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Development of Some Young Aspen Stands In Arizona

John R. Jones and David P. Trujillo¹

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CONTENTS

	Page
Review	1
Study Area	2
Objectives	2
Data Collection	2
Calculations	3
Results	4
Stocking, Height Growth, and Standing Crop	4
Growth in Diameter, Basal Area, and Bole Wood	7
Clonal Comparisons	8
Discussion	9
Literature Cited	10

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John R. Jones and David P. Trujillo

Quaking aspen (*Populus tremuloides* Michx.) forests occupy somewhat more than a half million acres in Arizona, New Mexico, and the adjacent San Juan Basin of Colorado. In the same region, aspen is also a significant stand constituent in roughly 2½ million acres of conifer forest, which wildfire or heavy cutting can convert to aspen dominance.

The zone of important aspen occurrence—the upper montane and lower subalpine elevations—receives annual precipitation averaging from 15 to 45 inches, but mostly 20 to 30 inches. This zone includes much of the more productive timber-growing land, produces much of the streamflow originating within the region, and constitutes important summer range for deer and elk. Cool summers, scenic diversity, and wildlife make it important to recreationists.

Increasing demands for those commodities and amenities call for increasingly intensive and skillful forest management. That, in turn, requires improved understanding of the biological, ecological, hydrological, and sociological processes involved. This study looks at some biological and ecological aspects of the development of young aspen stands which sprouted in the ashes of a coniferous forest.

REVIEW

Burning or clearcutting aspen forest in the West may result in sucker stands with densities of 14,000 to 110,000 stems per acre. Maximum density is likely the year following disturbance (Sampson 1919, Baker 1925, Smith et al. 1972, Jones 1975); numbers decline gradually thereafter. Losses to disease, browsing, competition, and so forth are not made up by additional suckering, presumably because of the apical dominance and shading effects of the numerous survivors (Maini and Horton 1966, Steneker 1974).

Stand establishment can take a somewhat different course when a coniferous stand with an aspen mixture is clearcut or burned. Regeneration is likely to be substantial the year following disturbance, but the site may be less than fully occupied. Additional suckering may then increase the number of young aspen for several years despite attrition. This pattern has been observed on mixed conifer clearcuttings in Arizona, and was documented by Patton and Avant (1970) on a burn in the Sangre de Cristo Mountains of New Mexico and by

Jones and Trujillo (1975) in the White Mountains of Arizona. On the area studied by Patton and Avant, the number of aspen peaked the third year after the fire at 14,550 per acre. Where aspen are fairly numerous in a coniferous stand, the number of aspen suckers following stand destruction may soon approach the number surviving where the parent stand was pure aspen.

Data on aspen growth and stand development in the West are very limited. Baker (1925) published a valuable and broadly informative collection of observations, but his data on growth are largely for stands of age 30 or older from one central Utah watershed. Recent data on development on a 4-year-old aspen clearcut in Arizona (Jones 1975) are from a single site.

Aspen suckers grow much faster than coniferous seedlings: 3-year-old conifers at these elevations in the Southwest commonly are about 3 inches tall (Jones 1971), while 3-year-old aspen are likely to exceed 3 feet (Baker 1925, Jones 1967) and may exceed 10 feet (Jones 1975).

For forest species in general, densities as great as those commonly found in young aspen stands lead either to heavy juvenile mortality or severe growth stagnation. Normally, early differentiation into crown classes results in heavy mortality among overtopped aspen, and allows continued good growth by trees with strong canopy positions (Graham et al. 1963, Pollard 1971, Jones 1975). Stagnation seems to occur in occasional clones, however (fig. 1). Graham et al. (1963) stated that, in

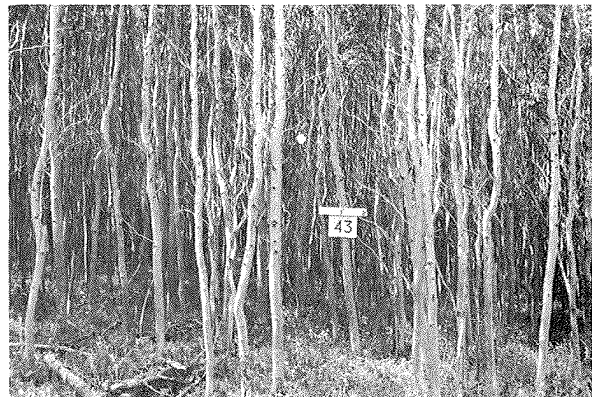


Figure 1.—Clone of stunted 70-year-old aspen showing little sign of natural thinning. Sierra del Don Fernando, Carson National Forest, New Mexico.

Michigan, major natural thinning in young aspen stands commonly occurs at about age 5 and again at about ages 15 and 25. In the Southwest the climate, pathology, and to a degree the growth rates are different, however, and according to Pauley et al. (1963) the aspen differ appreciably genetically from those in the Lake States. Therefore one might expect natural thinning to be timed differently in the Southwest.

STUDY AREA

Between June 23 and July 3, 1951, fire destroyed 19,600 acres of coniferous forest on Escudilla Mountain on the Apache National Forest in east-central Arizona (fig. 2). Most of the forest was virgin. Young aspen stands now occupy much of the burn (fig. 3). The study sites, at 9,300-9,600 feet elevation, were dominated, before burning, by Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) and Engelmann spruce (*Picea engelmannii* Parry), but had substantial though variable mixtures of aspen as well as other conifers. Salvage logging began shortly after the fire, and apparently was completed on the study sites before winter.

Judging from temperature stations at similar elevations elsewhere in the White Mountains, average daily July maxima and minima are about 68° and 43°F. For January they are about 39° and 9°F. Average annual precipitation is about 22-23 inches, with perhaps 8 inches falling as monsoon rains in July and August and 10 inches as snow from November through April.

Parent rock is vesicular basalt, which has given rise to very stony silty-loam soils. The plots are on gentle to moderate slopes.



Figure 2.—Mixed conifer forest on unburned flank of Escudilla Mountain, similar to that burned.

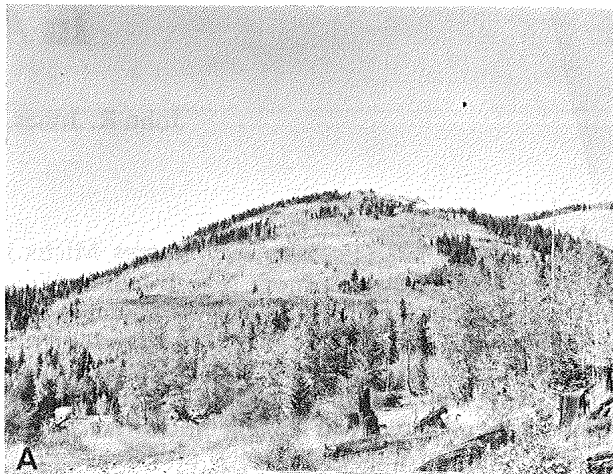


Figure 3.—Young aspen forest on part of the Escudilla Mountain burn: A, Perspective view. B, Interior view.

OBJECTIVES

The broad purpose was to describe some young aspen stands and their development. Specific objectives were to:

1. Describe stocking, height growth, and standing crop in several 22-year-old stands.
2. Describe the growth in diameter, basal area, and aboveground volume in one of the stands.
3. Compare growth and stocking in different clones sharing the same sites.

DATA COLLECTION

Objective 1

A square 0.01-acre plot was laid out in each of four locations. Each plot had from 62 to 95 live

aspens. Each was fairly representative of the stand in which it occurred, except for one constraint: small gaps such as old truck trails, skid roads, and log landings, occur throughout the stands, but none were included in or were immediately adjacent to any plot. Each plot was within a single clone, and no two plots shared the same clone. Plot 1 was located where growth had been notably superior. Plots 2 and 3 showed intermediate height growth. Plot 4 had exceptionally poor growth; its soil was very shallow and stony, and bedrock was exposed nearby.

On each plot, all live and dead trees were numbered and their diameters at breast height (d.b.h., 4.5 feet aboveground) recorded. The crown classes of live trees were also recorded. Dead trees which had broken below breast height were counted but not measured.

On each plot, five randomly selected sample trees from each live crown class were felled. The total height of each sample tree and height to the lowest live branch were recorded. Heights at the end of 1971 and 1972 also were recorded, as defined by bud scars. Below the 1971 height, diameters were taped at eight measured heights along the bole, except that some small, overtopped trees had as few as six diameter measurements. At each point of diameter measurement, a cross section was cut for ring counts.

Rings were counted in the laboratory on all sections except for a few decayed sections from overtopped trees.

Some dead trees were also cut, but the severe growth suppression preceding death made meaningful ring counts impossible.

Objective 2

Plot 2 was chosen for this part of the study. Many of the needed data were acquired for objective 1. In addition, on all sections from live trees, two widths for each ring were measured with a dendrochronograph across a stem diameter subjectively chosen as representative. On all overtopped trees, outer rings were too narrow to measure, even with maximum magnification. On these trees the inner rings, which were larger, were measured individually. The outer rings were measured as a group. Individual ring widths for rings measured as a group were roughly estimated by dividing group width by the number of rings in the group.

Objective 3

Clones in the clonal comparisons were selected because of their noticeable contrasts.

Adjacent to plot 3 and entirely surrounded by the clone occupying plot 3 was another, relatively open, clone of only about 20 ramets. Its bark color was substantially different, the trees were much larger, the wood was distinctly yellow, and the leaves were still green when those on plot 3 were yellow and falling. The site appeared to be the same as on the adjacent plot 3; digging did not reveal any subsurface difference. The four dominant trees in this clone were felled. Measurements and cross sections were taken as on plot 3 for comparison with the dominant sample trees from plot 3. This small clone was designated plot 3A.

Plots 5 and 6 were established a half mile from plot 3, each in a different clone. The site appeared to be homogeneous. As is common, the boundary between these two clones was quite sharp. The clones were distinguished by a notable difference in bark color, tree size, stocking density, and (at the time of sampling) leaf color. The clone with the largest trees also had noticeably closer spacing between trees.

The plots used to characterize these two clones were narrow, linear, nearly parallel, up and down hill, and only 18 to 25 feet apart, to maximize habitat similarity while avoiding interclonal competition. Each plot consisted of five equal subplots in a row. Each subplot was paired with one in the other clone; each was 2.5 milacres. Trees were counted and their d.b.h.'s recorded, by subplot. On each subplot the tree with the largest d.b.h. was felled, its height recorded, and cross sections collected at eight measured heights for ring counts. Heights at the end of 1971 and 1972 were also recorded.

CALCULATIONS

Height-Growth Curves

A height-growth curve was made for each live tree cut on every plot, based on the ring count at each cross section. To assume that a section height marked the end of a year's growth would introduce a small but consistent bias. Therefore it was assumed that height growth had been linear between two cross sections and that each cross section was the midway point in a year's height growth. This reduced the error effect and largely freed it from bias.

The mean curve of height growth was also constructed for each sampled live crown class on each plot.

Objective 1

Basal area was determined for plots 1-4 as the sum of the basal areas of all trees on the plot.

Standing crop was estimated for plots 1-4. The bole volume of each sample tree was taken as the sum of the volumes of its trunk sections including the stump. Volumes per acre were estimated from sample tree volumes. The mass of wood, bark, branches, and summer foliage were estimated from bole measurements using selected equations from Zavitkovski (1971). Branch and foliage weight equations used were those based on diameter at base of live crown. While Zavitkovski did not indicate coefficients of determination for his equations, his data points for the equations used here showed little dispersion around the regression lines, indicating good precision within his sample.

Objective 2

For each year, beginning with 1960 (stand age 9 years), the volume of each sample tree was estimated as the sum of the volume of its segments as calculated from its height-age curve and the width of growth rings. The cross sections had been oven-dried to avoid molding in storage, so measurements were conservative. Basal area was reconstructed from growth-ring measurements at breast height. Because past diameters were known only from growth ring measurements, basal areas and volumes in this part of the study were computed only for the stem inside the bark.

Expanding tree volumes to area volumes involved considerations of sampling adequacy for years prior to 1973. Sample-tree selection was random within crown classes for 1973, but in previous years the sample trees did not all belong to their 1973 crown class. Therefore a height-year matrix was made for all the sample trees on plot 2 as a basis for assigning trees to crown classes for years prior to 1973.

Prior to 1960 most of the 21 sample trees were dominant or codominant. Therefore, basal area and standing volumes before 1960 were not estimated.

The sample of overtopped trees is increasingly biased for earlier years because many of the overtopped trees of, say 1965, were dead in 1973 and not suitable for sampling. Therefore the overtopped class is not included in data on the development of basal area, diameter growth, or growth of standing volume.

Objective 3

The height-growth curves and current heights of the dominant trees on plot 3 are compared with those for plot 3A. The comparisons of plots 5 and 6 include number of dead and live trees; heights,

height curves, and d.b.h. of dominant trees; and basal area.

RESULTS

Stocking, Height Growth, and Standing Crop

We know too little about young aspen forests in Arizona to say how typical these stands are. The plots are sufficiently different from one another, however, to give us some idea of the variability that can be expected, even within a small climatically homogeneous area.

Stocking

Examination of stumps and down timber indicates that, although aspen was frequent in the parent stands, conifers had predominated on all but plot 4. Stocking data are summarized in table 1. In the 22-year-old postfire stands of plots 1-4, the number of young aspen, alive and dead, averaged 9,400 per acre when disturbance openings are excluded. Of these, 77 percent are still alive.

Many of the broken dead stubs were less than 0.3 inch in diameter near the ground, suggesting that trees dead as long as 15 years were still recognizable for tallying. Therefore, while some suckers certainly died early enough that they had disappeared by 1973, the combined tally of live and dead aspen in table 1 is believed to account for a large majority of all the suckers that came up.

Although the fire burned at the end of June 1951, no sample tree on any plot reached stump height (6 inches) in 1951. We do not even know that any suckers appeared above the soil surface that first summer. Of the 7,250 aspen per acre alive in 1973, 67 percent seem to have emerged in 1952; at least that is when they reached stump height. Another 22 percent first showed up in 1953, and scattered others later. On plot 4, the only plot where aspen outnumbered conifers in the pre-fire overstory, all sample trees, even the overtopped, came up by 1952.

The most important regeneration—all 40 of the sample dominants and codominants on plots 1-4—apparently took place in 1952 and 1953. All sample trees that came up in 1954 or later were in subordinate crown classes by 1973. We do not know when the trees appeared that were dead in 1973. It is reasonable to suppose that many of them came up in 1954 or later, considering the competitive disadvantage of late suckers (Jones 1975).

Almost 70 percent of all trees tallied were dead or overtopped. Only 23 percent were in the dominant and codominant classes, but that 23 percent constitutes 64 percent of the total live and dead basal area.

Table 1.--Number of trees, and basal area, by plot and tree class (per-acre and per-hectare basis)

Tree class	Number of trees				Basal area			
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
	- - - - No./acre - - - -				- - - - ft ² /acre - - - -			
Dominant	500	500	500	500	44	38	25	18
Codominant	1,600	1,700	1,900	1,500	87	73	56	35
Intermediate	600	500	1,100	900	20	13	16	10
Overtopped	6,700	4,500	3,200	2,800	75	36	15	13
All live	9,400	7,200	6,700	5,700	226	160	112	76
Dead	1,300	3,000	1,700	2,600	3	7	2	(¹)
All trees	10,700	10,200	8,400	8,300	--	--	--	--
	- - - - No./hectare - - - -				- - - - m ² /hectare - - - -			
Dominant	1,235	1,235	1,235	1,235	10.2	8.8	5.7	4.1
Codominant	3,954	4,201	4,695	3,707	20.0	16.7	12.9	8.0
Intermediate	1,483	1,236	2,718	2,224	4.6	3.1	3.6	2.3
Overtopped	16,556	11,119	7,907	6,919	17.3	8.2	3.6	2.9
All live	23,228	17,791	16,555	14,085	52.1	36.8	25.8	17.3
Dead	3,212	7,413	4,201	6,425	.6	1.7	.5	(¹)
All trees	26,440	25,204	20,756	20,510	--	--	--	--

¹Less than 0.5 ft²/acre (0.05 m²/hectare)

Height Growth

Plots 1-4 were numbered in order of dominant height in 1973 (fig. 4). That is also the order of basal area and number of stems. There are no obvious habitat differences between plots 1, 2, and 3 that would seem to account for height differences. The plots were considerably separated, however, and detailed habitat measurements were not made. Plot 4, on the other hand, is notably stonier, and bedrock is exposed in the immediate vicinity.

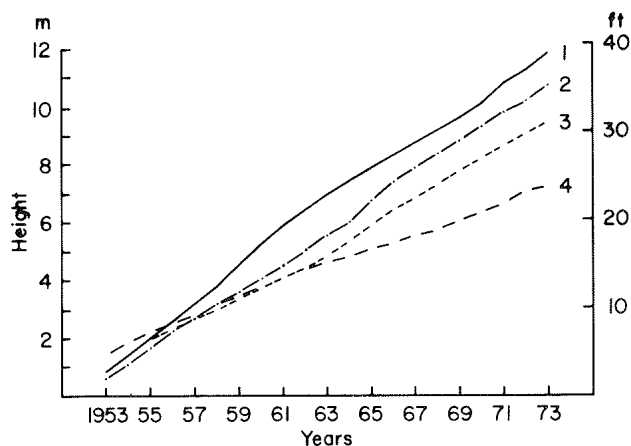


Figure 4.—Height-growth curves for the average dominant tree on plots 1-4.

On plots 1, 2, and 3 the height curves of the current dominant and codominant classes could be differentiated only after several years (fig. 5). In contrast, those for plot 4 were distinct from the beginning. On plots 1 and 2 the overtopped sample trees were more inferior in height and have been inferior longer, than those on plot 3 and particularly plot 4. That may have been due to the heavier stocking and presumably more severe shading on plots 1 and 2, or from site or genetic differences. It probably does not reflect sampling chance; on each plot, the sample mean d.b.h. for each class was quite close to the mean of all trees in the class.

Standing Crop

Under the conditions of site and genotype represented by plots 1-4, bole volumes of live trees ranged from 4,268 cubic feet per acre to 929 cubic feet per acre at age 22 (table 2). From 67 to 79 percent of bole volume was in dominant and codominant trees, despite the large preponderance in number of overtopped trees.

In terms of total bole volume, the mean annual increment of plot 4, the slowest growing, was 42 cubic feet per acre, and of plot 1, the fastest growing, 194 cubic feet per acre.

Zavitkovski's (1971) equations allow us to estimate the oven-dry weight of the aboveground

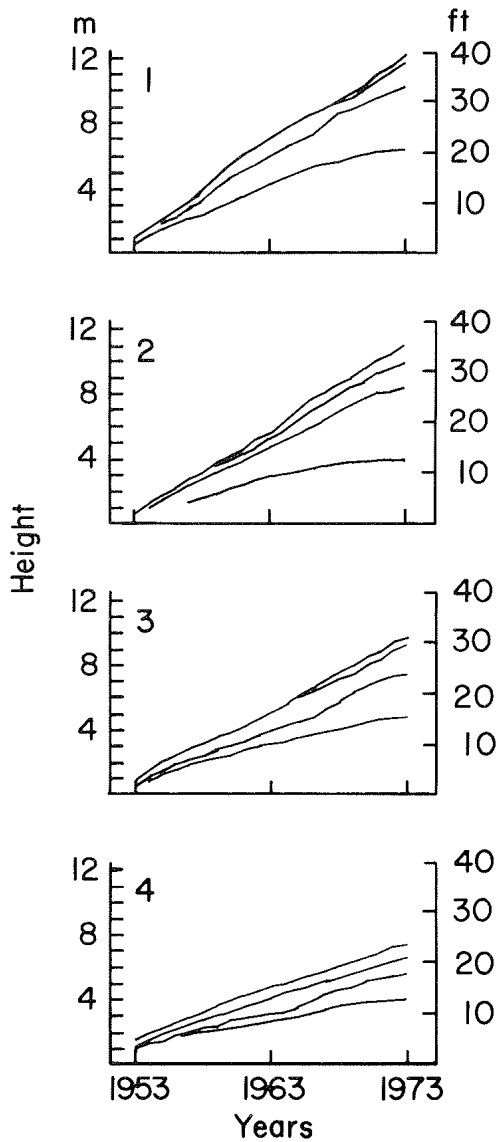


Figure 5.—Height-growth curves for each live crown class, plots 1-4.

Table 2.—Bole volume of live trees, and its distribution among crown classes

Volume and distribution	Plot 1	Plot 2	Plot 3	Plot 4
	-- ft ³ /acre (m ³ /hectare) --			
<u>Volume</u>	4,268 (299)	2,486 (174)	1,776 (124)	929 (65)
	----- Percent -----			
<u>Distribution:</u>				
Dominant	21	29	24	26
Codominant	46	49	55	50
Intermediate	7	8	12	12
Overtopped	26	14	9	12

parts of trees, and by expansion, of stands (table 3). Dry-weight estimates for boles (wood plus bark) using Zavitkovski's equations (table 3) are close to values determined from bole volumes (table 2), as shown below:

	Bole dry weight, based on— Zavitkovski (1971) Tree volume (lb/acre)	
Plot 1	101,745	101,133
Plot 2	57,467	58,842
Plot 3	39,956	42,023
Plot 4	18,499	21,993

Table 3.—Ovendry weight (DW) of live trees, excluding roots, using equations from Zavitkovski (1971)¹

Tree components	Plot 1	Plot 2	Plot 3	Plot 4
	----- lb/acre -----			
Bole wood	83,775	47,234	32,709	15,075
Bole bark	17,970	10,233	7,247	3,424
Branches	9,503	9,148	6,569	5,655
Foliage	2,646	2,310	1,851	1,550
Total	113,894	68,925	48,376	25,704
	----- kg/hectare -----			
Bole wood	93,896	52,953	36,658	16,890
Bole bark	20,140	11,469	8,122	3,837
Branches	10,649	10,251	7,362	6,337
Foliage	2,965	2,589	2,074	1,737
Total	127,650	77,262	54,216	28,801

¹Equations used are for individual trees. They were applied to each sample tree, and the results expanded to weights per area by crown classes.

$$\log_{10} DW_{kg} =$$

for bole wood--

$$1.028 \log_{10} (d.b.h._{cm}^2 \times ht_m) - 1.961$$

for bole bark--

$$0.981 \log_{10} (d.b.h._{cm}^2 \times ht_m) - 2.500$$

for branches--

$$2.716 \log_{10} (diam_{cm} \text{ at crown base}) - 1.764$$

for foliage--

$$2.242 \log_{10} (diam_{cm} \text{ at crown base}) - 2.031$$

Values based on bole volumes assume a wood specific gravity of 0.36 for green volume (Brown et al. 1949). Data on the specific gravity of aspen bark are rather variable (Hale 1955, Lamb and Marden 1968, USDA Forest Products Laboratory unpublished); an intermediate value of 0.50 was used here, along with a bark-wood dry-weight ratio of 0.22 based on Zavtkovski (1971).

The dry-weight estimates indicate that production of bole wood and bark is much more strongly influenced by the site-genotype interaction than is the production of branches and leaves (table 4). This is not surprising. Where conditions are limiting, one might expect the crown to have priority in resource allocation.

Table 4.--Weight of tree components, on different plots, as ratios of their weights on plot 4

Tree components	Plot 1	Plot 2	Plot 3	Plot 4
Bole wood	5.56	3.14	2.17	1.00
Bole bark	5.25	2.99	2.12	1.00
Branches	1.68	1.62	1.16	1.00
Foliage	1.71	1.49	1.19	1.00

Growth in Diameter, Basal Area, and Bole Wood

All data in this section are from a single plot, plot 2.

Diameter Growth

The diameter growth of a year's new leader extension is much greater near the base than near the tip. In the second and subsequent years it is similar throughout the internode. Therefore, diameter growth at breast height (fig. 6) is considered here only for the second and subsequent summers after breast height was surpassed. The indicated growth rates are conservative, since they are based on ring measurements of oven-dried wood. The trees contributing to the graph for each class were members of that class in 1973. Judging from the individual tree-height curves, the sample trees for all three classes were codominants or dominants in 1961 and earlier.

A conspicuous feature of figure 6 is the marked reduction in diameter growth from 1959 through 1962. Records from the weather station at Alpine, Arizona, 7 miles away and 1,400 feet lower, show no climatic peculiarities for that period. The reduction may have resulted from intensifying

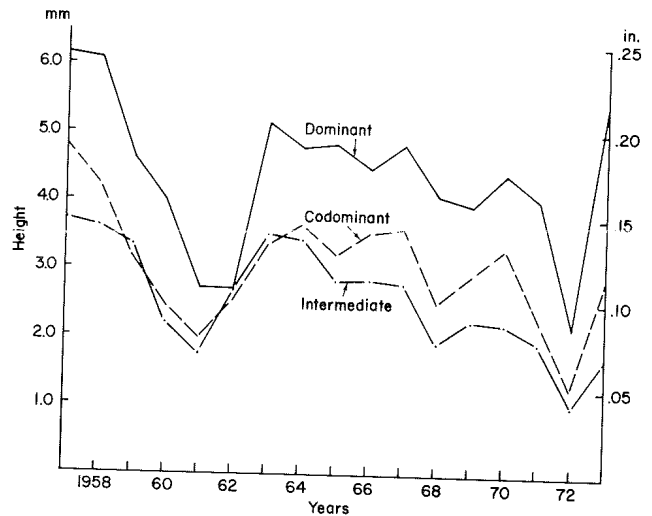


Figure 6.—Diameter growth at breast height, by year, for the dominant, codominant, and intermediate classes on plot 2.

competition in the dense sucker stand. The recovery might then reflect an easing of overstory competition as many of the competitors were overtopped and suppressed.

Competition would not seem to explain the abrupt growth reduction in 1972 followed by the strong recovery of 1973. January through April 1972 was almost utterly without precipitation, and our first reaction was that drought accounted for the poorer 1972 growth. But the soil profile was nonetheless moist in spring, recharged by heavy rains the previous October and by the melting of heavy November and December snows. Then, in late May at about the time leafing began, the normal May-June dry season was aborted by substantial showers which were repeated with unprecedented frequency through June. Soil moisture must have been more favorable than usual.

Defoliation can reduce aspen diameter growth. In two Arizona locales, including one in the White Mountains, the senior author noticed occasional light partial defoliation in 1972 by the western tent caterpillar, *Malacosoma californicum* Packard. Only heavy defoliation would have caused such severe growth reduction, however (Hodson 1954, Stelzer 1968). It is not known whether heavy, or any, defoliation occurred on Escudilla Mountain that year.

In almost every year, maximum diameter growth occurred in the upper bole, within the crown. The narrowest rings were laid down in the uppermost meter. Two years or so later, rings at that same cross section typically were wider than anywhere else along the stem. That pattern broke down abruptly in 1971, possibly due to the same factor that caused the marked diameter growth reduction of 1971 and 1972.

Growth of Basal Area and Bole Wood

Growth of basal area and bole wood fluctuated substantially from year to year (fig. 7) with fluctuations in diameter growth (fig. 6). They were graphed as relative growth—the ratio of growth in a given year to growth in the best year. Relative growth was used because the volume and basal area growth data are from oven-dried samples, and because it was necessary to omit overtopped trees. Although many of the sample trees had been in stronger crown classes in 1960 than in 1973, this should not markedly affect the graphs, which are based on weighted crown class averages for the years graphed.

There was no apparent tendency for growth of either basal area or bole wood to increase or decline in this stand over the short period included in the study. If such a tendency exists, it was obscured by year-to-year variability, particularly the low points already discussed in the section on **diameter growth**.

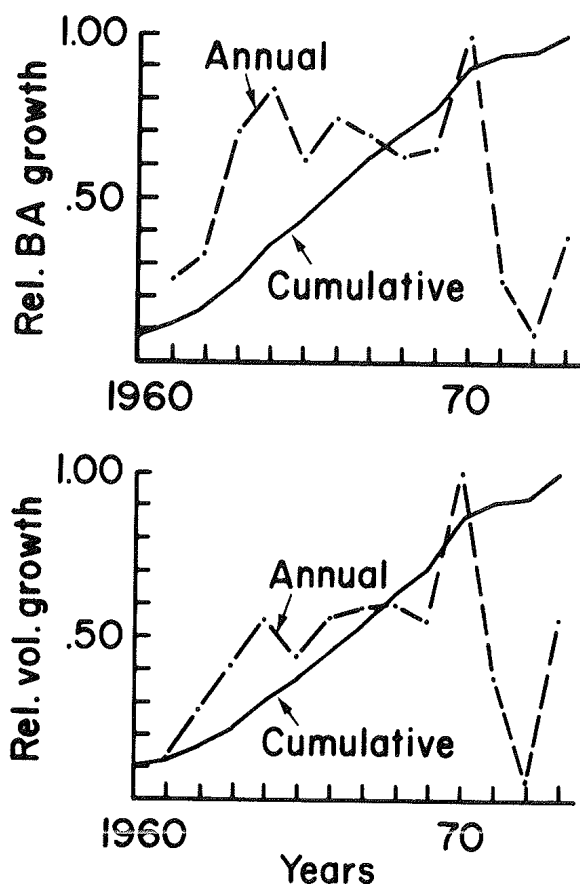


Figure 7.—Relative growth of basal area and bole wood on plot 2. 1.00 represents growth in the year of greatest growth. Data are weighted for the estimated number of trees per acre in the dominant, codominant, and intermediate classes in each of the years graphed. Data from the overtopped class were omitted.

Clonal Comparisons

Because there was no opportunity for randomization in clonal comparisons, probability tests were not used.

Plots 3 and 3A

The contrasts between these two clones are noticeably greater than usual. Heights of dominants on plots 3 and 3A began to diverge rather abruptly about 1957; the divergence continued until 1963 when the dominants on plot 3A averaged more than 23 feet tall while those on plot 3 averaged 16 feet. Since 1963 they have grown at similar rates (fig. 8). Beginning in 1961, the shortest dominant on plot 3A has been taller than the tallest on plot 3. Stocking data were not taken on plot 3A, but its stocking was clearly the least, and the clumpiest, in the study.

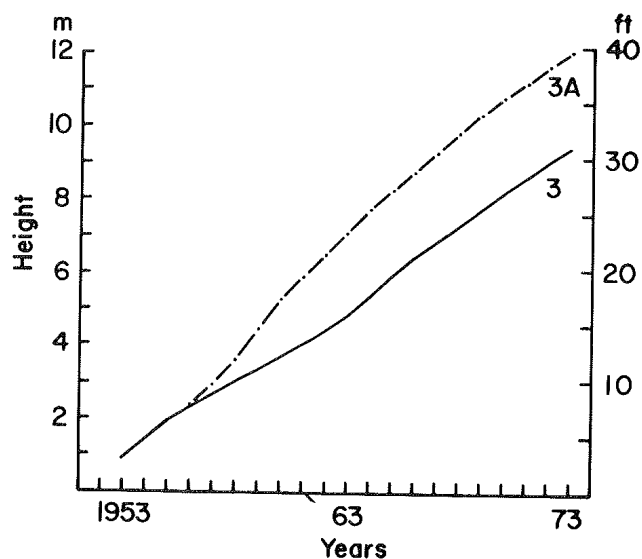


Figure 8.—Height-growth curves for paired clones, plots 3 and 3A.

Plots 5 and 6

The two clones represented by plots 5 and 6, are compared in the tabulation below. For each subplot pair, plot 6 had more live trees and more total trees than plot 5. Furthermore, in every subplot comparison the largest diameter and height were on plot 6. Plot 6 had the greatest basal area on all but one of the subplot pairs, and a 35 percent greater basal area overall.

Character	Plot 5	Plot 6
Number of stems		
Alive	96	139
Dead	54	103
All	150	242
Diameter breast height (max)		
Inches	2.4	3.0
Centimeters	6.1	7.7
Live basal area		
Square feet/acre	90	122
Square meters/hectare	20.7	28.1
Average height of dominants		
Feet	23.6	27.6
Meters	7.20	8.42

Unlike the dominants on plots 3 and 3A, dominants on plots 5 and 6 grew at similar rates until the stand was 16 years old (fig. 9).

Plots 5 and 6 had been the most heavily stocked of any in the study. Plot 5 had 12,000 trees per acre alive and dead, and plot 6 had 19,360 per acre.

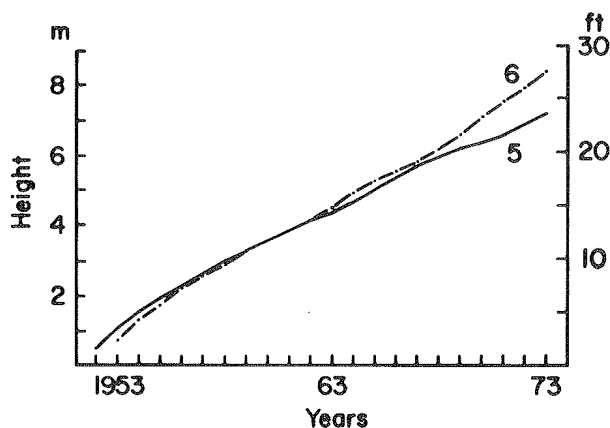


Figure 9.—Height-growth curves for paired clones, plots 5 and 6.

DISCUSSION

Aspen, where frequent in conifer stands, has the ability to reforest sites promptly and heavily following destructive burning. Also, aspen regeneration grows much faster than young conifers on the same sites (Baker 1925, Jones 1971). In this study, dominant aspen varied from 24 to 40 feet tall 23 years after the fire. Where conifers instead of aspen had regenerated the burn, dominants stood only about 5 to 12 feet tall. Mostly, though, where aspen had been absent before the fire, few trees of any species were present after 23 years.

Where a good coniferous seed source was available, coniferous seedlings usually had invaded the young aspen stands in significant numbers.

Our data conform with limited observations (Patton and Avant 1970, Jones and Trujillo 1975) that, if aspen stands follow the burning or clear-cutting of mixed conifer forest, new suckering may increase stocking for several years and produce a dense stand. In this instance, however, dominant and codominant trees originated very largely during the first two summers of regeneration.

The apparent absence of aspen regeneration the summer following this late-June fire also conforms with limited earlier data. Sampson (1919), and Baker (1925) did not find significant regeneration on aspen summer clearcuttings until the following year. Further, regeneration was light during the summer immediately following spring clearcutting. Jones (1975) found 1970 regeneration inadequate following clearcutting of an Arizona aspen stand in May and June 1970. In all those cases, stocking was heavy the following year. It may be that the growth inhibitor which mediates apical dominance in aspen and inhibits sucker development (Farmer 1962, Schier 1973, Steneker 1974) begins moving into the roots about the time growth starts in spring, which is before logging or fire usually occurs at these elevations, and persists through that growing season.²

Some of the factors influencing aspen height growth may also influence early stocking. The order of dominant heights on plots 1-4 was the same as the order of number of trees. Plots 5 and 6 fell outside that ranking, but of the two, plot 6, with the tallest trees, had many more trees than plot 5 on a seemingly identical habitat.

Plot 3A was the marked exception to the above relationship. Its dominants were the tallest in the study but stocking was relatively light and clumpy.

The long persistence of young, overtopped suckers was unexpected. The height curves of some live overtopped trees indicate they had been overtopped since before 1960. Some had very little foliage. Perhaps they survived on photosynthates from clone-mates via the root connections described by Day (1944), DeByle (1964), and subsequent publications.

Plot 1 had the fastest growing aspens of any plot where volume measurements were made. (The dominants on plot 3A were slightly taller.) The mean annual volume increment (MAI) on plot 1 had been 194 cubic feet/acre, much greater than the potentials indicated for the best Arizona aspen sites, fully stocked, in the recent Forest Survey summary (Green and Setzer 1974). Forest Survey indicates no aspen sites in Arizona with potential MAI greater

²Personal communication from George A. Schier, Intermountain Forest and Range Experiment Station, Logan, Utah.

than 120 cubic feet/acre, and only about 8 percent of Arizona aspen acreage with a potential MAI as high as 85 cubic feet/acre.

Considering limited data from other Arizona aspen stands (Jones and Trujillo 1975 and unpublished data), height growth on plot 1 was good but not exceptional for Arizona. That on plot 3, with an MAI nearly in the best 8 percent according to Forest Survey, is actually quite mediocre. This suggests that: (1) the aspen yield equations used by Forest Survey are not satisfactory for Arizona, or (2) sampling procedures used by Forest Survey did not adequately describe aspen sites in Arizona.

The equations used by Forest Survey were designed to express peak MAI for fully stocked stands. They are from Baker's (1925) yield tables, adapted for use with Jones's (1966) site index table—the existing available sources. Baker's yield tables, however, are based on data from a single Utah watershed. Jones's site index tables were developed largely from Colorado data and may not be as suitable for Arizona as originally thought (Jones and Trujillo 1975). In addition, Forest Survey sampling intensities were chosen to provide a good overall picture of timber supplies. Although suitable for extensive forest types such as ponderosa pine in Arizona, they are weak for restricted types such as aspen.

The differences in height, diameters, and trees per acre of paired clones presumably are hereditary. They may be more conspicuous now than at maturity. Differences in initial sucker numbers will be increasingly obscured by natural thinning. Also, in most cases observed, height differences between paired clones tend to be established in early life, with growth curves later becoming more or less parallel (Jones and Trujillo 1975, and plots 3 and 3A in this study). An 8-foot height difference is more striking in 22-year-old stands than in 80-year-old stands. Nonetheless, associated differences in volume at maturity should be substantial for clones differing by 8 feet in height.

Our knowledge of the growth and yield of aspen in the western United States is inadequate. Small studies like this one only explore the potentials and problems. Definitive studies of growth and yield are needed within a framework of habitat types to provide improved evaluations for planning at regional levels, and for on-site management decisions at local levels.

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