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Sixty Years of Change in Tree Numbers and Basal Area in Central Utah Aspen Stands

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The Author

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Research Summary

Plots established in 1913-14 in three separate aspen (*Populus tremuloides* Michx.) stands on the Wasatch Plateau in central Utah were inventoried at irregular intervals over a 64-year period. The stands ranged in age from 40 to 70 years at the time of plot establishment. Each stand contained two contiguous plots, one thinned and the other untreated. All trees on each plot were tagged to enable tracing growth and mortality of individual stems in subsequent years. The data indicate that (1) stem numbers declined continuously as the stands aged; (2) an inverse relationship existed between aspen site quality and stem numbers in middle age stands; (3) basal area peaked probably sometime around 80 years of age and declined appreciably by age 100; (4) greatest subsequent mortality in middle age stands was those stems in diameter size classes smaller than the mode; and (5) stands thinned between the ages of 40 and 70 contained more but smaller stems at maturity and greater total basal area than those not thinned.

Acknowledgments

Frederick S. Baker, Forest Examiner with the U.S. Forest Service, began this study in 1913. Many other individuals were involved with data collection over the 64-year period. Those known to have collected data are: F. S. Baker, F. T. Mclean, and P. H. Roberts in 1913; S. E. Bower and E. R. Hodson in 1914; R. W. Beeson and C. F. Korstian in 1918; F. S. Baker and F. Stevenson in 1919; W. Thurby and L. F. Watts in 1929; K. T. Harper and R. D. Pfister in 1970; and R. O. Harniss and R. B. Campbell, Jr. in 1977.

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Long-term demographic records of trembling aspen (*Populus tremuloides* Michx.) are scarce. This is especially true for stands in the Western United States despite aspen's abundance in the Rocky Mountains and on the Colorado Plateau. In the Lake States where aspen is also abundant, 41 years of population change in several aspen stands was reported by Roberts and Richardson (1985). In the West, however, repeat measurements on the same stands usually have been confined to the first decade following stand regeneration (Bartos and Mueggler 1982; Bartos and others 1991; Crouch 1986). The work of Harniss and Harper (1982) is an exception; they determined stem numbers and basal area on the same 48 stands of mid-age aspen after an 8-year interval.

In the early 1900's Fredrick S. Baker began silvicultural studies on aspen stands growing in central Utah and adjoining areas. He later published a comprehensive monograph on aspen in the Central Rocky Mountain Region (Baker 1925). In 1913-14 Baker established a series of paired thinned and unthinned plots at the Great Basin Experiment Station on the Manti-La Sal National Forest. Three of these paired plots were remeasured at irregular intervals until the last measurements in 1977, but the data were never published. A review of these data and the scarcity of such records in the literature suggested the merit of making the records available in published form.

Methods

The plots described in this paper are in three separate stands (Willow Creek, Dusterberg Hill, and Potato Patch) at the Great Basin Experiment Station on the Wasatch Plateau approximately 60 miles south of Provo, UT. Each stand was sampled by two contiguous equally sized plots, one of which was thinned and the other not thinned. Each plot in both the Willow Creek stand and Dusterberg Hill stand was 0.5 acre in size. Each plot in the Potato Patch stand was 0.18 acre in size.

The Willow Creek stand is located at approximately 8,000 ft elevation on a 30 percent, slightly convex, west-facing slope. At the start of measurement in 1913 the stand was 40 years old. Aspen site index (Edminster and others 1985) in this stand is 51. Data on species composition of the undergrowth collected in 1977 indicated the stand is of the *P. tremuloides/Symphoricarpos oreophilus/Thalictrum fendleri* community type (Mueggler 1988). The 40-year-old unthinned plot contained 2,220 trees/acre, totaling 131.3 ft^2 of basal area. A "medium thinning" took place on the thinned plot in 1913 that removed all intermediate, suppressed, and dead trees. Of the original 2,288 trees/acre, 758 were removed for a 33 percent reduction in tree numbers. The basal area was 89.5 ft^2/acre following thinning. Light readings taken shortly after indicated 17-23 percent of full sunlight in the unthinned plot, and 25-30 percent of full sunlight in the thinned plot.

The Dusterberg Hill stand is at 8,800 ft elevation on a 15 percent, slightly convex, northwest-facing slope. The stand was 70 years old at the beginning of the study. Aspen site index is 41. Species composition data collected in 1977 indicated this stand to be of the *P. tremuloides/Amelanchier alnifolia-S. oreophilus/* Tall Forb community type. The 70-year-old unthinned plot contained 1,037 stems/acre with basal area totaling 196 ft^2. Originally the thinned plot contained 1,256 stems/acre. In 1914, 576 intermediate, suppressed, and dead trees, plus some of the co-dominant trees were removed. Following thinning, the basal area totaled 149.2 ft^2/acre. Light readings on the thinned plot were 42 percent of full sunlight; the unthinned stand had light readings averaging only 22 percent of full sunlight. An additional 15 trees were removed in 1919 for a total reduction of 47 percent of the stems by thinning.

The Potato Patch stand is on an 8 percent northwest-facing slope at approximately 8,000 ft elevation. The stand was 50 years old at the first measurement. Site index for this stand is 34. Vegetation composition in 1977 indicated that this stand is of the *P. tremuloides-Abies concolor/S. oreophilus* community type. The 50-year-old unthinned plot contained 3,007 stems/acre totaling 146.5 ft^2. The thinned plot in this stand originally contained 2,720 stems/acre; 939 were removed in 1914. After thinning this plot contained 101.6 ft^2/acre of basal area. The light intensity after thinning was 51 percent of full sunlight in the thinned stand, and 30 percent of full sunlight in the unthinned stand. An additional 242 stems were removed in 1915 and 129 in 1919. Total reduction in stem numbers was 48 percent. Only those stems that were intermediate, suppressed, or dead were removed.

At the beginning of the study all of the trees 1-inch diameter at breast height (d.b.h.) and over on each plot were tagged with an identification number to facilitate future measurements of individual stems. (The tags were nailed to the trunks; this might have provided an entry point for pathogens which in turn could have increased the level of stem mortality [Shepperd 1994].) The d.b.h. of each stem was measured and recorded by identity number. Height and age were also recorded for a few of the dominant stems on each plot. These measurements were repeated each time the plot was inventoried. The unthinned and thinned plots in the Willow Creek stand were inventoried in 1913, 1918, 1929, 1970, and 1977. The two plots in the Dusterberg Hill stand were inventoried in 1914, 1919, 1970, and 1977. The Potato Patch plots were inventoried in 1914, 1919, 1929, 1969, and 1977. Tree ingrowth (those stems not present at the first inventory) was measured only in the last 2 inventory years.

Some of the trees, by their size obviously present at the time of the original inventories, lost their identification tags in later years. Usually these trees could be properly identified by their location, identification numbers of surrounding trees, missing tag numbers, and d.b.h. measurements from prior inventories.

These demographic data are summarized in tables of changes in tree numbers by d.b.h. size classes, changes in total tree basal area, percent survival of trees of a given size class at the beginning of the study, and differences in the amount of ingrowth toward the end of the measurement period.

Results

The most obvious change that occurs as aspen stands age is the overall decrease in number of living trees as the trees become larger. Most mortality in aspen occurs in the first decade following stand regeneration. Sucker numbers the first two growing seasons following fire or clearcutting can exceed 30,000 per acre, but then usually decrease precipitously (Bartos and others 1991; Crouch 1986; Shepperd 1993). This decline in numbers slows but continues as stands grow older and the tree size classes shift toward the larger diameters.

Willow Creek

The unthinned plot in the Willow Creek stand contained 2,220 stems/acre at age 40; it lost 91 percent of these stems by the time it reached the age of 97 (table 1; fig. 1). During this time, average living stem d.b.h. increased from 3.2 inches to 8.2 inches. Stem numbers continued to decrease until by the age of 104 only 7 percent of the original stems were left. The total basal area of aspen on the plot increased gradually at least through age 56, but by age 97 had decreased over 40 percent from basal area at age 40 (fig. 2). This decrease in basal area also continued as the stand aged.

The thinned Willow Creek plot contained 1,458 stems following thinning at age 40. It lost only 77 percent of these stems by the time it reached the age of 97. By the end of the study the thinned plot contained over two-thirds more stems than the unthinned plot. The average living stem d.b.h. on the thinned plot increased from 3.3 to 7.0 inches by age 97, over 1 inch less than on the unthinned plot, probably because of the greater density of stems on the thinned plot. Average d.b.h. of the original stems on the thinned plot was only 7.5 inches by age 104 compared to 9.0 inches on the unthinned plot. Although the total basal area of aspen on the thinned plot following thinning was only about two-thirds that on the unthinned plot at age 40, it was approximately 20 percent greater than on the unthinned plot by age 97. As with the unthinned plot, aspen basal area on the thinned plot declined markedly by age 97.

The d.b.h. of the aspen at age 40 ranged from 1 to 6 inches, with a modal size class of 3 inches for both the unthinned and thinned plots. By age 97, the d.b.h. ranged from 6 to 12 inches with a 9-inch mode on the unthinned plot. On the thinned plot the trees were smaller overall with a size class range from 5 to 12 inches and a mode of only 7 inches. The trees in the unthinned plot gained 8.8 inches in d.b.h. over the 64-year interval, or an average increment of 0.09 inch/year. The gain in the thinned stand was only 4.2 inches, or 0.07 inch/year.

Natural thinning over the 64-year period occurred by mortality in the smaller diameter size classes (table 2). Very few of the trees 3 inches or less d.b.h. at age 40 were still alive by age 104. However, at least one-third of the trees on the unthinned plot with 5-inch or greater d.b.h. at 40 years were still alive after 64 years. Over one-third of the trees on the thinned plot with 4-inch or greater d.b.h. were still alive at the end of the study (with the exception of the two trees with 6-inch d.b.h. which may have been cut by trespass).

Ingrowth of aspen over 1-inch d.b.h. on the unthinned plot amounted to 40 stems per acre still alive at age 104 (table 3). About 20 percent of these were recruited during the previous 7 years, suggesting that aspen reproduction was occurring as the overstory deteriorated.

Table 1—Changes in the number of aspen trees per acre, excluding reproduction ingrowth, by diameter size classes (d.b.h.) in the unthinned and thinned portions of the Willow Creek aspen stand.

	Unthinned stand age (years)									
D.b.h.	40		45		56		97		104	
Inches	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*
1	10	(<1)	6	(<1)	2	(<1)				
2	478	(22)	258	(13)	4	(<1)				
3	1,000	(45)	766	(39)	324	(24)				
4	588	(26)	632	(33)	506	(37)				
5	132	(6)	244	(12)	360	(26)	10	(5)		
6	12	(<1)	30	(2)	136	(10)	30	(15)	22	(14)
7			4	(<1)	24	(2)	44	(21)	14	(8)
8					4	(<1)	36	(17)	24	(15)
9					2	(<1)	40	(19)	42	(26)
10							20	(10)	28	(17)
11							20	(10)	14	(8)
12							6	(3)	20	(12)
Total	2,220	(100)	1,940	(100)	1,362	(100)	206	(100)	164	(100)
Height dominant trees (ft/SE)[1]	32/1.1		—		42/0.9		54/1.8		56/1.4	

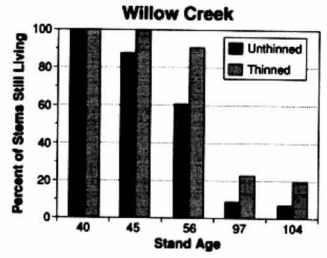
	Thinned stand age (years)									
D.b.h.	40		45		56		97		104	
Inches	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*
1	2	(<1)								
2	94	(6)	66	(5)	12	(<1)				
3	880	(60)	678	(47)	374	(28)				
4	438	(30)	584	(40)	574	(44)				
5	42	(3)	110	(8)	288	(22)	30	(9)	20	(7)
6	2	(<1)	2	(<1)	60	(5)	96	(29)	36	(13)
7			2	(<1)	6	(<1)	102	(30)	98	(35)
8					2	(<1)	72	(21)	62	(22)
9							20	(6)	46	(17)
10							14	(4)	12	(4)
11							4	(1)	4	(1)
12									4	(1)
Total	1,458	(100)	1,442	(100)	1,316	(100)	338	(100)	282	(100)
Height dominant trees (ft/SE)[1]	30/0.7		—		33/1.3		55/1.6		55/1.7	

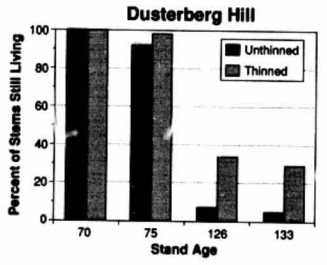
[1]Height in feet and Standard Error of estimate.

Dusterberg Hill

The unthinned plot in the Dusterberg Hill stand contained 1,037 stems per acre at least 1-inch d.b.h. at age 70 (table 4). Natural thinning resulted in a 93 percent loss of these stems by age 126, with only 5 percent of the original number of stems remaining by the end of the 63-year observation period (fig. 1). The stems in the 70-year-old stand averaged 5.8 inches d.b.h.; this increased to an average 12.2 inches by the age of 133 years. The basal area of the original stems on the plot decreased 76 percent between ages 75 and 126 (fig. 2). Unfortunately, data were not obtained in the intervening years to permit determining the age of maximum basal area production.

The thinned plot in the 70-year-old Dusterberg Hill stand contained 656 stems at least 1-inch d.b.h. following thinning (table 4). This plot lost two-thirds of these stems through subsequent natural mortality by age 126. By age 133 the thinned plot contained well over three times as many stems as the unthinned plot. The average 6.4-inch d.b.h. of the stems remaining immediately following thinning was slightly greater than on the unthinned plot. At 133 years, the d.b.h. of the





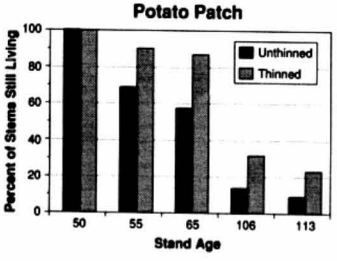
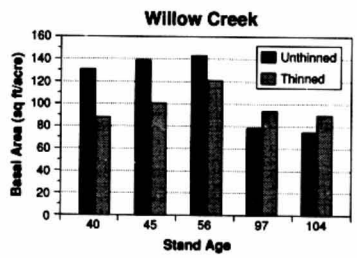
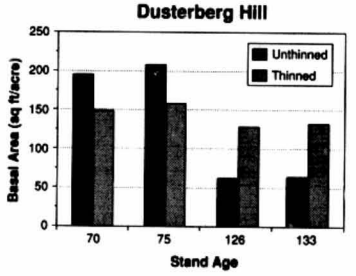


Figure 1—Aspen mortality (percent survival) on unthinned and thinned plots in three separate aspen stands over a 63-year period.





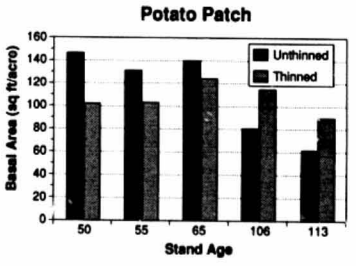


Figure 2—Changes in total basal area of aspen on unthinned and thinned plots in three separate aspen stands over a 63-year period.

Table 2—Number of tagged aspen trees per acre by diameter size class (d.b.h.) in the unthinned and thinned portions of the Willow Creek aspen stand, and the percent survival of these tagged trees in subsequent years.

	Unthinned stand age (years)				
D.b.h.	40	45	56	97	104
Inches	No./acre	Percent			
1	10	60	1	0	0
2	478	58	5	0	0
3	1,000	95	70	5	4
4	588	100	92	18	12
5	132	100	95	36	33
6	12	100	100	60	40

	Thinned stand age (years)				
D.b.h.	40	45	56	97	104
Inches	No./acre	Percent			
1	2	0	0	0	0
2	94	94	49	9	4
3	880	99	93	16	12
4	438	100	96	37	34
5	42	100	95	52	48
6	2	100	100	0	0

original remaining stems on the thinned plot averaged 10.6 inches. This was 1.6 inches less than the d.b.h. of stems on the unthinned plot. Again this suggests that the smaller average stem diameters on the thinned plot may be attributed to greater stem density. Although the total basal area of the original stems on the thinned plot began decreasing sometime between ages 75 and 126, it did not decrease nearly as much as that on the unthinned plot. By age 133 the thinned plot had over 2.5 times more original stem basal area than the unthinned plot; this was composed of the more numerous but somewhat smaller trees.

The d.b.h. size class of aspen in the unthinned plot at age 70 ranged from 2 to 9 inches, with a modal class of 6 inches. The post-thinning trees in the thinned plot at this age were somewhat larger and ranged from 5 to 14 inches, but also with a mode of 6 inches. By age 133, the range of size classes in the unthinned plot was from 9 to 15 inches d.b.h., with a mode of 12 inches. In the thinned plot, the trees ranged from 8 to 15 inches with a mode of 11 inches. Over this 63-year period the surviving aspen in the unthinned stand gained 6.4 inches d.b.h. for an average increment of 0.1 inch/year. The average increment gain in the thinned plot was only 0.07 inch/year.

Table 3—Ingrowth of aspen and conifer reproduction on unthinned plots by diameter size classes (d.b.h.) at final two measurement years[1].

	Willow Creek Stand							
	Aspen		White fir		Douglas-fir		Total conifers	
D.b.h.	1970	1977	1970	1977	1970	1977	1970	1977
Inches	No./Acre							
1-2	22	30	4	0	0	2	4	2
2-4	2	8	0	2	2	0	2	2
4-6	0	2	0	2	0	2	0	4

	Dusterberg Hill							
	Aspen		White fir		Blue spruce		Total conifers	
D.b.h.	1970	1977	1970	1977	1970	1977	1970	1977
Inches	No./Acre							
1-2	28	0	0	0	0	0	0	0
2-4	104	4	0	0	0	0	0	0
4-6	142	96	0	0	0	0	0	0
6-8	0	18	0	0	0	0	0	0

	Potato Patch Stand							
	Aspen		White fir		Blue spruce		Total conifers	
D.b.h.	1968	1977	1968	1977	1968	1977	1968	1977
Inches	No./Acre							
1-2	129	39	67	19	6	0	73	19
2-4	22	6	56	56	6	6	62	62
4-6	0	0	73	39	0	6	73	45
6-8	0	0	45	51	6	0	51	51
8-10	0	0	22	28	0	0	22	28
10-12	0	0	0	28	0	6	0	34

[1]Earlier reproduction data not available.

Table 4—Changes in the number of aspen trees per acre, excluding reproduction ingrowth, by diameter size classes (d.b.h.) in the unthinned and thinned portions of the Dusterberg Hill aspen stand.

	Unthinned stand age (years)									
	70		75		85		126		133	
D.b.h.	No./acre	Percent	No./acre	Percent	No./acre	Percent	No./acre	Percent	No./acre	Percent
Inches										
2	2	(<1)								
3	6	(<1)								
4	110	(11)	58	(6)	—	(—)				
5	276	(27)	174	(18)	—	(—)				
6	382	(37)	356	(37)	—	(—)				
7	224	(21)	246	(26)	—	(—)				
8	30	(3)	96	(10)	—	(—)	2	(3)		
9	7	(1)	20	(2)	—	(—)	2	(4)		
10			2	(<1)	—	(—)	12	(17)	2	(4)
11					—	(—)	22	(31)	10	(18)
12					—	(—)	28	(40)	20	(37)
13					—	(—)	6	(9)	12	(22)
14									6	(11)
15									2	(4)
Total	1,037	(100)	952	(100)	—	(—)	70	(100)	54	(100)
Height dominant trees (ft/SE)[1]	39/0.8		—		—		58/1.6		52/2.3	

	Thinned stand age (years)									
	70		75		85		126		133	
D.b.h.	No./acre	Percent	No./acre	Percent	No./acre	Percent	No./acre	Percent	No./acre	Percent
Inches										
5	94	(14)	42	(7)	—	(—)				
6	322	(49)	278	(43)	—	(—)				
7	162	(25)	202	(32)	—	(—)	4	(2)		
8	62	(10)	86	(13)	—	(—)	18	(8)	8	(4)
9	14	(2)	30	(5)	—	(—)	74	(33)	44	(23)
10					—	(—)	70	(31)	46	(24)
11					—	(—)	24	(11)	48	(26)
12					—	(—)	22	(10)	22	(12)
13					—	(—)	12	(5)	10	(5)
14	2	(<1)							10	(5)
15			2	(<1)					2	(1)
Total	656	(100)	640	(100)	—	(—)	224	(100)	190	(100)
Height dominant trees (ft/SE)[1]	47/0.4		—		—		60/0.8		56/2.3	

[1]Height in feet and Standard Error of estimate.

Mortality over the 63-year period on the unthinned plot was most severe in those stems falling in the 6-inch and under size classes (table 5). Almost none of these trees were still alive at age 133. Percent survival improved with trees that were in the larger size classes. Percent survival of the smaller size class trees was greater in the thinned plots. Even those trees in the 5- and 6-inch size classes at age 70 had 13 percent and 29 percent survival, respectively. As in the unthinned plot, the greatest survival rate, 57 percent, occurred in those few trees originally in the 9-inch size class. The two trees in the thinned plot that were 14 inches d.b.h. at age 70 died prior to age 126. Judging from their size, they very likely were much older than the majority of stems on the plot.

Aspen ingrowth at least 1-inch d.b.h. at age 133 in the unthinned plot amounted to 120 stems per acre (table 3). Most of these were in the 4- to 6-inch size class, with none in the 1- to 2-inch class. Considerable mortality of the smaller reproduction occurred during the prior 7 years. At age 133 there were over twice as many ingrowth stems as original aspen

Table 5—Number of tagged aspen trees per acre by diameter size class (d.b.h.) in the unthinned and thinned portions of the Dusterberg Hill aspen stand, and the percent survival of these tagged trees in subsequent years.

	Unthinned stand age (years)				
D.b.h.	70	75	85	126	133
Inches	*No./acre*		*Percent*		
3	6	0	—	0	0
4	110	58	—	0	0
5	276	79	—	0	0
6	382	99	—	3	3
7	224	97	—	16	11
8	30	100	—	29	26
9	7	100	—	57	57
	Thinned stand age (years)				
D.b.h.	70	75	85	126	133
Inches	*No./acre*		*Percent*		
5	94	96	—	17	13
6	322	100	—	34	29
7	162	96	—	41	35
8	62	94	—	35	32
9	14	100	—	57	57
10	0	0	—	0	0
/					
/					
/					
14	2	100	—	0	0

stems still alive, and these ingrowth stems comprised over one-fourth of the total aspen basal area on the plot.

Potato Patch

At age 50, the unthinned plot in the Potato Patch stand contained 3,007 stems per acre that were at least 1 inch d.b.h. (table 6). Almost half of these stems were dead by age 65; over 90 percent of the original number were dead by age 113 (fig. 1). The stems in the 50-year-old unthinned stand averaged 2.9 inches d.b.h. By age 113 the stems still alive averaged 6.4 inches d.b.h. The total basal area of aspen on the unthinned plot decreased about 10 percent between ages 50 and 55 (fig. 2), probably because of the 30 percent mortality of stems during this 5-year period. During the next 10 years basal area increased 6 percent despite an almost additional 20 percent loss in number of stems. However by age 106 basal area of aspen on the plot decreased to almost half of that at age 50; this decrease continued until by age 113 aspen basal area was only 42 percent of that at age 50.

The thinned plot in the 50-year-old Potato Patch stand contained only 1,378 stems per acre at least 1-inch d.b.h. following thinning (table 6). Stem numbers declined in subsequent years, but not as precipitously as in the unthinned plot (fig. 1). By age 65 this plot lost an additional 12 percent of its stems, and by age 113 still contained 23 percent of the original post-thinning stem numbers. At the end of the study the thinned plot contained one-fifth more stems than the unthinned plot. The average stem d.b.h. immediately following thinning was 3.6 inches, approximately 0.75 inch greater than on the unthinned plot. Average d.b.h. of the stems still alive at age 113 was 7.1 inches, still over 0.5 inch greater than that on the unthinned plot. The aspen basal area increased at least through age 65; however, even after 15 years the basal area of the thinned plot had not reached that of the unthinned plot (fig. 2). By age 106, however, the 8 percent decline in aspen basal area on the thinned plot was not nearly as great as that on the unthinned plot. The result was a 44 percent greater basal area production on the thinned plot. Basal area declined appreciably during the following 7 years.

The d.b.h. of aspen at age 50 ranged from 1 to 5 inches with a mode of 3 inches in the unthinned plot, and from 2 to 6 inches also with a mode of 3 inches in the thinned plot. By age 113 the size classes ranged from 4 to 10 inches in the unthinned plot and 5 to 10 inches in the thinned plot. The modal size class in the thinned plot was 1 inch greater than in the unthinned plot. Over the 63-year period the surviving aspen on both the unthinned and thinned plots gained an average diameter increment of 0.06 inch per year.

Natural mortality in the Potato Patch stand was most severe in those stems 3 inches d.b.h. or less at age 50 (table 7). As in the other two stands, the larger stems tended to survive better than the smaller. Thirty-five percent of those trees in the 5-inch size class at age 50 survived to age 113. The increased mortality of trees in the original 5-inch class on the unthinned plot, and those in the 6-inch class on the thinned plot is suspect. Judging from survival records of the Willow Creek stand (table 2) and Dusterberg Hill stand (table 4) at least some, if not all, of the mortality in these larger classes in the Potato Patch stand could well be the result of trespass cutting.

Aspen ingrowth by age 113 was minor and consisted only of stems in the 2- to 4-inch d.b.h. size class or smaller (table 3). Ingrowth comprised only 15 percent of the total aspen stems on the unthinned plot at this time, and approximately 1 percent of the aspen basal area. Over two-thirds of the ingrowth that was present at age 106 had died by age 113.

Although data are not available on the presence of conifers in these three aspen stands during the early

Table 6—Changes in the number of aspen trees per acre, excluding reproduction ingrowth, by diameter size classes (d.b.h.) in the unthinned and thinned portions of the Potato Patch aspen stand.

	Unthinned stand age (years)									
D.b.h.	50		55		65		106		113	
Inches	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*
1	96	(3)								
2	882	(29)	180	(9)	56	(3)				
3	1,400	(47)	1,152	(55)	613	(36)				
4	562	(19)	646	(31)	736	(43)	34	(9)	11	(4)
5	67	(2)	96	(5)	292	(17)	107	(27)	45	(17)
6			6	(<1)	17	(1)	128	(33)	95	(37)
7							79	(20)	51	(20)
8							34	(9)	45	(17)
9							6	(2)	6	(2)
10									6	(2)
Total	3,007	(100)	2,080	(100)	1,714	(100)	388	(100)	259	(100)
Height dominant trees (ft/SE)[1]	27/0.4		—		32/1.4		36/1.1		40/2.2	

	Thinned stand age (years)									
D.b.h.	50		55		65		106		113	
Inches	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*	*No./acre*	*Percent*
2	6	(<1)								
3	641	(47)	416	(33)	152	(13)				
4	613	(44)	686	(54)	635	(52)	6	(1)		
5	112	(8)	135	(11)	382	(31)	28	(7)	11	(3)
6	6	(<1)	22	(2)	39	(3)	152	(34)	73	(23)
7					11	(1)	185	(42)	140	(45)
8							51	(12)	67	(21)
9							11	(2)	11	(4)
10							11	(2)	11	(4)
Total	1,378	(100)	1,259	(100)	1,219	(100)	444	(100)	313	(100)
Height dominant trees (ft/SE)[1]	30/0.4		—		34/1.4		39/0.6		50/2.4	

[1]Height in feet and Standard Error of estimate.
(NOTE: age 106 heights differed at 0.90 and age 113 at 0.95 probabilities.)

sampling years, conifers were recorded in 1970 and 1977. Only the Potato Patch stand contained an appreciable number of conifers (table 3). The amount of conifers in the larger size classes suggests that conifer reproduction may have been present when the stand was 50 years old. At age 113 there were almost two-thirds as many conifer stems 1 inch or greater d.b.h. in the unthinned plot as aspen stems (including aspen ingrowth). Ninety percent of these conifers were white fir (*Abies concolor*). Conifer basal area by this time was 70 percent as great as aspen area. The Potato Patch stand obviously is succeeding to white fir dominance.

Discussion and Conclusions

Certain generalizations are possible from these long-term observations on three aspen stands: (1) stem numbers continue to decline appreciably from mid-age to old-age stands; (2) an inverse relationship exists between aspen site quality and stem numbers in mid-age stands; (3) basal area peaks probably sometime around 80 years of age and then declines appreciably by age 100; (4) in mid-age stands, greatest subsequent natural mortality will be those stems in diameter size classes smaller than the mode; (5) stands thinned from below at 40 and 70 years of age will contain more, but smaller, stems

Table 7—Number of tagged aspen trees per acre by diameter size class (d.b.h.) in unthinned and thinned portions of the Potato Patch aspen stand, and the percent survival of these tagged trees in subsequent years.

	Unthinned stand age (years)				
D.b.h.	50	55	65	106	113
Inches	*No./acre*		*Percent*		
1	96	0	0	0	0
2	882	32	19	0	0
3	1,400	88	71	13	8
4	562	97	93	38	29
5	67	67	50	17	17
	Thinned stand age (years)				
D.b.h.	50	55	65	106	113
Inches	*No./acre*		*Percent*		
2	6	100	100	0	0
3	641	98	95	16	11
4	613	90	89	47	33
5	112	65	55	46	35
6	6	100	100	100	0

at maturity (100+ years) and greater total basal area than those not thinned.

Natural mortality of aspen stems in mid-age stands (those 40 to 70 years old) can be expected to reduce the total number of stems in those stands at least 90 percent by the time they reach the age of about 110. Ingrowth of aspen reproduction at least 1-inch d.b.h. tends to increase stem numbers, but this is highly variable. Ingrowth was greatest in the oldest stand that had the poorest survival of original stems; aspen ingrowth here was twice as numerous as the surviving older stems. As stands age, stand density thins permitting the survival and growth of reproduction. Of course this scenario will be greatly altered if excessive browsing of aspen suckers prevents the growth of any reproduction (DeByle 1985). Even including ingrowth in the younger stands (those less than 115 years in this study), total stem numbers were still only about 10 percent of what they were when these stands were mid-age.

Not only do stem numbers decrease with stand ageing, but there appears to be an inverse relationship between site quality for aspen growth and number of stems, at least in mid-age and older stands. The poorer sites appear to produce more stems, but stems with smaller d.b.h., than the better sites. The Potato Patch stand, which had the lowest site index of 34, produced 3,007 stems per acre at age 50. Measurement of the Dusterberg Hill stand did not begin until it was 70 years old, but extrapolating its stem number curve back to age 50 indicates that this stand, with a site index of 41, had approximately 2,300 stems at age 50. Interpolation of the stem number curve of the Willow Creek stand to age 50 indicates that this stand, with the highest site index of 51, produced only about 1,600 stems. The average stem d.b.h. of the Potato Patch stand at age 50 was 2.9 inches; that of the 45-year-old Willow Creek stand was 3.5 inches despite being 5 years younger. This agrees with yield tables presented by Perala (1977) for aspen in the Lake States that show an approximate 25-35 percent increase of number of stems at age 50 with each 10-unit decrease in site index, as well as a corresponding decrease in average stem d.b.h. with increase in stem density. In Saskatchewan, "poor" site aspen at age 50 contained 12 percent more stems than "average" site aspen, and 35 percent more trees than aspen on "good" sites (Kirby and others 1957).

Data collection was not continuous enough to closely determine at what age maximum total basal area was reached. In the Willow Creek stand, basal area on the unthinned plot began to decline sometime between ages 56 and 97; in the Dusterberg Hill stand this occurred between ages 75 and 126. Maximum basal area in these two stands probably occurred after age 75 and before age 97. Aspen basal area then declined rather rapidly; the Willow Creek stand at age 104 contained only 53 percent of the measured maximum, and the Dusterberg Hill stand at age 126 contained only 28 percent of the measured maximum. Both of these stands are considered to be relatively stable, if not climax. The Potato Patch stand differed in being obviously successional and being replaced rapidly by conifers. Total aspen basal area in this stand was greatest at the time of the first measurement, age 50. Empirical yield tables presented by Kirby and others (1957) for aspen in Saskatchewan indicate a continual increase in aspen basal area through age 100.

Natural aspen mortality in these mid-age stands was greatest in the smaller diameter stems. On the unthinned plots none of the original stems that were less than 3 inches d.b.h. in the Willow Creek or Potato Patch stands were still alive when these stands reached approximately 100 years. None of the stems in the Dusterberg Hill stand that were less than 6 inches d.b.h. at age 70 were still alive when this stand reached 126 years. Generally, the larger the stem at mid-age, the greater the chances of survival. This generalization is fogged somewhat by the likelihood of a higher rate of mortality of the larger stems in ageing stands (older than about 130 years), especially if these larger stems are older than the majority of stems in the stand. From a survey of 713 aspen stands and determining the age of over 1,500 trees, I concluded that aspen in the Intermountain

Region matures at about 80 years, deteriorates rather rapidly after 120 years, and rarely attains ages over 200 years (Mueggler 1989).

Thinning stands from below at mid-age enabled more aspen trees to survive as the stands aged than if the stands were not thinned. This was particularly true for those stands not rapidly seral to conifers. Removing 33 percent of the intermediate and suppressed aspen in the 40-year-old Willow Creek stand resulted in 1¾ times more trees at age 104 than if thinning had not occurred. The effects of thinning were even more pronounced in the Dusterberg Hill stand where 47 percent of the trees were removed at age 70. The thinned portion of this stand at age 133 contained 3½ times more aspen than the contiguous portion that was not thinned. Although the 50-year-old Potato Patch stand, which was succeeding to white fir, was thinned just as drastically as Dusterberg Hill, surviving aspen by age 113 were only slightly more numerous than those on the unthinned portion of the stand.

The stems on the thinned portions of the two stable aspen stands were smaller in average stem diameter at stand maturity than the less numerous stems on the unthinned portions of the stands. This probably results from less competition between fewer stems for light, water, and nutrients in the unthinned portion as the stands aged. This was not as apparent in the seral Potato Patch stand probably because of the invasion of competing conifers. Average stem diameters were greater in the thinned portions of the stable Willow Creek and Dusterberg Hill stands only for those few years following thinning before the competitive relationships changed. These findings are at odds with the general rule that thinning will increase diameter growth to favor production of saw timber or veneer logs (Jones and Shepperd 1985; Perala 1977, 1978).

Thinning aspen stands at mid-age resulted in more, but highly variable amounts, of aspen basal area than on unthinned stands at old age. Although between one-fourth and one-third of the total basal area was removed by thinning, reduced subsequent stem mortality on the thinned plots eventually more than compensated for this loss. The one-fifth to 2 times greater aspen basal area on the thinned than unthinned portions of the stands at the end of the 60-year study period resulted from the one-fifth to 2½-times greater number of surviving aspen. As mentioned earlier, data collection was too intermittent to determine when maximum basal area occurred; also unknown is the maximum difference in basal area production between the thinned and unthinned plots at the time of maximum production. However, Brinkman and Roe (1975) found that thinning 20-year-old aspen from below in the Lake States did not improve stand basal area after 30 years.

It should be noted that thinnings in the early 1900's very likely were done without the use of mechanical equipment. This would minimize the probability of damage to the leave trees, especially when thinned from below. Any bole damage to leave trees could result in infection and subsequent mortality that might offset survival benefits from reduced competition between the leave trees.

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Data from 60 years of inventory in three central Utah aspen stands indicate: (1) stem numbers decline with age, (2) an inverse relationship exists between aspen site quality and stem numbers, (3) basal area peaks at about age 80 and then declines, (4) greatest middle age mortality is in small d.b.h. stems, (5) thinned stands contain more but smaller stems at maturity and more total basal area than unthinned stands.

Keywords: ***Populus tremuloides*****, aspen, demographics, stand development, thinning**

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