Fig. 1. Aerial view of Stands 1-13 in study areas at A, Flinton (1953 photo); B, Coe Hill (1960 photo); and C, Northbrook (1960 photo).

Gale damage in coniferous plantations in southeastern Ontario

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Dommages par le vent dans des plantations de conifères. Les vents forts du nord, nord-est, accompagnés de neige et de verglas causent des dommages importants dans les plantations de conifères du sud-ouest de l'Ontario. L'importance des dommages a été évaluée. Les arbres ont été classifiés comme étêtés, décimés, cassés et déracinés. Des espèces observées, le pin rouge en éclaircie est celui qui a le moins souffert alors que les dommages les plus importants sont survenus chez le pin gris non-éclairci. Des pratiques sylvicoles ayant pour but de réduire les dommages causés par le vent sont recommandées.

Introduction

Situations of wind damage to forests in Ontario are scarce and have not been reported in the literature. As the program of plantation establishment extends, we may begin to notice the presence of destructive winds. This could influence our decision to incorporate special silvicultural measures into the management plan with respect to wind damage to forests.

Storms of gale velocity on December 5 and 6, 1968, resulted in severe damage to coniferous plantations located about 50 miles north of the shoreline of Lake Ontario, between 70° 10' and 77° 45' longitudes and between 44° 37' and 44° 52' latitudes, in the Tweed Forest District of southeastern Ontario. These storms presented an opportunity to assess the extent of broken and uprooted trees in stands of red pine (*Pinus resinosa* Ait.), Jack pine (*Pinus banksiana* Lamb.), Scotch pine (*Pinus silvestris* L.), white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss).

Literature review

The ability of a plantation to withstand wind should be taken into account at the time of establishment. A number of factors must be considered to reduce wind damage. Some presented in the literature are briefly reviewed.

Wind flows over the canopy of a well-stocked, even-aged coniferous forest. However, if gaps are left in the canopy, winds are likely to dip down into the openings and cause damage to trees along the

perimeter, especially on the leeward side. Gaps in the canopy should, therefore, be avoided (2, 3, 5, 7, 8, 14).

Stand margins should be of mixed composition and laid out in relation to topography. Furthermore, these margins should be irregular but with no indentations that can funnel the wind into the interior of the stand (2, 4, 15, 22). Margins should be thinned heavily and early to gradually create a permeable barrier with less air turbulence beyond the sheltered area (2, 6, 10, 14).

Spacing is important (2, 5, 14). Wind should filter through well-spaced firmly-rooted trees, rather than forced up over a dense barrier of trees on the perimeter and strike inside the plantation (2, 14, 18). Pruning of marginal trees also requires special attention (10, 14).

Mixed stands with irregular structure are usually the most windfirm (17). The choice of species, especially along the protective margins, deserves consideration. Spruce is unstable under most conditions (2). Hemlock is not recommended as a border tree (4). White pine appears to be more windfirm than either Scotch or red pine (5).

Depth of soil and other items that affect depth of rooting are only one set of factors that influence the resistance of individual trees to wind. Others to be considered include size and shape of crown, shape of the bole, and previous exposure to wind that may or may not condition a tree to withstand violent winds (1, 4, 9, 19, 21).

Most workers recommend early, frequent and light thinnings to produce trees resistant to wind (6, 9, 11, 12, 14, 21). Time and space are needed to allow for the formation of "bracket" roots and strengthening tissue; it takes a stand 15-20 years to stabilize after it has been cut over (4). The consensus is that recently thinned stands suffer most and that heavy and delayed thinning encourages wind throw (6, 13, 14, 20).

Stands examined

The plantations observed in this study were on well-drained deep sands at spacings of 5 or 6 feet. Three plantations — at Flinton, Coe Hill and Northbrook in the Tweed Forest District — were chosen and conveniently divided into 13 stands to assess the extent and type of damage. The location of stands and conditions of the surrounding area are shown in Figure 1. Supplemental stand data are presented in Table 1.

The weather conditions

Records were obtained from the weather stations of the Air Force Base at Trenton, Department of Transport at Stirling, and Department of Lands and Forests at Tweed, about 40, 38 and 24 miles south, respectively, of the study areas.

The period prior to the wind damage was marked with mild temperatures, heavy snowfalls, rain and high winds. Tweed recorded 16.85 in. of snow between December 1 and 6 mixed with some rain at temperatures slightly above freezing during the day and at 32° F or slightly below freezing at night. The winds were light and from the south-south-west and north-north-east on December 1 and 3. They increased on December 4 to a maximum speed of 26 mph from the north-east. Gusts from the west and

west-south-west, reaching peak speeds at 51 mph, occurred on December 5 and 6.

Measurements

Sample plots, one by five chains, were laid out to assess the extent and type of damage to trees. Stands 2, 4, 10 and 11 at Flinton (Fig. 1A) and Stand 5 at Northbrook (Fig. 1C) were completely tallied. In addition, a complete tally of all damaged trees per 1 or ½-chain square area was made throughout Stands 1-9. The extensive damage in Stands 12 and 13 at Coe Hill (Fig. 1B) was estimated by criss-crossing at one or ½-chain intervals, depending on the accessibility of the devastated areas.

Type of damage was recorded by the following classes:

- Class 1: Top of crown broken — "topped"
- Class 2: Entire crown broken — "decrowned"
- Class 3: Trunk broken
- Class 4: Uprooted trees, or severely bent trees (recovery questionable) — "uprooted"

The main direction of destructive winds was obtained from the direction of fall of broken trunks and uprooted trees.

Results

The windthrow index (8) of species by treatment ranged from 1.0 for thinned red pine in Stand 1 to 26.6 for unthinned Jack pine in Stand 13 (Table 1). The greatest percentage of trees fell to the south and south-east (Table 2), suggesting that the main wind force was from the north to north-west. However, 47% and 40% of trees were broken or blown to the west in Stands 4 and 9, respectively.

Pruned and thinned red pine in Stand 1 — pro-

TABLE 1. Relative susceptibility of some coniferous species to wind damage

Location and stand ^a	Composition of Stands						Wind damage				Susceptibility ratio ^c	Windthrow index ^d
	Size (acres)	Species	Age (yr.)	Ave. height (ft.)	Ave. dbh (in.)	Trees per acre (no.)	Trees examined (no.)	Trees standing (no.)	Trees damaged ^b (all classes) (no.)	(%)		
Flinton												
1	7.0	Red pine	42	60	7	503	693	582	111	16	0.191	1.0
2	1.0	Red pine	25	50	6	699	699	548	151	22	0.275	1.4
3	3.9	Red pine	25	40	5	1,400	5,460	3,633	1,827	33	0.503	2.6
4	0.7	Red pine	42	60	7	547	390	255	135	34	0.529	2.8
Northbrook												
5	4.0	Red pine	39	60	7	698	2,093	993	1,100	52	1.107	5.7
Flinton												
6	6.7	Scotch pine	42	60	9	267	535	316	219	41	0.693	3.6
7	2.0	Scotch pine	42	50	7	850	249	122	127	51	1.040	5.4
8	2.6	Red pine	42	50	6	690	345	220	125	36	0.568	3.0
		Scotch pine	42	50	7	220	110	70	40	36	0.571	3.0
9	3.6	Scotch pine	42	50	7	416	416	193	223	54	1.155	6.0
		Jack pine	42	50	6	383	383	145	238	62	1.641	8.5
10	0.1	White spruce	42	60	8	—	128	54	74	58	1.370	7.2
11	2.0	Jack pine	25	50	5	684	1,369	391	978	71	2.463	12.9
Coe Hill												
12	3.0	Jack pine	29	55	6	950	2,880	640	2,240	78	3.500	18.3
13	1.7	Jack pine	29	55	6	950	475	78	397	83	5.090	26.6

^aStands 1 and 4 were pruned in 1958 and row-thinned in 1963. Stand 6 was pruned and row-thinned in 1958 and thinned selectively in 1963. Stands 1, 4, 6 and 10 are on Crown Land.

^bTrees knocked down by others and trees with their tops slightly leaning were excluded.

^cThe susceptibility ratio (SR) was obtained by dividing the number of damaged trees by the number of standing trees for each species..

^dThe windthrow index was obtained by dividing the SR for each species by the SR for red pine in Stand 1. (See Gratkowski 1956.)

Fig. 2. Windthrow in an unthinned red pine stand. **Fig. 3.** Wind breakage in a thinned Scotch pine stand. **Fig. 4.** Decrowned Jack pine in an unthinned stand.

TABLE 2. Direction and percent of fall of 2,439 wind-broken trunks or uprooted trees in 11 stands

Stand	Trees recorded (no.)	Direction of fall							
		N	NE	E SE S SW				W	NW
				(percent)					
1	72	10	5	8	14	24	17	21	1
2	142	13	4	0	11	30	27	10	5
3	568	3	0	17	15	46	8	10	1
4	56	1	0	0	20	22	6	47	4
5	238	7	1	6	12	35	23	10	6
6	80	12	11	5	21	22	11	17	1
7/8	172	6	5	20	50	12	2	3	2
9	135	13	8	4	6	17	3	40	9
10	250	6	6	16	23	17	13	13	6
11	588	1	0	0	58	32	5	3	1
12	138	0	0	2	80	12	3	3	0
Total	2,439	Av.	7	4	7	28	24	11	3

tected on the west — suffered the least damage. However, severe damage occurred in an area of about 1½ sq chains where 48 trees around the perimeter of a gap in the crown canopy were broken or blown. In addition, there were 20% more trees with broken trunks than in the unthinned red pine Stand 2 where slightly more trees were topped or uprooted. No damage occurred to the red pine, 10 to 35 ft in height, west and south-west of Stand 1.

Unthinned red pine in Stand 3 suffered heavily from uprooting. About one-third of the damage was concentrated on the west side bordering a Jack pine stand. Figure 2 depicts an area of uprooted red pine.

Thinned red pine in Stand 4 — exposed to the north — suffered heavy damage especially in the south-east corner where most of the trees were broken. In the unthinned red pine Stand 5 — exposed to the west and north-west — the greatest loss occurred in damage classes 1 and 2, covering a ½-acre area in the western section. Overall damage was double that of the thinned Stand 4.

Scotch pine in the thinned Stand 6 suffered less damage than unthinned Stand 7. Damage to the tops of trees was mainly in the 5- to 8-in. dbh classes in the thinned stand, and in the 9- to 10-in. dbh classes in the unthinned stand. Trees with broken trunks with diameters of 5-8 in. occurred frequently in both thinned and unthinned Scotch pine stands. Generally, heavier damage occurred in the western and eastern sections of Stands 6 and

7, respectively. Damage to trees was scattered throughout the former while in the latter it was concentrated on areas from 1 sq. chain to ½-acre in size. Figure 3 shows trees with broken trunks.

Mixed, unthinned red pine and Scotch pine in Stand 8 suffered equally, but the latter was about twice as heavily damaged in mixture with Jack pine in Stand 9. Jack pine, however, experienced the greatest damage. Both Jack pine and Scotch pine suffered heavily in the damage classes 1, 2 and 3 while red pine was usually decrowned or broken. The peak losses were 32% and 56% of Scotch pine trees topped in the 7- and 8-in. dbh classes, as well as 30%, 35% and 32% of Jack pine trees broken in the 5-, 6- and 7-in. dbh classes, respectively. Some uprooting occurred to the young Jack pine, 25 ft in height, north of Stand 9.

There were 128 white spruce trees in two rows about 12 chains long in Stand 10. The peak damage was 45% of trees topped in the 5-in. dbh class, 38% with broken trunks in the 6-in. dbh class and 31% decrowned in the 7-in. dbh class. Generally, spruce trees were damaged more severely than red pine in Stand 1 to the west or Scotch pine in Stand 6 to the east.

Unthinned Jack pine in Stand 11 was situated below an elevated area to the west that caused the wind to drop into the plantation. Breakage was much more frequent than uprooting. The sloping terrain to the south-east may have also contributed to the very severe damage to unthinned Jack pine in Stands 12 and 13. Both breakage and uprooting occurred in the former while most of the trees were decrowned in the latter. Figure 4 shows an area of damage in Jack pine.

Red pine, just east of Jack pine in Stand 12, were windthrown in an area of ½-acre; several areas of 1 sq. chain and smaller were windthrown further east.

White pine was the most windfirm species but it was not a major component of any plantation observed. There were only five trees slightly damaged in a stand with an average diameter of 8.5 in. located west of Stand 4. In Stand 6, there were about twice as many damaged Scotch pine trees west of the five rows of white pine than those to the east, but white pine was undamaged. Furthermore, no damage occurred to the white pine in Stand 12.

Summary

- Thinned red pine was the least damaged species while unthinned Jack pine was the most heavily damaged species.
- Scotch pine suffered heavy losses and was about twice as heavily damaged in mixture with Jack pine than with red pine.
- White spruce between areas of Scotch and red pine suffered heavy damage.
- White pine was the most windfirm species but it was not a major component of any plantation observed.
- More trees of all species, thinned or unthinned, were broken off than uprooted.

In general, a reduction of damage in relation to the diameter of trees seemed to be noticeable only in the class of uprooted trees starting with the 7-in. diameter class. Generally heavier damage occurred to trees around the perimeter of a gap in the crown canopy. Gaps were caused when areas were left unplanted because of rock outcrops, sudden drop in

The following recommendations are suggested the terrain, etc.

The crown in thinned and unthinned stands may be important to the stability of trees when ice loading precedes gales. In thinned stands, red pine had a much smaller crown than Scotch pine. In thinned stands, the damage appeared to be limited to trees scattered throughout the area. In dense unthinned stands, the damage was heavier and concentrated on trees in groups or entire areas, making the cleaning operation difficult.

Marginal trees suffered least damage in all stands. Generally they were of larger diameters with heavier crowns.
from this study:

Recommendations

1/ The layout of plantations and silvicultural practices with respect to wind damage should be incorporated in the management plan. This should include primarily the planting of widely spaced, windfirm species on the stand border; within the stand, early, frequent and light thinnings, and pruning. Optimal stand conditions should be initiated in the young stand to reach the stage of stability early.

2/ Gaps left after planting operations by machine should be immediately planted out by hand.

3/ The establishment of pure Jack pine stands relatively safe from wind damage is questionable. In mixtures, Jack pine should be the least represented species.

4/ White pine should be used as a safe wind breaker reducing the airflow to other species.

5/ Landowners should be encouraged to treat their forests accordingly because the heaviest damage occurred in privately owned (unthinned) stands.

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Literature Cited

1. ALEXANDER, R. R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. *Forest Sci.* 10:130-42.
2. ANDERSEN, K. F. 1954. Gales and gale damage to forests, with special reference to the effects of the storm of 31st January 1953, in the North-East of Scotland. *Forestry* 27:97-121.
3. BAGULEY, M. J. 1962. Thinning intensity at wood margins in coniferous even-aged crops. *Scot. Forest.* 16: 157-9.
4. BUSBY, J. A. 1965. Studies on the stability of conifer stands. *Scot. Forest.* 19:86-102.
5. CURTIS, J. D. 1943. Some observations on wind damage. *J. Forest.* 41:877-82.
6. FRAZER, A. I. 1963. Wind tunnel and other related studies on coniferous trees and tree crops. *Scot. Forest.* 18:84-92.
7. GEIGER, R. 1950. The climate near the ground. Harvard Press, Cambridge, Mass. 482 p.
8. GRATKOWSKI, H. J. 1956. Windthrow around staggered settings in old-growth Douglas-fir. *Forest Sci.* 2: 60-74.
9. GROTH, O. 1927. Die Wurzelbildung der Douglasie und ihr Einfluss auf die Sturm — und Schneefestigkeit dieser Holzart. *Allg. Forst — und Jagdzeitung* 103:268-85.
10. HUETTE, P. 1964. Sturmschutz in Fi-Bestaenden. *Allg. Forstz.* 19:356-58.
11. KOHLSTOCK, N. 1964. Rationalized tending of young spruce exposed to wind damage in the Harz. *Arch. Forstwiss.* 13:1057-88. Abstract in *For. Abstr.* 26:3673. 1965.
12. LEIBUNDGUT H. 1969. Erhoeht eine starke Durchforstung die Windwurfgefahr? *Schweiz. Zeitschr. f. Forstwesen* 120:110-2.
13. NELSON, T. C. and G. W. STANLEY. 1959. Hurricane damage related to thinning intensity in East Texas slash pine plantations. *J. Forest.* 57:39.
14. PALMER, R. W. V. (Compiler). 1968. Wind effects on the forest. Supplement to: *Forestry*, Oxford Univ. Press. 93 p.
15. RANDALL, J. M. 1969. Wind profiles in an orchard plantation. *Agr. Meteor.* 6:439-52.
16. REIFSNYDER, W. E. 1955. Wind profiles in a small isolated forest stand. *Forest Sci.* 1:289-97.
17. SCHMIDT-VOGT, H. 1966. Zwischen engen und weiten Verbaenden. *Der Forst — und Holzwirt* 21:73-7.
18. SOLOVEV, B. P. 1965. Wind breakage and windthrow in the forest. *Lesn. Z., Arhangel'sk* 8:51-2. Abstract in *For. Abstr.* 27:6071. 1966.
19. WÄNGLER, F. 1969. Die entscheidenden Faktoren fuer die Sturmgefahr der Waldbestaende in Oberschwaben. *Allg. Forstz.* 24:565-6.
20. WEBB, L. S. 1960. The results to date of the partial cutting experiment of 1949. *Forest Res. Note Causal Forest Sta. No. 9.* 6 p. Abstract in *For. Abstr.* 22: 4634. 1961.
21. VITE, P. 1951. Methode und Ergebnis einer Sturmschadenkartierung im Lehrforstamt Bramwald (Oberweserbergland). *Forstwiss. Cbl.* 70:336-46.
22. WOELFLE, M. 1935-36. Wald und Windschutz. *Forstwiss. Cbl.* 57:349-62, 58:325-38, 429-48.