To Thin or Not to Thin: Using the Forest Vegetation Simulator to Evaluate Thinning of Aspen

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ABSTRACT: *Thinning experiments are costly to install and take decades of monitoring. Computer simulation tools, however, allow for the creation of "virtual" thinning experiments that forest managers can use as a guide in prescribing thinnings. The Forest Vegetation Simulator (FVS) was used to conduct a "virtual" thinning experiment to a range of residual densities (8, 10, 12, 15, and 20 ft spacings) at a range of thinning ages (5, 10, 25, and 40 yr) over a 50 yr time period. Stand level volume production was not enhanced through precommercial thinning, but average tree diameter was increased. Stand level volume was less after commercial thinnings but total volume production was increased if volumes removed during thinnings were considered. Tree diameter growth was greater when thinnings were performed at a younger age at and at a wider spacing. The greatest total volume production (removed during thinning and standing at age 50) was found to be nearly equal at 8 ft and 10 ft spacing with thinnings occurring at ages 10 or 25 on a site index of 80. North. J. Appl. For. 20(1):14–18.*

Key Words: Aspen, Forest Vegetation Simulator, productivity, silviculture, thinning.

Aspen fiber shortages in the Lake States have been predicted to occur in the early decades of the 21st century since the 1940s (Chase 1947), and these concerns continue today (Berguson and Perala 1988, David et al. 2001). Thinning is a silvicultural tool that has been touted as a means to capture aspen mortality occurring through self-thinning and increase future yields. Ideally, thinning would stimulate the growth of the highest quality trees, increase the total yield of merchantable material, and increase the net value of the products harvested at the end of the rotation. In reality, thinning improves the growth of individual trees but reduces total foliar biomass that offsets any increases in individual tree growth at the expense of total stand growth. High quality crop trees must be retained in order to maximize the economic benefits of thinning.

There have been few published recommendations for thinning aspen. All thinning studies reviewed (Bickerstaff 1946, Zehngraff 1946, 1947, Steneker 1964, Steneker and Jarvis 1966, Schlaegel 1972, Perala 1977, 1978), however, recommend that aspen thinning be limited to better quality sites in order to derive maximum economic benefits. Regression (Ek and Brodie 1975, Perala et al. 1996, Edger and Burk 2001) and computer (Bella 1972, Rauscher et al. 1995, Perala et al. 1996) simulation models have been developed to forecast aspen yields, but to my knowledge no regression or computer simulation models have been used in an experimental context to develop thinning guidelines for aspen.

The purpose of this article is to use the Forest Vegetation Simulator (FVS) (Dixon 2001) to quantify the effects of thinnings performed at different ages and at a range of residual tree densities on aspen growth and yield. Data collected over a 27 yr time period from a quaking aspen (*Populus tremuloides* Michx.) stand in Grand Rapids, Minnesota, growing on a high-quality site was used to test the local validity of FVS and to simulate the effects of precommercial and commercial thinnings on aspen growth and yield. The practicality of thinning depends on economic factors (i.e., market prices, thinning costs) that vary from region to region. Therefore, economic analyses are not incorporated into this discussion.

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Methods and materials

Study Area

Periodic measurement data were collected from an aspen stand of sucker origin located at the University of Minnesota, North Central Research and Outreach Center. The stand originated from the clearcutting of a second growth (approximately 45 yr old) aspen stand with scattered red oak and red maple in the winter of 1973. Slash was burned following harvest. Stem density in 1974 was 35,120 trees ac^{-1} and averaged 5.17 ft in total height. An unconventional precommercial thinning was applied to the majority of the stand whereby selected crop trees were spaced to an approximate 8 ft spacing with competing vegetation removed in 1974, 1975, 1976, and 1979 with a brush saw. Six permanent plots were established within the thinned portion of the stand and measured in 1974 (age 0), 1984, and 2001. Two control plots were established in small, unthinned portions of the stand. The integrity of these plots could not be maintained due to their small size, and they could not be relocated in 2001. The 1984 data from the unthinned, control plots is of high quality, however, and the stems ac^{-1} at age 10 (7,200 trees ac^{-1}) is within the range (2,800 to 7,200 trees ac^{-1}) of data for aspen stands of sucker origin (Table 1). The 1984 unthinned, control data were used as the starting point for all thinning simulations. Based on 2001 measurement data, site index was estimated to be 80 at an index age of 50 yr (Perala 1977).

The Forest Vegetation Simulator

The Forest Vegetation Simulator (FVS) model is a computer simulation model developed by the USDA Forest Service and includes regionally calibrated growth and yield models. FVS is an ideal tool for compiling inventory data and to simulate a variety of management options including site preparation, planting, thinning, and partial harvesting. Complete details of the FVS model and its application can be found at the USDA Forest Service website www.fs.fed.us/fmsc/fvs.

The Lake State version of TWIGS (Miner et al. 1988) is imbedded in FVS and was used for all growth and yield projections. Individual tree volume equations within FVS were modified to calculate total cubic volume per tree based on a 6 in. stump height, a 0.5 in. dbh, and 0.1 in. top diameter using the default form class setting of 80. Site index was set to 80. The in-growth feature for natural regeneration in FVS was turned off for all simulations.

FVS Simulations

The validity of FVS for the study area was evaluated using the remeasurement data for the thinned portion of the stand. Data collected in 1984 were used as a starting point for the simulation, and annual growth of the stand was simulated to 2001 for comparison with remeasurement data. Growth was projected using data collected in 1984 from the thinned and unthinned portions of the stand to evaluate the impact of spacing at an early age on aspen growth and yield.

Fourteen 50 yr simulations of thinnings implemented at a range of stand ages and densities were run to evaluate the effect of thinning age and spacing on aspen growth and yield. In addition to the output provided by FVS, the ratio of diameter and volume growth from thinning relative to the growth of the unthinned stand was used to evaluate the impact of thinning on individual tree size and stand volume growth.

Finally, two thinning schedules proposed in the *Manager's Handbook for Aspen* (Perala 1977) were simulated. The first thinning schedule calls for a single thinning at age 30 with basal area between 130 and 140 $ft^2\ ac^{-1}$ leaving about 240 trees ac^{-1} (TPA) and 60 to 70 $ft^2\ ac^{-1}$ of basal area. The second schedule simulated multiple thinnings. The first was a precommercial thinning leaving 550 TPA (~ 9 ft spacing) at age 10. The second was scheduled after age 30 when the basal area surpassed 130 $ft^2\ ac^{-1}$ leaving 200 TPA and 80 to 90 $ft^2\ ac^{-1}$ of basal area.

There were greater differences between the actual and simulated TPA, BA, D_q, and volumes for the stand thinned to

Table 1. Age, trees per acre (TPA), and volume per acre of unmanaged aspen sucker stands.

Location	Age	TPA	Total volume (ft^3/ac^{-1})	Study
Minnesota	1	35,120	N/a	This study
Minnesota	4	18,650/19,300/26,200	—*	Noreen (1968)
Wisconsin	6	14,463	151	Einspahr (1972)
Minnesota	7	9,650/10,850	—*	Noreen (1968)
Wisconsin	9	8,659	272	Einspahr (1972)
Minnesota	10	4,450/4,750/6,000	—*	Noreen (1968)
Minnesota	10	7,200	1,861	This study
Minnesota	10	2,800	—*	Schlaegel (1972)
Wisconsin	12	1,900	650	Einspahr (1972)
Minnesota	13	968	—*	Zehngraff (1946)
Manitoba	13	7,695	1,373	Bella and Jarvis (1967)
Manitoba	14	5,990	830	Steneker (1964)
Minnesota	15	1,950/2,850/3,350	—*	Noreen (1968)
Wisconsin	15	2,200	1,379	Einspahr (1972)
Ontario	17	2,812	478	Bickerstaff (1946)
Wisconsin	18	1,700	1,770	Einspahr (1972)
Manitoba	19	2,464	1,239	Steneker (1964)
Ontario	22	1,577	2,183	Bickerstaff (1946)
Manitoba	23	2,226	2,082	Steneker (1964)
Ontario	25	2,474	1,631	Bickerstaff (1946)
Minnesota	33	567	—*	Hubbard (1972)
Ontario	40	741	2,777	Bickerstaff (1946)

* Volume data not available

Table 2. Actual and simulated tree acre^{-1}, basal area (BA), quadratic stand diameter (D_q), total volume acre^{-1}, and the percent difference between observed and predicted values for a 27-yr-old aspen stand thinned to an 8 ft spacing annually age ages 1 through 5.

	Inventory data				FVS projections							
					TPA		BA		D_q		TVOL	
Year	TPA	BA	D_q	TVOL	Predicted	% diff.	Predicted	% diff.	Predicted	% diff.	Predicted	% diff.
	(actual)											
1984	558	24	2.8	5								
1989	567	64	4.5	1,341	517	–9	45	–30	4.0	–11	816	–39
2001	433	97	6.4	2,670	420	–3	93	–4	6.4	0	2,204	–17

an 8 ft × 8 ft spacing during its first 5 yr of growth in 1989 than in 2001 (Table 2). In 2001, projected values for TPA and BA were underpredicted 3 and 4%, resulting in volume being underpredicted by 17%. Observed and predicted values for D_q (quadratic stand diameter) did not differ. The intent of this "virtual" experiment was not to evaluate the accuracy of FVS. Results (Table 2), however, compare favorably with a separate study undertaken to compare FVS output to actual growth data (Canavan and Ramm 2000).

Results

With the exception of an 8 ft × 8 ft thinning prescribed at age 10, no simulation at any age or residual spacing produced a stand having greater volume than the unthinned stand at the end of 50 yr (Table 3). Eight foot spacings prescribed at all ages and a 10 ft spacing prescribed at age 10 produced volumes within 2 cords of the unthinned control at age 50. If one considers the total volume removed during thinnings plus the standing volume available at age 50, all thinning prescriptions implemented from age 10 on except the 20 ft spacing at age 10 and the 20 ft spacing at age 25 produced volumes greater than the unthinned control. The two entry prescription recommended by the USDA Forest Service (Perala 1977) produced the greatest volume (standing at age 50 plus thinned). This volume did not differ greatly from those projected for 8 ft and 10 ft spacing prescriptions at age 10 and 25.

Projected volume at age 50 for the unthinned control differs only slightly from the unconventional, precommercial thinning treatment at an 8 ft spacing. These results concur with those of a study recently reported for Ontario (Rice et al. 2001). Average tree size at age 50 increased in all thinning simulations (Tables 3 and 4). Not surprisingly, wider spacings at earlier ages resulted in larger trees. The largest average tree size resulted from the two entry thinning prescription (Table 3).

Discussion

Four alternative options for the timing of thinnings to produce the greatest volume and an average tree size

Table 3. Simulated trees ac^{-1} (TPA), basal area ac^{-1} (BA), quadratic stand dbh (D_q), volume at age 50, and volume at age 50 plus volume removed in thinnings initiated at various ages and at various spacings.

					Volume at age 50			Volume at age 50 + thinning vol		
Spacing	Thinning		BA	D_q	Total vol*		Merchan-table vol†	Total vol*		Merchan-table vol†
(ft)	age	TPA	(ft^2 ac^{-1})	(in.)	(ft^3 ac^{-1})	(tons ac^{-1})	(cords ac^{-1})	(ft^3 ac^{-1})	(tons ac^{-1})	(cords ac^{-1})
Control	No thinning	726	167	6.5	4,606	116	37	4,606	116	37
8 × 8	1 through 5	277	153	10.1	4,520	113	36	4,520	113	36
8 × 8	10	354	163	9.2	4,629	116	37	6,174	155	49
10 × 10	10	242	147	10.5	4,435	111	35	6,108	153	49
12 × 12	10	176	124	11.4	3,879	97	31	5,621	141	45
15 × 15	10	123	98	12.1	3,051	77	24	4,849	122	39
20 × 20	10	96	83	12.6	2,529	63	20	4,353	109	35
8 × 8	25	470	157	7.8	4,510	113	36	6,051	152	48
10 × 10	25	323	135	8.8	3,980	100	32	6,004	151	48
12 × 12	25	231	114	9.5	3,389	85	27	5,685	143	45
15 × 15	25	150	89	10.4	2,881	72	23	5,215	131	42
20 × 20	25	85	56	10.9	1,730	43	14	4,454	112	36
8 × 8	40	576	153	7	4,252	107	34	5,194	130	42
10 × 10	40	388	120	7.5	3,432	86	27	5,373	135	43
12 × 12	40	273	94	8	2,719	68	22	5,271	132	42
15 × 15	40	176	67	8.4	1,966	49	16	5,027	126	40
20 × 20	40	99	42	8.8	1,240	31	10	4,729	119	38
USDA Forest Service recommendations (Perala 1977)										
240 TPA	10	196	95	9.4	2,806	70	22	5,438	136	44
550/200 TPA	10/30	164	118	11.5	3,776	95	30	6,437	162	51

* Conversion from Perala (1977): 2.51 green whole tree tons per 100 ft^3.
† A conversion of 0.80 merchantable bark free cords per 100 ft^3 was used.

Table 4. Ratio of thinned to non-thinned quadratic stand diameters (D_q) and total volume for simulated thinnings at various ages and various spacings.

Control (ft)	Thinning age	Ratio of thinned to nonthinned	
		D_q	Total volume
	No thinning	1	1
8 × 8	10	1.41	1.01
10 × 10	10	1.61	0.96
12 × 12	10	1.75	0.84
15 × 15	10	1.86	0.66
20 × 20	10	1.93	0.55
8 × 8	25	1.20	0.98
10 × 10	25	1.35	0.86
12 × 12	25	1.46	0.73
15 × 15	25	1.60	0.58
20 × 20	25	1.67	0.37
8 × 8	40	1.07	0.92
10 × 10	40	1.15	0.74
12 × 12	40	1.23	0.59
15 × 15	40	1.29	0.42
20 × 20	40	1.35	0.27
USDA Forest Service recommendations (Perala 1977)			
240 TPA	10	1.44	0.60
550/200 TPA	10/30	1.77	0.82

greater than 10 in. are presented from this study. The first would be a precommercial thinning at age 5 to an 8 ft spacing. This would produce a volume nearly equal to the unthinned stand at 50 yr with growth concentrated on roughly one-third the number of trees. The second would be a thinning at age 10 at 10 ft, 12 ft, or 15 ft spacings. A thinning at age 10 may be a precommercial or commercial thinning depending on markets (e.g., whole tree chips, pulpwood merchantability limits). This would produce combined standing and thinned volumes that exceed the unthinned control at all three spacings with higher densities producing greater stand volumes at age 50. The third would be a commercial thinning at age 25 at a 15 ft spacing. This would produce a combined standing and thinned volume that exceeds the unthinned control at age 50 and concurs with results reported by Zasada (1952). The fourth alternative would be a two-entry thinning prescription at ages 10 and 30. This would produce the largest average tree size and the greatest combined standing and thinned volume for all simulations.

Let us revisit the question asked by Zasada in 1952, "Does it pay to thin young aspen?" We can answer, "It depends." If the management objective is to concentrate growth on a few selected high-quality trees then yes. If, on the other hand, the management objective is to grow low-cost fiber and tree size is not a concern, then the benefits from thinning would be minimal.

To obtain the maximum benefits of thinning, residual trees should be uniformly spaced. Hence, the thinning technique prescribed is important. Thinnings from below remove smaller trees of inferior quality thereby improving the quality of the residual stand but may not increase the growing space for individual trees. Thinnings from above, also known as crown thinnings, favor selected crop trees. Geometric thinnings are operationally attractive and usually entail removing uniform strips of trees. The only thinning prescription implemented using FVS in this "virtual" experiment was a thinning in which the smaller diameter, presumably less vigorous trees, were removed to meet the trees ac^{-1} targets. This prescription produced a uniform spacing, thereby creating more or less equal growing conditions for all residual trees. Geometric thinnings do not create a uniform spacing of residual trees and cannot be simulated with FVS. A growth response from a geometric thinning would be expected on trees at the edge of the residual strip. Little or no response to thinning would be expected from trees at the center of the residual strip, but this would depend on the size of the width of the retention strip. Geometric thinnings do not improve stand quality and have a limited effect on stand structure. Stand diameter, species composition, and density are affected primarily at the edges of the residual strips. To realize the full benefits of thinning, uniform spacing of the residual stand with retention of the highest quality trees is imperative. This could be accomplished with a combined geometric and crop tree release thinning prescription whereby trees in the residual strips between travel corridors are thinned. This is prescription could be applied following the two-stage thinning guidelines of Perala (1977).

Given the technological advancements in fiber utilization, trees removed during thinnings at very young ages (between 5 and 10 yr) could be used for biofuels or whole tree chips, and for specialty forest products that utilize small diameter stems (e.g., bean poles, walking sticks). Merchantable pulpwood, biofuels, and whole tree chips could be extracted from thinning at ages 15 yr and older. In a thorough analysis of the economic benefits of precommercial thinning of aspen in Minnesota during the prechipping, biofuel era, Noreen (1968) concluded that the investment in precommercial thinning could not be justified. Indeed the highest internal rates of return that Noreen (1968) projected, based on 1968 prices, were for unthinned stands.

Thinning Recommendations for Quaking Aspen

Individual stand conditions (e.g., site quality, stem density, age) vary, and the results derived from this "virtual" experiment were from the simulated growth of an individual stand with a stem density of 7,200 TPA at age 10. While FVS can be used to evaluate thinning alternatives for specific stands, general thinning recommendations can be made from these results depending on management objectives.

- If the management objective is to produce low cost fiber, and individual tree size and individual tree quality are not important, thinning is not recommended.
- Thinning is recommended to accelerate the growth of individual trees and to "capture" the mortality occurring naturally through self-thinning on the highest quality sites. A site index of 80 was used for simulations in this study, Perala (1977) recommends thinning on site indices of 70 or greater.
- Maximum individual tree growth would be derived from thinnings implemented at young ages (< 15 yr old).

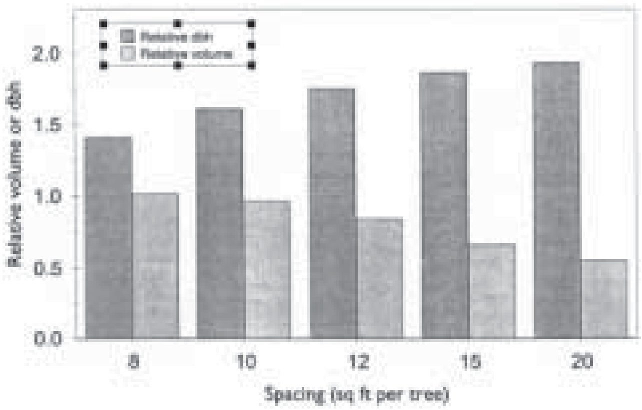

Figure 1. Illustration of the trade-off between diameter and volume growth resulting from thinnings at various spacings implanted at age 10. Data, extracted from Table 4. Relative volume and dbh are relative to an unthinned stand for a simulated stand age of 50 yr. The differences between relative volume and dbh decrease as stands are thinned at older ages.

- Individual tree growth would be enhanced at post-thinning densities less than 680 trees ac^{-1}. The trade-off would be between greater stand volumes at higher densities versus greater tree size at lower densities (Figure 1).
- Thinning beyond a stand age of 25 to 30 yr is not recommended to maximize timber production but may be desired to achieve nontimber objectives.

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