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Commercial Thinning in Small-Diameter Aspen Stands in Northern Minnesota: Study Establishment Report

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Abstract

In the spring of 1999, a long-term study was established to examine the physical and biological aspects of thinning young aspen stands in Minnesota. Three aspen stands ranging in age from 25 to 35 years were selected on lands owned by the State of Minnesota and UPM Kymmene. Two thinning treatments (low and high density) and an unthinned control were installed at each of the three locations. Permanent plots were installed to measure tree, shrub, and herb growth, and to monitor harvesting damage, insect and disease damage, soil strength, and fuel loadings.

After 4 years, tree mortality was greater in the unthinned controls. Thinning treatment had no significant effect on the incidence of white trunk rot (*Phellinus tremulae*), Hypoxylon canker, or *Saperda calcarata*. No differences in post-harvest fuel loadings were detected among locations and treatments. Thinning increased the amount of light reaching the forest floor that resulted in greater herb and shrub biomass in the year immediately following thinning.

Cover Photos

Clockwise from left: harvesting damage on reserve tree, clearcut travel corridor in high density thinning treatment, commercial thinning of aspen with a mechanical harvester.

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INTRODUCTION

Since the 1940s, aspen fiber shortages in the Lake States have been predicted to occur in the early decades of the 21st century (Berguson and Perala 1988, Chase 1947, David et al. 2001). To avoid such shortages, thinning has been suggested as a means to capture fiber volume that would otherwise be lost through self-thinning. Ideally, thinning would increase 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. This often offsets any increases in individual tree growth at the expense of total stand growth (Smith et al. 1997).

Aspen is host to a large number of endemic insect pests and pathogens that under some conditions reduce the productivity and quality of affected trees. Fortunately, few insect pests and pathogens have been serious enough to concern forest managers under most management systems. However, there is evidence to suggest that Hypoxylon canker caused by the fungus *Entoleuca mammata* has greater negative impact in understocked or thinned stands than in well-stocked stands (Anderson and Anderson 1968, Anderson and Martin 1981, Bruck and Manion 1980, Capony and Barnes 1974, Day and Strong 1959, Ostry and Anderson 1979, Ostry and Anderson 1998, Schreiner 1925). In other studies investigators did not observe increases in Hypoxylon canker in thinned stands (Anderson 1964, Pitt et al. 2001). Differences in disease susceptibility among aspen clones may have more influence on disease incidence and severity than treatment or location effects (Ostry et al. 2004).

In all the thinning studies reviewed (Bickerstaff 1946; Gilmore 2003; Perala 1977, 1978; Schlaegel 1972; Steneker 1964; Steneker and Jarvis 1966; Zasada 1952; Zehngraff 1946, 1947), the authors recommended that aspen thinning be limited to better quality sites to promote stand vigor and health, derive maximum growth, and economic benefits. Based on the accumulated experience of trials conducted from the 1940s through the 1970s, Perala provided the following guidelines for thinning for increased wood and fiber production: 1) conduct thinning on higher quality sites—site index 70 and above; 2) thin in stands that are 25 to 35 yr old, preferably 25 to 30 yr. The commercial thinning options outlined by Perala (1977) were a single thinning to about 240 trees ac^{-1} (TPA) at 30-35 yr; or two precommercial thinnings to 550 TPA at 10 yr and to 200 TPA at 30 yr. In Perala (1978), more intensive thinning schedules are modeled: the lowest density recommended is 180-190 TPA at 30 yr, but this recommendation follows two precommercial thinnings at 10 and 20 yr.

The thinning prescriptions are based on older trials using individual tree selection as opposed to the new system that is basically a row thinning with all trees removed in an 8- to 12-ft area. Variable amounts of removal occur between rows depending on the desired density/basal area. To our knowledge, no aspen thinning trials have been established using a cut-to-length harvesting system that compare two residual densities and a control. Three stands between the ages of 25 and 35 yr were selected for study in northern Minnesota to determine the effects of thinning with cut-to-length technology in aspen forests on 1) mechanical damage; 2) development of understory trees, shrubs, and herbs; 3) soil compaction as determined via soil strength; 4) insect and disease damage to the residual stand; and 5) forest fuel loadings immediately following thinning.

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METHODS AND MATERIALS

Study Locations and Thinning Treatments

The three study locations were located in Itasca County, Minnesota. The legal description for the UPM Kymmene site is T58 R23 S35 SW1/4. The legal descriptions for the two sites managed by the Minnesota Department of Natural Resources are T60 R25 S29 NE1/4 (site 29), and T60 R25 S33 N1/2 SW1/4 (site 33). Pre-treatment data were collected using temporary plots only in the areas to be thinned. Across all locations, pre-treatment basal area (BA) ranged from 100 to 170 ft^2 ac^{-1}, trees per acre (TPA) ranged from 680 to 1,110, and average diameter at breast height (d.b.h.) ranged from 4.8 to 5.8 in. (Table 1a). Site indices were 80, 75, and 60; and ages were 35, 35, and 30 yr for site 29, site 33, and the UPM Kymmene site, respectively. White birch was a significant component of the stand on site 29 before thinning (Table 2). The UPM Kymmene site was harvested in the fall of 2000, and sites 29 and 33 were harvested in the winter of 2001.

Two thinning treatments (low and high density) and an unthinned control were installed at each of the three locations. The target BA and density was 40 $ft^2 ac^{-1}$ and 180 to 200 TPA, respectively, for the low-density treatment and 60 ft^2 ac^{-1} and 280 to 300 TPA, respectively, for the high-density treatment. Travel corridors (8 to 12 ft wide) were spaced approximately 40 to 45 ft apart and designated before thinning began. Using a cut-to-length harvester, the equipment operator removed trees from either side of the designated travel corridor. The operator was instructed to retain apparently healthy trees with good form and no injuries.

Experimental Design and Field Procedures

Rectangular (132 ft by 33 ft) one-tenth acre sample plots to measure tree data were established the spring following treatments (2001) and the corners were identified using wooden and metal stakes and an identification tag. Plots within the thinning treatments were positioned to include three travel corridors. The diameter for all living and dead trees greater than 1 in. d.b.h. was measured (the tree locations on each plot were mapped). Total height was measured on every tenth tree. Pre- and post-thinning mechanical, insect, and disease damage on boles was examined with the aid of binoculars, and the presence and extent of the major damaging agents were recorded on all residual trees, which were the potential crop trees.

Twelve 4.1-ft radius plots to measure shrub and tree regeneration, and twelve 1.9-ft radius plots to measure herbs and forbs were nested within the rectangular plots. The total number of shrub species and tree regeneration, stem diameter at 6 in. above the soil surface, and height of the tallest individual of each species were recorded on the shrub and regeneration plots. Shrub control plots were not measured in 2001. Shrub biomass was estimated using equations extracted from the literature by Johnson (2004). Biomass for herbs and forbs was estimated by 100 percent removal and ovendrying of a sample collected from a one-thousandth-ha plot located on 100 percent of the subplots before treatment and on a subsample of the subplots following treatments. Soil strength was measured before and after thinning on semipermanent plots with a soil penetrometer. Soil compaction meters (often called penetrometers) are used to determine the density of soil. An operator pushes a rod with attached cone (ASAE standard) into the ground. The resistance of the cone as it is pushed in the ground is measured and recorded in the memory of the compaction meter. The depth of the cone below the soil surface is also measured and recorded in the storage memory of the penetrometer.

Table 1a.—Pre-thinning[a] (yr 2000), post-thinning (winter 2001-2002), and 2-yr post-thinning basal area (BA), trees per acre (TPA), and average diameter at breast height (d.b.h.) measurement for the three treatments in the three stands included in the aspen thinning study (English units of measure)

Location and treatment	Target BA	Basal area			Target TPA	Trees per acre			Quadratic d.b.h. by location		
		Pre-thin	Post-thin	Spring 2004		Pre-thin	Post-thin	Spring 2004	Pre-thin	Post-thin	Spring 2004
UPM-Kymmene		------------------ft^2 ac^{-1}--------------------							----------------in.----------------		
Control			99	95			509	427		6.0	6.4
Low density	40	108	48	37	180-200	680	219	180	5.4	6.3	6.1
High density	60	100	56	52	280-300	782	339	292	4.8	5.5	5.7
Site 29											
Control			137	133			872	617		5.4	6.3
Low density	40	143	47	47	180-200	1,110	201	181	4.9	6.5	6.9
High density	60	129	72	75	280-300	902	301	279	5.1	6.6	7.0
Site 33											
Control			125	121			1,040	768		4.7	5.4
Low density	40	125	43	44	180-200	816	212	191	5.3	6.1	6.5
High density	60	170	64	65	280-300	918	276	268	5.8	6.5	6.7

[a] Note: UPM Kymmene thinnings occurred in the fall of 2000.

Table 1b.—Pre-thinning[a] (yr 2000), post-thinning (winter 2001-2002), and 2-yr post-thinning basal area (BA), trees per acre (TPA), and average diameter at breast h eight (d.b.h.) measurement for the three treatments in the three stands included in the aspen thinning study (Metric units of measure)

Location and treatment	Target BA	Basal area			Target TPA	Trees per acre			Quadratic d.b.h. by location		
		Pre-thin	Post-thin	Spring 2004		Pre-thin	Post-thi	Spring 2004	Pre-thin	Post-thin	Spring 2004
UPM-Kymmene		--------------------m^2 ha^{-1}------------------							----------------cm----------------		
Control			23	22			1.258	1,055		15.2	16.2
Low density	9	25	11	8	445-494	1,680	541	445	13.7	16.1	15.6
High density	14	23	13	12	692-741	1,932	838	722	12.3	14.0	14.5
Site 29											
Control	0	0	31	31		0	2.155	1,525	0.0	13.6	16.0
Low density	9	33	11	11	445-494	2,743	497	447	12.3	16.6	17.5
High density	14	30	17	17	692-741	2,229	744	689	13.0	16.8	17.8
Site 33											
Control	0	0	29	28		0	2.570	1,898	0.0	11.9	13.7
Low density	9	29	10	10	445-494	2,016	524	472	13.5	15.5	16.5
High density	14	39	15	15	692-741	2,268	682	662	14.8	16.6	16.9

[a] Note: UPM Kymmene thinnings occurred in the fall of 2000.

Table 2.—Percent standing dead trees for all species and percent birch[a] composition by location and treatment in 2000, 2002, and 2004

Location and treatment	2000 pre-thin	2000 % birch (living trees)	2002 post-thin	2004
UPM-Kymmene				
Control	23[b]	0	no data	21
Low density	22	1	2	14
High density	17	1	19	32
Site 29				
Control	1[b]	18	no data	19
Low density	22	17	0	10
High density	23	24	0	7
Site 33				
Control	1[b]	4	7	32
Low density	22	5	1	12
High density	24	3	0	6

[a] Paper birch was the only non-aspen species that was a significant stand component before thinning

[b] Data collected for crop tree aspen only.

Damage from Harvest and Insects and Diseases

Harvesting damage was considered to be removal of bark from the tree bole. The affected area and height on the tree of all wounds was recorded on all trees in each plot. The establishment of this study coincided with a forest tent caterpillar (*Malacosoma disstria*) outbreak in 2000-2001. Other damaging agents recorded included Hypoxylon and Nectria cankers, white trunk rot caused by *Phellinus tremulae, Saperda calcarata*, *Agrillus* flat-headed wood borers, frost cracks/ sunscald, and open scars caused by animal debarking and mechanical wounds through the bark.

Forest Fuels Sampling

A planar intersect sampling method was used to inventory fuel loadings (Brown 1974). The method is rapid, easy to use, and can be applied to naturally fallen debris and slash. In brief, 32.8-ft (10 m) fuel sampling transects were established across subplots. The 10-m transects included smaller nested transects to measure diameter classes that correspond to 1-hr, 10-hr, and 100-hr average moisture time lag classes. One-hr [0 to 0.25 in. (0.63 cm) diameter] and 10-hr [0.25 to 1.0 in. (0.63 to 2.54 cm) diameter] fuels were measured in the first 1 m (3.28 ft) of each transect. In the unharvested controls and thinned plots, 100-hr [1.0 to 3.0 in. (2.54 to 7.5 cm) diameter] fuels were tallied along the entire 10 m (32.8 ft) of each transect. In the travel corridors, 100-hr fuels were measured along a 2-m (6.56 ft) transect. Heavy fuels greater than 3.0 in. (7.5 cm) are 1,000-hr fuels and were measured along the entire length of every 10-m transect. Diameter and condition class (sound, rotten) were recorded for 1,000-hr fuels only. At intervals of 5, 6, 10, and 11 m (16.4, 19.7, 32.8, and 36.1 ft) along each transect, duff and litter depths were recorded.

Field data were converted to tons ac^{-1} using techniques described by Brown (1974). The equation for fine fuels was:

$$\textbf{(1)} \quad \text{tons ac}^{-1} = (11.64 \bullet n \bullet d^2 \bullet S_g \bullet a \bullet c)/(N \bullet l)$$

where n = total tally of pieces for size class, d^2 = average diameter class squared in imperial units of measure—constant for each size class (metric groupings for each fuel size class: 0-0.6 cm = 0.0151; 0.6-2.5 cm = 0.289; 2.5-7.6 cm = 2.76), S_g = specific gravity, a = nonhorizontal angle correction factor, c = slope correction factor, N = number of transects, and l = transect length in feet.

Table 3.—Results of ANOVAs performed on the location and extent of mechanical damage from timber harvesting using the general linear model: y = location + treatment + location•treatment + ε, where y = the measured variable, location = site 29, site 33, or the UPM Kymmene site, treatment = high-density thinning or low-density thinning, and ε = error NID~(0, σ^2)

	P-value for significance of effect			Average (standard error)	
Measured variable	Location	Treatment	Location•treatment	High density n = 93	Low density n = 74
Surface area of wound (cm^2)	0.261	0.766	0.737	78.01 (10.12)	87.55 (10.80)
Height of wound (m)	0.249	0.747	0.021	1.24 (0.07)	1.22 (0.12)
Surface area of wound ($in.^2$)				12.09	13.57
Height of wound (ft)				4.06	4.00

Tons ac^{-1} of heavy fuels were estimated with the equation:

(2) $$\text{tons ac}^{-1} = (11.64 \bullet \Sigma d^2 \bullet S_g \bullet a \bullet c)/(N \bullet l)$$

where all variables are as previously defined except that Σd^2 represents a sum of the actual squared diameters. Tons ac^{-1} were converted to tonnes ha^{-1} using a conversion factor of 2.2417.

Data Analyses

Summary data are presented in tabular form by location and treatment. Analyses of variance (ANOVA) were performed using the general linear model:

$$y = \text{location} + \text{year} + \text{treatment} + \text{location}\bullet\text{treatment} + \text{location}\bullet\text{year} + \text{year}\bullet\text{treatment} + \text{location}\bullet\text{year}\bullet\text{treatment} + \varepsilon$$

where y = the measured variable, year of measurement, location = site 29, site 33, or the UPM Kymmene site, treatment = control, high density thinning, or low density thinning, and ε = error NID~(0, σ^2).

RESULTS

Pre- and Post-thinning Stand Conditions

Pre- and post-thinning stand conditions are presented in Tables 1a and 1b. Note that trees were not numbered during the collection of pre-treatment data. Therefore, it is not possible to match individual tree measurements from the pre- and post-treatment time periods. In addition, unharvested control plots were measured the winter following the thinning of the treated plots. In all instances, greater BAs were retained than the target BA except at the high-density UMP Kymmene plot where residual BA was slightly lower. Target TPAs were nearly achieved in all but the UPM Kymmene plots where TPA was higher. Average d.b.h. increased in all plots following thinning, which is indicative of thinning from below where high-quality, larger diameter trees are retained (Smith et al. 1997).

Before thinning, standing tree mortality ranged between 17 and 24 percent; after thinning it was reduced to nearly zero (Table 2). Standing tree mortality in the unthinned control plots varied considerably during the initial measurement period. Average tree mortality in the control plots differed by location, ranging between 19 and 32 percent following two growing seasons (Table 2). The number of standing dead trees in the thinned plots also increased in the two growing seasons following thinning. The low-density treatments had greater tree mortality than the high-density treatments except on the UPM Kymmene site.

Mechanical Damage from Thinning

Wound size averaged slightly larger than 1 ft^2, and wound height above ground averaged approximately 4 ft in both the high-density and low-density thinning treatments. The size of the wound on the tree and wound height above ground were not affected by study location or treatment, but there was a marginally significant interaction between study location and treatment for the height of the wound (Table 3).

Table 4.—Summary of percentage mechanical and insect and disease damage by location, treatment, and year

	Mechanical	Frost/sunscald	*Phellinus*	Hypoxylon	*Saperda*	Dead
UPM						
2000 - Pre-treatment						
Control[a]	0	0.01	2.12	0.28	1.45	23.0
Low density	0	0	5.88	0	0.70	14.48
High density	0	0	3.21	0.51	1.61	17.03
2001 - Post-treatment						
Control[a]	0	0.01	2.12	0.28	1.45	23.0
Low density	29.95	0	4.50	1.18	0	18.48
High density	26.74	0	6.21	0	0	25.83
2004 - Post-treatment						
Control	0	0.01	1.06	0.56	0.72	15.66
Low density	9.65	0	8.08	1.30	0.23	20.24
High density	8.92	0	8.01	0.81	1.18	24.23
Site 29						
2000 - Pre-treatment						
Control[a]	0	0	0	0	0	1.16
Low density	0	0	0	0.24	0.09	0.89
High density	0	0	0	0.10	0	0.65
2001 - Post-treatment						
Control[a]	0	0	0	0	0	1.16
Low density	10.45	0.01	0.92	0.48	0	10.32
High density	12.62	0	0.65	0	0	8.30
2004 - Post-treatment						
Control	0	0.01	0.38	0.40	0	0.79
Low density	3.48	0.06	1.56	0.24	0.32	8.83
High density	4.21	0.07	1.01	0.03	0	8.52
Site 33						
2000 - Pre-treatment						
Control[a]	0	0	0.27	0.66	0	0.86
Low density	0	0	0.53	1.65	0.28	2.84
High density	0	0	0	1.08	0.37	1.98
2001 - Post-treatment						
Control[a]	0	0	0.27	0.66	0	0.86
Low density	10.63	0.01	0.85	0	0	10.82
High density	7.49	0.01	1.45	0	0.38	9.89
2004 - Post-treatment						
Control	0	0	0	0	0	0.20
Low density	0	0.01	11.73	1.01	0	19.00
High density	0	0.01	8.44	0.38	0.40	15.21

[a] Control plot measurements are the same for 2000 and 2001.

Damage from insects and diseases

The percentage of trees affected by frost/sunscald, *Phellinus*, Hypoxylon, *Saperda*, and the number of dead potential aspen crop trees greater than 12 cm within each treatment at each location are provided in Table 4. Table 5 presents ANOVAs on pre-treatment, immediately post-treatment, and 3-yr post-treatment evaluations for frost/sunscald, *Phellinus*, Hypoxylon, *Saperda*, and the number of dead potential aspen crop trees greater than 5 in. d.b.h. testing the significance of location, treatment, and the interaction between location and treatment. Pre-treatment ANOVAs detected an interaction between location and treatment for frost/sunscald and the number of dead trees. Location had a significant impact on all measured attributes before treatment. Not surprisingly, treatment was not significant for all measured variables, except for frost/sunscald. The majority of trees affected by damaging agents were removed during thinning. Thus, results of post-treatment ANOVAs detected few difference between locations or treatments. Location and treatment effects became more evident after 3 yr because additional trees became affected by damaging agents. Some trees also died, which had an effect on the results.

The prevalence of mechanical damage was greatest at the UPM site immediately post-treatment where the percentage damage was nearly triple the 1-yr post-treatment amount for sites 29 and 33 (Table 4). There was a greater amount of frost/sunscald at site 29 3 yr post-treatment. In general, a greater incidence of *Phellinus* was present at the UPM site except 3 yr post-treatment when there was a greater incidence of *Phellinus* at site 33. The incidence or prevalence of Hypoxylon canker and damage by *Saperda* decreased immediately post-treatment and then increased slightly 3 yr post-treatment. The percentage of dead trees decreased immediately following treatment and increased 3 yr post-treatment.

Table 5.—Summary of analyses of variance using the model y = location + treatment + location•treatment + ε, where y = the measured damage metric, location = site 29, site 33, or the UPM Kymmene site, treatment = control, high-density thinning, or low-density thinning, and ε = error NID~(0, σ^2)

Attribute	Location	Treatment	Location•treatment
2000 – Pre-treatment			
Frost/sunscald	0.015	0.012	0.004
Phellinus	0.000	0.256	0.457
Hypoxylon	0.000	0.322	0.159
Saperda	0.012	0.728	0.811
Dead	0.001	0.102	0.006
2001 – Post-treatment			
Mechanical	0.001	0.001	0.004
Frost/sunscald	0.505	0.908	0.657
Phellinus	0.017	0.593	0.829
Hypoxylon	0.375	0.095	0.375
Saperda	0.474	0.422	0.474
Dead	0.001	0.410	0.108
2004 – Post-treatment			
Mechanical	0.018	0.080	0.444
Frost/sunscald	0.000	0.058	0.035
Phellinus	0.117	0.019	0.592
Hypoxylon	0.035	0.490	0.473
Saperda	0.508	0.191	0.110
Dead	0.001	0.001	0.190

Herb Biomass

A comparison of pre-treatment aboveground herb biomass and 1- and 2-yr post-treatment aboveground herb and forb biomass for each location is provided in Table 6. Analyses of variance showed the effects of location ($P < 0.001$), year ($P < 0.001$), and treatment ($P < 0.001$) were significant. Due to missing data (Table 6), the location•year interaction term could not be tested. The treatment•location ($P = 0.188$) and year•location•treatment ($P = 0.093$) interaction terms were not significant. Herb and forb biomass was the same across all locations before treatments. The forest tent caterpillar outbreak in 2001 and 2002 increased the amount of light reaching the forest floor and resulted in greater herb and forb biomass for the control treatments as well as the high- and low-density thinning treatments. The 2-yr forest tent caterpillar outbreak likely negated any differences that would have been detected between the controls and thinning treatments.

Table 6.—Average (standard error in parentheses) herb and shrub biomass values by year, location, and treatment

Treatment	Herb biomass			Shrub biomass		
	n	kg ha^{-1}	lbs ac^{-1}	n	tonnes ha^{-1}	tons ac^{-1}
Year - 2000						
UPM site						
Control	5	183.9	164.0	44	3.8	1.7
		(16.8)	(15.0)		(0.7)	(0.3)
HD	5	129.7	115.8			
		(12.0)	(10.7)			
LD	5	166.1	148.2	44	3.1	1.4
		(30.1)	(26.9)		(0.4)	(0.2)
Site 29						
Control	6	25.4	22.7	54	2.4	1.1
		(5.2)	(4.6)		(0.3)	(0.1)
HD	9	39.7	35.4	81	3.2	1.4
		(7.0)	(6.3)		(0.3)	(0.1)
LD	9	36.4	32.5	78	11.4	5.1
		(5.3)	(4.8)		(0.3)	(0.1)
Site 33						
Control	6	32.2	28.7	52	2.4	1.1
		(9.1)	(8.1)		(0.2)	(0.1)
HD	9	49.1	43.8	81	4.8	2.1
		(9.3)	(8.3)		(0.3)	(0.1)
LD	9	35.0	31.2	80	4.6	2.0
		(6.3)	(5.6)		(0.3)	(0.1)
Year - 2001						
UPM site						
Control	5	1,239.0	1,105.5			
		(260.4)	(232.4)			
HD	10	1,487.3	1,327.0	60	360.6	160.9
		(227.7)	(203.2)		(31.5)	(14.1)
LD	10	1,180.4	1,053.1	60	585.8	261.3
		(241.2)	(215.2)		(38.3)	(17.1)
Site 29						
Control	6	837.9	747.6			
		(98.8)	(88.1)			
HD	18	555.2	495.4	108	1,080.8	482.2
		(54.6)	(48.7)		(70.4)	(31.4)
LD	18	656.3	585.6	108	1,060.7	473.2
		(94.2)	(84.1)		(66.8)	(29.8)
Site 33						
Control	6	682.3	608.8			
		(93.4)	(83.3)			
HD	18	538.3	480.3	108	1,519.9	678.0
		(78.5)	(70.1)		(70.1)	(31.3)
LD	--	--	--	108	1,289.7	575.3
					(55.6)	(24.8)

Continued

Table 6.—continued

Treatment	n	Herb biomass kg ha^{-1}	Herb biomass lbs ac^{-1}	n	Shrub biomass tonnes ha^{-1}	Shrub biomass tons ac^{-1}
Year - 2002						
UPM site						
Control	5	1,570.5	1,401.2		802.9	358.2
		(431.2)	(384.7)		(104.9)	(46.8)
HD	10	2,422.8	2,161.6	60	864.1	385.5
		(244.8)	(218.4)		(110.0)	(49.1)
LD	10	2,073.7	1,850.2	60	996.1	444.4
		(301.2)	(268.7)		(82.2)	(36.7)
Site 29						
Control	6	831.8	742.1			
		(59.5)	(53.1)			
HD	16	888.4	792.6	107	2,960.7	1,320.7
		(115.3)	(102.8)		(231.9)	(103.4)
LD	18	867.1	773.6	107	5,122.6	2,285.2
		(111.2)	(99.3)		(352.8)	(157.4)
Site 33						
Control	6	447.0	398.8			
		(159.0)	(141.8)			
HD	18	1,042.1	929.7	106	2,432.2	1,085.0
		(129.4)	(115.4)		(200.0)	(89.2)
LD	18	1,432.2	1,277.8	108	2,027.1	904.3
		(170.3)	(151.9)		(157.0)	(70.0)

Shrub Biomass

A comparison of pre-treatment aboveground shrub biomass and 1- and 2-yr post-treatment aboveground shrub biomass for each location is provided in Table 6. Analysis of variance showed that location, year, and treatment effects along with all combinations of their interaction terms were significant ($P < 0.001$ for all effects). Due to these significant interactions, it is not possible to comment extensively on the individual effects. The 2-yr forest tent caterpillar outbreak likely influenced the shrub aboveground biomass results. Note, however, that there was less of a detectable effect over time with the control treatments at sites 29 and 33. At the UPM Kymmene site, however, there was an increase in shrub biomass in the control.

Soil Compaction

A major source of yield loss in agriculture is soil compaction. Soil compaction prevents moisture penetration and hinders plant root growth, and it is becoming increasingly important in forest management (Smith et al. 1997). Penetrometer readings at depths of 4, 8, 12, and 18 in. were highly variable, and the variation in the density of forest soils overwhelmed any statistical analyses. In some instances, greater compaction was detected before treatment (Table 7). Separate two-factor analyses of variance (ANOVAs) conducted on pre-treatment and post-thinning penetrometer data at the above soil depths did not detect any pre- or post-treatment similarities in the data among locations and treatments or suggest any trends.

Table 7.—Minimum, maximum, average (standard errors in parentheses), and probability values for a t-test of the hypothesis of pre- and post-thinning differences in soil penetrometer readings averaged for depths of 10, 20, 30, and 40 cm by location and treatment. Soil compaction data are presented in metric units only. Note that one cm equals 0.39 in.

Treatment	n	Pre-thin	Post-thin	Difference	P-value of t-test
10 cm depth		----------------------------------kilopascals	----------------------------------		
UPM Kymenee					
Control	60	425.42 (13.75)	350.99 (13.52)	74.43 (12.54)	< 0.001
		251.0 – 718.9	178.5 – 762.8	-154.4 – 246.3	
Thin	63	529.95 (27.61)	514.36 (19.34)	15.60 (23.14)	0.502
		156.9 – 1246.0	262.6 – 1011.9	-370 – 575.47	
Travel corridor	57	510.80 (27.88)	591.65 (22.54)	-80.85 (29.61)	0.008
		246.2 – 1018.5	274.2 – 1131.7	-424.8 – 638.6	
Site 29					
Control	72	616.71 (18.47)	398.14 (11.17)	218.57 (22.75)	< 0.001
		344.4 – 1081.8	226.5 – 705.7	-161 – 711.0	
Thin	116	646.76 (22.50)	405.87 (9.44) 215.3	240.89 (21.01)	< 0.001
		281.3 – 1722.9	– 903.3	-145.9 – 1019.6	
Travel corridor	100	654.82 (21.67)	508.03 (15.35)	146.78 (25.62)	< 0.001
		234.67 – 1,511.67	242.57 – 1,027.07	-430.5 – 780.4	
Site 33					
Control	72	490.76 (15.26)	638.22 (20.00)	-147.46 (17.22)	< 0.001
		222.1 – 1028.1	348.4 – 1290.3	-608.5 – 88.5	
Thin	142	722.07 (21.79)	535.5 (11.36) 262.0	186.57 (23.63)	< 0.001
		269.1 – 1636.6	– 1004.8	-539.8 – 1018.2	
Travel corridor	74	729.44 (30.81)	662.32 (28.91)	67.12 (37.20)	0.075
		226.0 – 1939.2	306.9 – 1544.9	-951 – 679.1	
20 cm depth		---------------------------------- kilopascals	----------------------------------		
UPM Kymenee					
Control	60	796.18 (52.17)	572.35 (25.64)	223.82 (55.15)	< 0.001
		328.3 – 2123.7	262.1 – 1333.9	-590.8 – 1345.6	
Thin	63	733.20 (36.10)	758.6 (37.46) 332.3	-25.35 (35.82)	0.481
		178.7 – 1731.2	– 1692.7	-600.5 – 817.8	
Travel corridor	57	714.07 (38.39)	1,028.07 (42.78)	-314.00 (48.63)	< 0.001
		346.5 – 1764.4	396.4 – 1923.0	-1468.9 - 292	
Site 29					
Control	72	974.04 (35.15)	634.38 (29.28)	339.65 (44.21)	< 0.001
		491.0 – 1864.9	235.7 – 1717.9	-1,121.3 – 1370.5	
Thin	116	1,051.84 (47.90)	657.06 (22.09)	394.78 (43.69)	< 0.001
		474.7 – 2715.9	258.4 – 1814.5	-591 – 2360.1	
Travel corridor	100	995.70 (39.79)	867.95 (28.35)	127.74 (43.50)	0.004
		279.3 – 3012.5	257.7 – 1741.1	-828.6 – 2136.0	
Site 33					
Control	72	774.87 (32.99)	880.97 (43.19)	-106.10 (28.56)	< 0.001
		284.0 – 1939.2	421.6 – 2990.3	-1051.06 – 510.3	
Thin	142	987.57 (30.80)	802.41 (23.14)	185.17 (33.86)	< 0.001
		469.2 – 2522.9	379.8 – 1841.1	-1,092.5 – 1406.9	
Travel corridor	74	1,021.26 (42.87)	1,084.23 (45.84)	-62.97 (50.47)	0.216
		341.4 – 2447.0	455.3 – 2227.6	-1,005.6 – 902.9	

Continued

Table 7.—continued

Treatment	n	Pre-thin	Post-thin	Difference	P-value of t-test
30 cm depth		--------------------------------- kilopascals		----------------------------------	
UPM Kymenee					
Control	60	1,567.10 (116.75)	1,143.40 (82.43)	423.70 (105.53)	< 0.001
		447.6 – 3846.7	421.1 – 3080.3	-1,353.7 – 2,735.9	
Thin	63	1529.25 (82.32)	1,228.48 (57.44)	300.77 (78.62)	< 0.001
		363.5 – 2867.4	566.8 – 2726.9	-790.4 – 1,766.07	
Travel corridor	57	1,326.83 (64.93)	1,650.48 (73.23)	-323.64 (78.67)	< 0.001
		624.87 – 2,406.07	659.3 – 3,446.1	-1,740.9 – 977.4	
Site 29					
Control	72	1,324.57 (52.94)	879.15 (43.11)	445.42 (58.43)	< 0.001
		538.9 – 2,976.3	363.7 – 1932.1	-1,148.1 – 1294.7	
Thin	116	1,575.74 (81.29)	939.83 (39.42)	635.91 (73.26)	< 0.001
		458.1 – 4291.8	415.2 – 2527.4	-988.9 – 3,139.1	
Travel corridor	100	1,513.10 (69.09)	1,189.63 (40.86)	323.47 (66.83)	< 0.001
		496.1 – 4,265.6	283.6 – 2,314.1	-847.9 – 3120.3	
Site 33					
Control	72	988.59 (41.98)	1,047.02 (43.21)	-58.42 (34.64)	0.096
		271.1 – 2495.0	526.7 – 2,918.1	-736.9 – 893.9	
Thin	142	1,312.02 (42.04)	1,006.8 (26.51)	305.19 (41.28)	< 0.001
		564.8 – 3143.5	194.86 – 1965.1	-1,117.3 – 1,953.1	
Travel corridor	74	1,339.00 (54.81)	1,277.74 (42.79)	61.26 (63.23) -	0.335
		539.4 – 2,725.5	662.7 – 2,424.5	1,108.2 – 1,464.9	
40 cm depth		--------------------------------- kilopascals		----------------------------------	
UPM Kymenee					
Control	60	2,318.16 (116.13)	1,826.69 (98.04)	504.94 (120.09)	< 0.001
		812.7 – 3984.2	611.7 – 3,758.7	-1,838.3 – 2,480.7	
Thin	63	2,571.00 (95.90)	2,209.63 (69.86)	361.37 (103.98)	< 0.001
		1,067.6 – 4,393.6	1,070.2 – 3,396.7	-1,430.2 – 2,379.0	
Travel corridor	57	2461.61 (100.37)	2,557.27 (78.89)	-95.67 (102.23)	< 0.001
		1,215.0 – 4,157.2	1,370.3 – 3,830.5	-1,682.2 – 1,296.9	
Site 29					
Control	72	1,850.90 (83.00)	1,295.24 (59.18)	555.65 (77.42)	< 0.001
		684.1 – 3,900.9	362.5 – 2,892.8	-1,528.1 – 1,855.1	
Thin	116	2,116.93 (85.49)	1,305.71 (53.14)	811.21 (79.72)	< 0.001
		575.3 – 4432.0	401.1 – 3,575.9	-1,663.4 – 3,395.1	
Travel corridor	100	1,995.75 (80.02)	1,473.46 (58.08)	522.28 (77.03)	< 0.001
		670.3 – 4,376.7	375.8 – 3,719.7	-940.3 – 2,892.9	
Site 33					
Control	72	1,245.62 (47.78)	1,328.08 (46.94)	-82.46 (55.19)	0.144
		253.9 – 2,503.1	628.4 – 2,492.0	-1,204.1 – 1,259.6	
Thin	142	1,805.68 (61.08)	1,335.72 (42.18)	469.96 (58.54)	< 0.001
		675.4 – 3954.1	413.6 – 4,033.4	-1,390.3 – 2,896.1	
Travel corridor	74	1,823.47 (80.58)	1,583.95 (49.24)	239.52 (84.08)	0.005
		730.0 – 3,602.6	846.8 – 2,786.1	-1,301.9 – 2,202.7	

Fuel loadings

Tables 8a and 8b present summary statistics of 1 hr, 10 hr, 100 hr, total fine fuels, 1,000 hr sound, 1,000 hr rotten, total heavy fuels, total fuels, fuel depth, and duff depth by location. Results of separate two-factor ANOVAs performed on total fine fuels, total heavy fuels, total fuels, fuel depth, and duff depth are presented in Table 9.

Fine fuels were affected by treatment (Table 9) with lesser amounts of fine fuels observed in the control plots than in the thinned plots (Table 8). No effect of location or location by treatment interaction was detected for fine fuels. Heavy fuels and total fuels were not affected by location or treatment (Table 9). There was an interaction between location and treatment for fuel depth and duff depth (Table 9). This suggests that site quality, season of harvest, or the type of harvesting equipment used may have impacted slash density and forest floor disturbance.

DISCUSSION

We attempted to select sites that had a high site index for inclusion in the study. Numerous authors (Bickerstaff 1946; Gilmore 2003; Perala 1977, 1978; Schlaegel 1972; Steneker 1964; Steneker and Jarvis 1966; Zasada 1952; Zehngraff 1946, 1947) have suggested that aspen thinning be conducted on only the highest quality sites to maximize tree and stand growth. In our study, there was a light-on-the-land harvest and minimal harvesting damage to the residual stand. The percentage of trees damaged through harvesting and via insects and diseases decreased over time as these trees died. However, the UPM-Kymmene site had a very low site index (60) for aspen, and tree mortality was greater than on other sites (Table 2). It will be interesting to follow the development of this stand over time relative to the other two sites that had substantially higher (75 and 80) site indices.

The purpose of this establishment report is to provide scientists with baseline information that can be used to follow the growth, development, and change in these stands over time. Much of the information on growth and yield and on insects and diseases for aspen can be inferred or predicted from past studies. Two additional lines of important research can also be conducted on these sites. First, biomass production as an energy source is becoming increasingly important. Our baseline data would be useful to researchers studying the development of an understory in an aspen forest following thinning. Understory growth is being explored by the industry as a possible source of biomass fuel.

Second, aspen is an important food source for numerous wildlife species—most notably ruffed grouse. Ruffed grouse require a varied habitat that includes, in part, young regenerating aspen for cover and older, flowering aspen for food (Gullion 1984). Because there has been relatively little thinning of young aspen stands, we do not know the quality of grouse habitat that would be produced from thinning. Our thinning treatments produced linear corridors that could increase the level of predation by raptors and owls. On the other hand, the forest habitat requirements for an important grouse predator, the goshawk, do not overlap strongly with ideal grouse habitat (Zimmerman et al., in press). Grouse habitat in thinned aspen stands may either be poor or good depending on the interactions of the cover produced, the food available, and the suitability of the habitat for predators. We realize the limitations of our study sites for monitoring trends in wildlife populations, but it may be possible to monitor grouse habitat quality over time.

In conclusion, a careful operator using cut-to-length equipment results in minimal damage. Thinning from below increased stand diameter. Thinning did not appreciably affect insect and disease prevalence. Thinning did not affect fuel loadings. We were unable to measure soil strength but soil compaction did not appear to be a problem. Aspen stands growing on a low site index or poor site are not good candidates for thinning. It would be beneficial to explore the effects of thinning across a greater range of densities.

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Table 8a.—Average (standard errors in parentheses) summary of post-treatment fuel loadings by location and treatment (English units of measure)

Treatment	n	1 hr	10 hr	100 hr	Fine fuels	1000 hr sound	1000 hr rotten	Heavy fuels	Total fuels	Fuel depth	Duff depth
		--------------------	--------------------	--------------------	--------------------	tons ac^{-1}	--------------------	--------------------	--------------------	in.	in.
Site 29											
Control	18.00	0.07	0.38	1.31	1.75	18.46	5.04	23.51	25.26	2.49	2.05
		(0.01)	(0.09)	(0.21)	(0.23)	(14.54)	(2.31)	(14.40)	(14.37)	(0.31)	(0.30)
High density	18.00	0.13	0.75	1.38	2.26	19.98	7.20	27.19	29.45	5.19	1.38
Travel corridor	(0.04)	(0.12)	(0.26)	(0.35)	(3.25)	(2.36)	(3.90)	(4.08)	(0.72)	(0.26)	
High density	27.00	0.17	1.14	2.93	4.24	8.31	3.08	11.39	15.64	6.67	1.86
Thin		(0.03)	(0.31)	(0.39)	(0.65)	(2.08)	(1.14)	(2.39)	(2.49)	(0.78)	(0.14)
Low density	29.00	0.22	1.38	1.66	3.25	30.61	4.55	35.17	38.42	4.91	1.24
Travel corridor	(0.04)	(0.33)	(0.33)	(0.57)	(5.37)	(3.39)	(7.01)	(7.09)	(0.48)	(0.16)	
Low density	27.00	0.16	0.99	3.66	4.82	19.54	3.16	22.70	27.51	6.41	2.02
Thin		(0.20)	(0.19)	(0.45)	(0.62)	(7.16)	(2.12)	(8.96)	(9.08)	(0.84)	(0.16)
Site 33											
Control	17.00	0.06	0.26	1.04	1.36	0.59	2.26	2.84	4.21	2.39	2.25
		(0.01)	(0.05)	(0.12)	(0.15)	(0.58)	(1.31)	(1.61)	(1.62)	(0.34)	(0.16)
High density	18.00	0.18	1.35	1.03	2.56	24.87	10.98	35.86	38.42	9.19	1.91
Travel corridor	(0.03)	(0.27)	(0.15)	(0.42)	(3.93)	(4.20)	(5.35)	(5.26)	(2.65)	(0.10)	
High density	25.00	0.18	1.70	2.67	4.56	11.54	4.28	15.82	20.37	9.27	2.07
Thin		(0.02)	(0.46)	(0.43)	(0.88)	(3.95)	(2.68)	(4.43)	(4.63)	(1.03)	(0.09)
Low density	17.00	0.28	0.93	1.39	2.60	15.02	5.26	20.28	22.89	6.53	1.81
Travel corridor	(0.06)	(0.19)	(0.23)	(0.34)	(2.60)	(1.60)	(3.34)	(3.49)	(0.72)	(0.16)	
Low density	27.00	0.25	1.14	2.58	3.97	13.42	6.46	19.88	23.84	7.49	2.38
Thin		(0.02)	(0.24)	(0.22)	(0.36)	(2.98)	(2.08)	(3.45)	(3.65)	(0.76)	(0.14)
UPM Kymenee											
Control	15.00	0.06	0.55	1.49	2.10	11.45	5.65	17.10	19.20	5.16	0.30
		(0.01)	(0.17)	(0.17)	(0.28)	(3.07)	(2.07)	(4.47)	(4.50)	(1.31)	(1.20)
High density	10.00	0.09	0.72	1.43	2.25	39.11	4.43	43.54	45.79	3.37	0.99
Travel corridor	(0.02)	(0.20)	(0.17)	(0.35)	(7.83)	(3.54)	(7.77)	(7.84)	(0.72)	(0.23)	
High density	15.00	0.08	0.73	2.95	3.76	10.89	0.00	10.89	14.65	5.66	1.36
Thin		(0.01)	(0.15)	(0.39)	(0.47)	(3.68)		(3.68)	(3.72)	(0.55)	(0.22)
Low density	10.00	0.10	0.73	0.81	1.64	25.51	0.49	26.00	27.64	5.66	0.69
Travel corridor	(0.01)	(0.23)	(0.14)	(0.32)	(5.62)	(0.49)	(5.93)	(5.77)	(0.55)	(0.12)	
Low density	15.00	0.17	1.05	3.12	4.34	37.59	167.46	205.05	209.40	7.79	0.54
Thin		(0.04)	(0.28)	(0.51)	(0.75)	(28.96)	(165.43)	(194.31)	(194.53)	(0.78)	(0.07)

Table 8b.—Average (standard errors in parentheses) summary of post-treatment fuel loadings by location and treatment (Metric units of measure)

Treatment	n	1 hr	10 hr	100 hr	Fine fuels	1000 hr sound	1000 hr rotten	Heavy fuels	Total fuels	Fuel depth	Duff depth
		---------------	---------------	---------------	-------tonnes ha^{-1}	---------------	---------------	---------------	cm	cm	
Site 29											
Control	18.00	0.16	0.85	2.94	3.92	41.38	11.30	52.70	56.63	6.39	5.25
		(0.02)	(0.21)	(0.46)	(0.52)	(32.59)	(5.17)	(32.27)	(32.20)	(0.80)	(0.75)
High density	18.00	0.29	1.68	3.09	5.07	44.79	16.14	60.95	66.02	13.32	3.55
Travel corridor	(0.08)	(0.28)	(0.58)	(0.77)	(7.29)	(5.29)	(8.74)	(9.14)	(1.84)	(0.67)	
High density	27.00	0.38	2.56	6.57	9.50	18.63	6.90	25.53	35.06	17.09	4.77
Thin		(0.07)	(0.69)	(0.88)	(1.46)	(4.66)	(2.55)	(5.36)	(5.59)	(1.98)	(0.35)
Low density	29.00	0.49	3.09	3.72	7.29	68.62	10.20	78.84	86.13	12.59	3.17
Travel corridor	(0.09)	(0.73)	(0.74)	(1.27)	(12.04)	(7.60)	(15.71)	(15.89)	(1.22)	(0.42)	
Low density	27.00	0.36	2.22	8.20	10.80	43.80	7.08	50.89	61.67	16.43	5.19
Thin		(0.45)	(0.41)	(1.00)	(1.40)	(16.06)	(4.75)	(20.09)	(20.35)	(2.14)	(0.40)
Site 33											
Control	17.00	0.13	0.58	2.33	3.05	1.32	5.07	6.37	9.44	6.12	5.76
		(0.02)	(0.11)	(0.28)	(0.33)	(1.31)	(2.94)	(3.61)	(3.62)	(0.87)	(0.40)
High density	18.00	0.40	3.03	2.31	5.74	55.75	24.61	80.39	86.13	23.56	4.90
Travel corridor	(0.08)	(0.60)	(0.34)	(0.93)	(8.81)	(9.42)	(12.00)	(11.79)	(6.78)	(0.26)	
High density	25.00	0.40	3.81	5.99	10.22	25.87	9.59	35.46	45.66	23.78	5.31
Thin		(0.05)	(1.03)	(0.97)	(1.98)	(8.86)	(6.00)	(9.94)	(10.38)	(2.65)	(0.23)
Low density	17.00	0.63	2.08	3.12	5.83	33.67	11.79	45.46	51.31	16.74	4.63
Travel corridor	(0.13)	(0.43)	(0.50)	(0.77)	(5.83)	(3.58)	(7.49)	(7.83)	(1.86)	(0.42)	
Low density	27.00	0.56	2.56	5.78	8.90	30.08	14.48	44.56	53.44	19.21	6.10
Thin		(0.05)	(0.54)	(0.50)	(0.80)	(6.68)	(4.67)	(7.74)	(8.19)	(1.96)	(0.35)
UPM Kymenee											
Control	15.00	0.13	1.23	3.34	4.71	25.67	12.67	38.33	43.04	13.22	0.78
		(0.02)	(0.38)	(0.39)	(0.64)	(6.88)	(4.65)	(10.01)	(10.08)	(3.36)	(3.07)
High density	10.00	0.20	1.61	3.21	5.04	87.67	9.93	97.60	102.65	8.63	2.55
Travel corridor	(0.05)	(0.44)	(0.39)	(0.77)	(17.55)	(7.93)	(17.41)	(17.57)	(1.85)	(0.60)	
High density	15.00	0.18	1.64	6.61	8.43	24.41	0.00	24.41	32.84	14.52	3.48
Thin		(0.02)	(0.34)	(0.87)	(1.05)	(8.25)		(8.25)	(8.33)	(1.41)	(0.58)
Low density	10.00	0.22	1.64	1.82	3.68	57.19	1.10	58.28	61.96	14.52	1.78
Travel corridor	(0.03)	(0.52)	(0.32)	(0.71)	(12.60)	(1.10)	(13.30)	(12.93)	(1.41)	(0.31)	
Low density	15.00	0.38	2.35	6.99	9.73	84.27	375.40	459.66	469.41	19.98	1.38
Thin		(0.09)	(0.64)	(1.15)	(1.67)	(64.92)	(370.84)	(435.58)	(436.09)	(2.01)	(0.17)

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Table 9.—Results of ANOVAs performed on total fine fuels, total heavy fuels, total fuels, fuel depth, and duff depth y = location + treatment + location•treatment + ε, where y = the measured fuel metric, location = site 29, site 33, or the UPM Kymmene site, treatment = control, high density thinning, or low density thinning, and ε = error NID~(0, σ^2)

	P-values for factors		
Attribute	Location	Treatment	Location•treatment
Fine fuels	0.696	0.001	0.535
Heavy fuels	0.323	0.181	0.350
Total fuels	0.325	0.169	0.355
Fuel depth	0.094	0.001	0.015
Duff depth	0.001	0.398	0.001

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In the spring of 1999, a long-term study was established to examine the physical and biological aspects of thinning young aspen stands in Minnesota. Three aspen stands ranging in age from 25 to 35 years were selected on lands owned by the State of Minnesota and UPM Kymmene. Two thinning treatments (low and high density) and an unthinned control were installed at each of the three locations. Permanent plots were installed to measure tree, shrub, and herb growth, and to monitor harvesting damage, insect and disease damage, soil strength, and fuel loadings.

After 4 years, tree mortality was greater in the unthinned controls. Thinning treatment had no significant effect on the incidence of white trunk rot (*Phellinus tremulae*), Hypoxylon canker, or *Saperda calcarata*. No differences in post-harvest fuel loadings were detected among locations and treatments. Thinning increased the amount of light reaching the forest floor that resulted in greater herb and shrub biomass in the year immediately following thinning.

KEY WORDS: biomass, cut-to-length harvesting system, silviculture, *Populus tremuloides*

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