}}{\textit{Diameter Class Interval in Inches}} \times 5 \textit{ Years}$

[2] *ES = Engelmann spruce, = BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*

basal area and volume growth. Growth percentage multiplied by species-size class volume would give an estimate of annual volume growth. For example, Engelmann spruce in the 20-inch class with 347 board feet per acre and a growth percentage of 1.6%, would grow 5.6 board feet per acre in 1 year. The standard compound interest formula should be used to calculate growth over longer periods. Such volume estimates would be more precise for mature trees, where changes in height and tree form are slow, but could be used on all size classes if a short prediction period of 5 to 10 years is used or if precise estimates are not required (Embry and Gottfried 1971b). Basal area growth percentages are calculated by dividing periodic annual basal area growth per acre (table 7) by initial survivor basal area per acre (table 5b) and multiplying by 100. The survivor stand annually increased its basal area by an average of 1.8%; however, net increase was about 1.0%.

Ingrowth

Ingrowth is defined as the trees or the volume of those trees that grew into the lowest diameter class during the measurement period. In point sampling, ingrowth generally refers to trees which were "in" during both inventories and which have grown into a "minimum" d.b.h. class. Since we are studying the entire range of diameters in the stand, ingrowth would only refer to trees which were below breast height during the first inventory but are now "in-trees." Ingrowth into the stand during the past 5-year period was not observed.

Ingrowth was present if determined on the basis of in-trees growing into the minimum merchantable diameter classes. The minimum classes are 6 inches for cubic foot volumes and 10 inches for board foot volumes. Commercial ingrowth included 23.69 trees per acre growing into the 6-inch class and 10.82 trees per acre growing into the 10-inch class. The volumes of ingrowth trees are presented later.

Survivor Stand After Five Years

The stand tables (tables 11a and 11b) for Willow-Thomas Creek after five growing seasons reflect the growth of the survivor trees among the diameter classes, especially since true ingrowth was not measured. The original expansion (conversion) factors were used to generate the number of trees per acre shown in table 11a; for example, a 2-inch tree (which initially represented 2.06 trees per acre) would still represent 2.06 trees per acre when it grew into the 4-inch class. This procedure was also used in calculating the number of trees growing into the size classes which produce merchantable volume (table 12). Gross growth in number of trees per acre and basal area per acre is zero, since the same number of trees are present for both measurements, and mortality is not a consideration. The regression of number of trees per acre and d.b.h. class and the q value for the 5-year survivor stand are essentially the same as those for the initial stand.

Volume Growth

Volume is of major interest, because it reflects commercial value and is a prime consideration in management planning. Gross volume statistics, in board feet per acre and merchantable cubic feet per acre, are given in table 12. Board foot volumes are based on the Scribner or Scribner Decimal C Rule. Douglas-fir makes up 30% of the initial board foot volume and 29% of the cubic foot volume. Ponderosa pine, presently the most commercially valuable species, makes up 21% and 18% of the respective volumes.

The statistics in table 12 are used to calculate several 5-year growth values (table 13). The calculations follow the definitions proposed by Beers (1962). The commonly used term "accretion" is not applicable, since we used the initial volume of mortality trees instead of the volume at the time of death (Husch et al. 1972). In a harvested stand, gross growth (including ingrowth) would have been reduced by the initial volume of cut trees to give net increase.

It is interesting to compare our volume data with those from the managed mixed conifer plots at Cloudcroft, N. Mex. (Krauch 1956), even though Cloudcroft volumes are primarily in Douglas-fir and white fir. Krauch (1956) reported the annual mortality ranged from 1 to 77 board feet per acre on the "methods of cutting" plots and from 0 to 84 board feet per acre on the Cloudcroft Reserve plots. Annual mortality on Willow-Thomas Creek was higher — 114 board feet per acre. Mortality should be less in managed stands since poor risk trees can be harvested and utilized, depending on the frequency of entry into the stand. The Willow-Thomas annual survivor growth was 376 board feet per acre. Annual gross growth and net

Table 11a.—Five-year stand table of "survivor" trees by number of trees per acre.

D.B.H. size class	ES	BS	DF	Species[1] WF	CF	PP	WP	QA	All species
(Inches)									
2	14.42	4.12	39.17	20.60	6.18	12.35	10.31	2.06	109.21
4	17.01		47.40	18.55	4.12	16.49	5.66	11.33	120.56
6	7.79	2.47	21.32	10.08	2.40	4.92	4.87	23.49	77.34
8	5.56	0.52	10.32	5.06	2.44	2.11	2.36	18.34	46.71
10	6.80	0.78	6.11	1.68	1.92	1.40	1.79	11.99	32.47
12	4.90	0.31	4.59	1.58	1.52	1.22	0.90	5.40	20.42
14	3.36	0.55	4.50	1.09	0.82	1.07	0.75	2.44	14.58
16	2.12	0.20	2.89	0.99	0.47	0.93	0.89	1.56	10.05
18	1.37	0.11	2.00	1.00	0.27	0.94	0.51	0.59	6.79
20	0.83	0.15	1.61	0.60	0.12	1.19	0.29	0.26	5.05
22	0.49	0.12	1.40	0.58	0.09	1.02	0.19	0.13	4.02
24	0.20	0.03	1.28	0.50	0.03	0.81	0.13	0.03	3.01
26	0.16	0.01	1.15	0.42	0.01	0.82	0.16	0.03	2.76
28	0.07	0.01	0.57	0.42	0.01	0.45	0.10		1.63
30	0.02		0.54	0.38		0.31	0.08	0.01	1.34
32	0.01		0.32	0.26		0.18	0.04		0.81
34			0.32	0.19	0.01	0.03	0.03		0.58
36			0.13	0.14		0.05	0.01		0.33
38			0.11	0.07		0.02	0.02		0.22
40			0.12	0.07		0.01			0.20
42			0.05	0.03			0.01		0.09
44			0.02	0.01			[2]T		0.03
46			0.02						0.02
48			0.01						0.01
Total	65.11	9.38	145.95	64.30	20.41	46.32	29.10	77.66	458.23
%Distrib.	14	2	32	14	4	10	7	17	100

Table 11b.—Five-year stand table of "survivor" trees by basal area (square feet) per acre.

D.B.H. size class	ES	BS	DF	Species[1] WF	CF	PP	WP	QA	All species
(Inches)									
2	0.32	0.09	0.85	0.45	0.14	0.27	0.22	0.04	2.38
4	0.94		3.06	1.21	0.23	1.03	0.37	0.99	7.83
6	1.30	0.32	3.29	1.53	0.37	0.85	0.67	4.27	12.60
8	1.48	0.18	3.01	1.66	0.67	0.64	0.71	5.53	13.88
10	3.06	0.40	2.88	0.77	0.90	0.77	0.90	5.93	15.61
12	3.33	0.22	3.19	1.11	0.98	0.94	0.58	3.64	13.99
14	3.10	0.55	4.32	1.03	0.77	1.08	0.76	2.43	14.04
16	2.65	0.27	3.69	1.30	0.59	1.26	1.17	2.02	12.95
18	2.20	0.17	3.28	1.62	0.40	1.52	0.86	0.95	11.00
20	1.65	0.32	3.29	1.25	0.24	2.48	0.58	0.54	10.35
22	1.22	0.31	3.42	1.40	0.22	2.65	0.50	0.31	10.03
24	0.58	0.09	3.77	1.48	0.09	2.43	0.40	0.09	8.93
26	0.54	0.04	4.01	1.49	0.04	3.02	0.59	0.09	9.82
28	0.28	0.04	2.29	1.70	0.04	1.85	0.40		6.60
30	0.09		2.51	1.76		1.44	0.36	0.04	6.20
32	0.04		1.71	1.40		0.99	0.23		4.37
34			1.97	1.13	0.04	0.22	0.18		3.54
36			0.95	0.98		0.31	0.05		2.29
38			0.81	0.59		0.14	0.18		1.72
40			0.94	0.55		0.08			1.57
42			0.46	0.23			0.09		0.78
44			0.18	0.15			0.04		0.37
46			0.27						0.27
48			0.09						0.09
Total	22.78	3.00	54.24	24.79	5.72	23.97	9.84	26.87	171.21
%Distrib.	13	2	32	14	3	14	6	16	100

[1]ES = *Engelmann spruce*, BS = *Blue spruce*, DF = *Douglas-fir*, WF = *White fir*, CF = *Corkbark fir*, PP = *Ponderosa pine*, WP = *Southwestern white pine*, QA = *Quaking aspen*.
[2]*Trace*

Table 12.—Point summary of volume per acre statistics for the initial and 5-year stand inventories.

Species	Board feet [1]V_1	[2]M	[3]V_{s1}	[4]I	[5]V_{s2}	Cubic feet V_1	M	V_{s1}	I	V_{s2}
Engelmann spruce	2,732	105	2,627	168	3,029	622	25	597	6	698
Blue spruce	360	0	360	6	391	80	0	80	4	85
Douglas-fir	6,289	122	6,167	51	6,721	1,300	29	1,271	18	1,385
White fir	3,609	138	3,471	19	3,751	685	27	658	6	710
Corkbark fir	553	10	543	27	664	134	3	131	2	159
Ponderosa pine	4,404	149	4,255	0	4,475	794	28	766	2	803
Southwestern white pine	1,097	8	1,089	18	1,163	236	2	234	8	251
Quaking aspen	2,007	38	1,969	185	2,165	632	23	609	9	695
Total	21,051	570	20,481	474	22,359	4,483	137	4,346	55	4,786

[1]*V_1 = Volume of trees measured at the first inventory.*

[2]*M = Initial volume of mortality trees.*

[3]*V_{s1} = Initial volume of trees measured at both inventories (survivor trees).*

[4]*I = Final volume of ingrowth trees.*

[5]*V_{s2} = Final volume of trees measured at both inventories.*

Table 13.—Point summary of 5-year volume growth.

Species	Board feet per acre [1]Survivor growth	[2]Gross growth	[3]Net growth	Cubic feet per acre Survivor growth	Gross growth	Net growth
Engelmann spruce	402	570	465	101	107	82
Blue spruce	31	37	37	5	9	9
Douglas-fir	554	605	483	114	132	103
White fir	280	299	161	52	58	31
Corkbark fir	121	148	138	28	30	27
Ponderosa pine	220	220	71	37	39	11
Southwestern white pine	74	92	84	17	25	23
Quaking aspen	196	381	343	86	95	72
Total	1,878	2,352	1,782	440	495	358

[1]*Survivor growth = $G_S = V_{S2} - V_{S1}$*

[2]*Gross growth = $G_S + I$*

[3]*Net growth = $G_S + I - M$*

growth were 470 board feet and 356 board feet, respectively. The Cloudcroft sites showed corresponding average annual values from all plots of 149 board feet, 200 board feet and 168 board feet per acre (Krauch 1956); however, growth should be concentrated on the best quality trees.

Ongrowth

We tallied 393 trees, of all size classes, which were out of the initial survey but "in" during the second inventory due to growth. These new trees are classified as ongrowth (non-growth). Their growth is not included in the evaluation for the measurement period nor are they considered ingrowth as previously defined (Beers and Miller 1964). Ongrowth trees can be added to the second inventory data to produce a new basis for evaluating a subsequent growth period. Myers and Beers (1968) indicate that the basal area growth of ongrowth trees from the time that they qualified as being in the sample to the end of the period should be considered ingrowth. However, a comparison of the methods did not cause significant differences between the plot and point sample estimates of ingrowth (Myers and Beers 1968). These authors found significant differences when ongrowth was treated like ingrowth.

Data for the ongrowth trees listed by species on a per acre basis are shown in table 14.

New "Initial" Stand

In point sampling, a new basis for evaluating growth can be established at the start of each period or after several periods (Beers and Miller 1964). New stand tables (tables 15a and 15b) are

Table 14.—Data for ongrowth trees, by species, on a per acre basis

Species	No. trees	Basal area	Board feet	Cubic feet
Engelmann spruce	19.96	3.78	383	89
Blue spruce	3.02	0.27	17	5
Douglas-fir	16.72	6.18	624	136
White fir	8.06	2.33	288	55
Corkbark fir	4.70	0.90	79	19
Ponderosa pine	0.68	1.02	167	32
Southwestern white pine	6.02	1.09	79	20
Quaking aspen	5.20	1.98	149	46
Total	64.36	17.55	1786	402

prepared for the survivor trees using final diameter measurements, and consequently, new expansion factors (e.g., a 2-inch tree which grew into the 4-inch class now represents 0.52 trees per acre instead of 2.06 trees per acre). The new tables would include ongrowth trees.

Volumes for the new stand on Willow-Thomas Creek are shown in table 16.

Note that the values for the 5-year inventory, including any ingrowth (tables 11a and 12), plus ongrowth do not equal the statistics for the new "initial" stand; for example, using board feet per acre: 22,833 + 1,786 ≠ 23,064. This example of the lack of additivity was referred to by Beers and Miller (1964) and by Beers and Myers (1965). The authors claim that this problem is inherent in polyareal sampling and reflects the use of different expansion factors. Basal area per acre, where each tree has equal weight, would be the exception.

Summary

There is a lack of information about forest stand and tree growth within the Arizona mixed conifer zone. Growth information is vital to evaluate past stand performance to design and plan forest management practices. Five-year stand and tree growth, based on repeated diameter measurements, was evaluated in a 1,800-acre, relatively balanced, uneven-aged mixed conifer stand. The stand had never been commercially harvested and had not had a serious fire within 90 to 100 years.

Some of the important stand and growth parameters are summarized in table 17. Ongrowth was also measured and was added to the new stand tables to provide a basis for evaluating the next growth period. Gross periodic point annual basal area growth per acre was 3.072 square feet, with 31% produced by Douglas-fir. Net periodic point annual basal area growth was 1.760 square feet per acre or 57% of the gross value. The stand annually increased its basal area by 1.8%; however, the increase amounted to 1% after deducting mortality.

Growth information from virgin forests provides an important ecological and historical record, especially since most accessible stands have already been harvested at least once. The information also provides benchmark data to compare with the effects of various management alternatives on stand growth and development in similar stands. It can be used in management planning when suitable local growth information — from managed or virgin stands — is unavailable. The data can be used in the development and validation of computer simulation models. The long-term records from the virgin southwestern ponderosa pine stands in the G. A. Pearson Natural Area (Avery et al. 1976) are an excellent example of a similar but longer data base.

The Willow-Thomas Creek virgin stand inventory base is being reduced as expermental watershed treatments are applied to it. Although it would be ideal for some undisturbed forest areas to be reserved for assessing long-term stand growth and development, it would be most advisable to establish these types of studies in managed stands to test the effects of various silvicultural prescriptions. This is particularly important, considering the lack of growth information from managed mixed conifer stands.

Table 15a.—New "initial" stand table by number of trees per acre (including ongrowth).

D.B.H. size class	Species[1]								
	ES	BS	DF	WF	CF	PP	WP	QA	All species
(Inches)									
2	26.79	6.18	43.28	22.67	8.24	12.37	12.37	2.06	133.96
4	12.88	0.52	40.70	18.03	4.12	11.85	6.70	12.88	107.68
6	8.70	1.83	19.24	8.24	1.83	4.35	3.89	22.21	70.29
8	5.15	0.64	9.79	5.41	2.32	1.93	2.58	17.65	45.47
10	6.35	0.74	6.18	1.48	1.81	1.48	1.81	11.54	31.39
12	5.04	0.34	4.52	1.60	1.55	1.26	0.74	5.10	20.15
14	3.41	0.50	4.50	1.09	0.88	1.01	0.76	2.31	14.46
16	2.12	0.19	3.03	1.03	0.48	1.03	0.90	1.61	10.39
18	1.42	0.10	2.21	0.94	0.25	0.89	0.56	0.58	6.95
20	0.80	0.14	1.69	0.64	0.10	1.28	0.27	0.27	5.19
22	0.48	0.14	1.43	0.54	0.08	1.07	0.22	0.12	4.08
24	0.23	0.03	1.35	0.52	0.03	0.80	0.14	0.03	3.13
26	0.16	0.01	1.15	0.44	0.01	0.84	0.17	0.02	2.80
28	0.06	0.01	0.56	0.42	0.01	0.43	0.10		1.59
30	0.03		0.56	0.38		0.29	0.08	0.01	1.35
32	0.01		0.33	0.28		0.18	0.04		0.84
34	0.01		0.34	0.18	0.01	0.04	0.03		0.61
36			0.15	0.17		0.04	0.01		0.37
38			0.11	0.08		0.02	0.02		0.23
40			0.11	0.06		0.01			0.18
42			0.05	0.02			0.01		0.08
44			0.02	0.01			[2]T		0.03
46			0.02						0.02
48			0.01						0.01
Total	73.64	11.37	141.33	64.23	21.72	41.17	31.40	76.39	461.25
%Distrib.	16	2	31	14	5	9	7	16	100

Table 15b.—New "initial" stand table by basal area (square feet) per acre (including ongrowth).

D.B.H. size class	Species[1]								
	ES	BS	DF	WF	CF	PP	WP	QA	All species
(Inches)									
2	0.58	0.14	0.94	0.50	0.18	0.27	0.27	0.04	2.92
4	1.12	0.04	3.55	1.57	0.36	1.03	0.58	1.12	9.37
6	1.71	0.36	3.78	1.62	0.36	0.85	0.76	4.36	13.80
8	1.80	0.22	3.42	1.89	0.81	0.67	0.90	6.16	15.87
10	3.46	0.40	3.37	0.81	0.99	0.81	0.99	6.30	17.13
12	3.96	0.27	3.55	1.26	1.21	0.99	0.58	4.00	15.82
14	3.64	0.54	4.81	1.17	0.94	1.08	0.81	2.47	15.46
16	2.97	0.27	4.23	1.44	0.67	1.44	1.26	2.25	14.53
18	2.52	0.18	3.91	1.66	0.45	1.57	0.99	1.03	12.31
20	1.75	0.32	3.69	1.39	0.22	2.79	0.58	0.58	11.32
22	1.26	0.36	3.78	1.44	0.22	2.83	0.58	0.32	10.79
24	0.72	0.09	4.23	1.62	0.09	2.52	0.45	0.09	9.81
26	0.58	0.04	4.23	1.62	0.04	3.10	0.63	0.09	10.33
28	0.27	0.04	2.38	1.80	0.04	1.84	0.40		6.77
30	0.14		2.74	1.89		1.44	0.40	0.04	6.65
32	0.04		1.84	1.57		0.99	0.22		4.66
34	0.04		2.16	1.17	0.04	0.22	0.18		3.81
36			1.03	1.17		0.32	0.04		2.56
38			0.85	0.63		0.14	0.18		1.80
40			0.94	0.54		0.09			1.57
42			0.45	0.22			0.09		0.76
44			0.18	0.14			0.04		0.36
46			0.27						0.27
48			0.09						0.09
Total	26.56	3.27	60.42	27.12	6.62	24.99	10.93	28.85	188.76
%Distrib.	14	2	32	14	4	13	6	15	100

[1] *ES = Engelmann spruce, BS = Blue spruce, DF = Douglas-fir, WF = White fir, CF = Corkbark fir, PP = Ponderosa pine, WP = Southwestern white pine, QA = Quaking aspen.*
[2] *Trace*

Table 16.—Volumes for the new stand on Willow-Thomas Creek.

Species	Board feet	Cubic feet
Engelmann spruce	3,229	709
Blue spruce	391	88
Douglas-fir	6,975	1,434
White fir	3,813	721
Corkbark fir	679	158
Ponderosa pine	4,499	809
Southwestern white pine	1,202	262
Quaking aspen	2,276	676
Total	23,064	4,857

Table 17.—Point summary of important stand and growth statistics for the 5-year measurement period (on a per acre basis).

	Initial stand	Mortality	Ingrowth	5-year stand w/ingrowth	Gross growth	Net growth
Trees	491.26	33.03	0	458.23	0	-33.03
Basal area (ft^2)	177.77	6.56	0	171.21	0	- 6.56
Board feet	21,051	570	474	22,833	2,352	1,782
Cubic feet	4,483	137	55	4,841	495	358

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Appendix

Common and Scientific Names of Trees Mentioned

Blue spruce	*Picea pungens* Engelm.
Corkbark fir	*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.
Douglas-fir (Rocky Mountain)	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco
Engelmann spruce	*Picea engelmannii* Parry
Gambel oak	*Quercus gambelii* Nutt.
New Mexican locust	*Robinia neomexicana* A. Gray
Ponderosa pine	*Pinus ponderosa* Laws.
Quaking aspen	*Populus tremuloides* Michx.
Southwestern white pine	*Pinus strobiformis* Engelm.
White fir	*Abies concolor* (Gord. & Glend.) Lindl.
Willow	*Salix* spp.

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