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bi-monthly research notes

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SOILS

Changes in the Chemical Properties of Soil in Northern New Brunswick Caused by Sulfur Dioxide Emission.—In 1971 sulfur dioxide (SO_2) fumes started to escape from a mine 30 km southwest of Bathurst, N.B., in which pyrite-rich overburden material from a nearby open pit mine was used as underground fill. As a result, the forest trees and ground vegetation in the surrounding area showed symptoms of SO_2 toxicity ranging from foliar necrosis to complete mortality (Van Sickle, Bi-mon. Res. Notes, 29:32-33, 1973). Since then, damage due to the SO_2 emission has decreased and new ground vegetation can now be found in some of the areas where all the trees died and negligible ground vegetation existed in 1971-72. In 1973, potted plants of several species were placed throughout the area and in 1976 only alfalfa (*Medicago sativa*) and white pine seedlings (*Pinus strobus* L.) located near the source of the emission showed symptoms of SO_2 toxicity. These species are sensitive to very low levels of SO_2 in the air.

The New Brunswick Department of Natural Resources intends to establish a forest plantation about 3-5 km from the SO_2 source in an area cut in 1973-74 and burned by wildfire during May 1976. The Department, in turn, requested that the Maritimes Forest Research Centre conduct an investigation to determine possible changes in the chemical properties of the soil in the forest surrounding the site of the SO_2 emission, and to evaluate the suitability of the area for plantation establishment. Results are reported here.

Soil samples were collected at distances up to 2.8 km from the source of SO_2 on the west (upwind) side and up to 11 km from the source on the east (downwind) side. The topography of the area surrounding the site of SO_2 emission is gently undulating. Locations and intensity of sampling were chosen to represent the areas where differing degrees of plant mortality were observed by Van Sickle (1973). Samples were also collected from areas on both upwind and downwind sides where little or no damage to the foliage from SO_2 fumes has ever been recorded. The prevailing wind during the growing season in this area is from the northwest. The samples from the burned area were collected on the east side of the mine site (solid circles in Fig. 1).

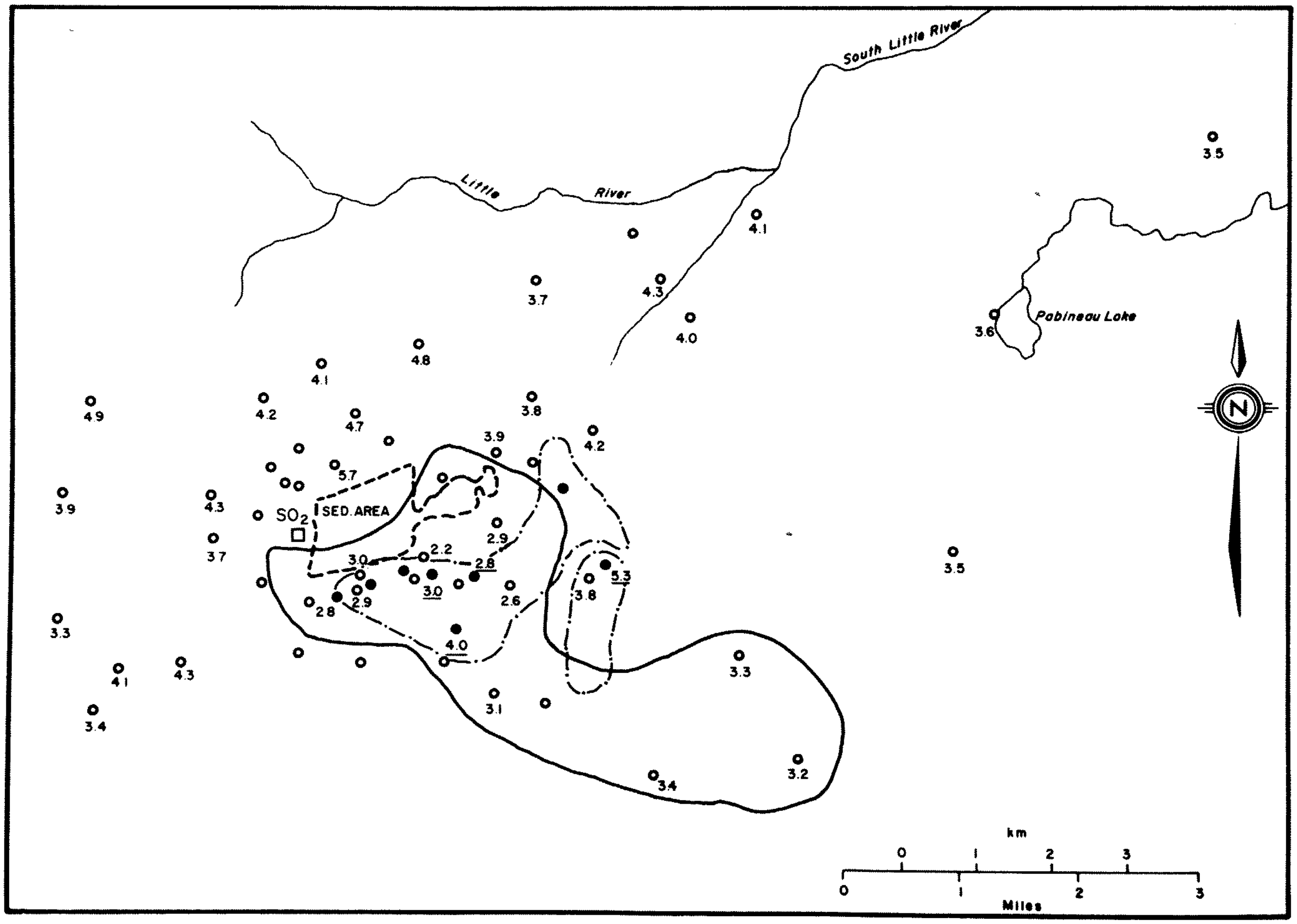

Figure 1. pH values of the organic (L = F + H) layers in the area affected by SO_2. The area most severely affected is enclosed by a solid line. Burned areas are enclosed by a .—.—line. Other indicators are: □ site of SO_2 emission; ● sampling sites in burned areas; o sampling sites in unburned areas (within the burned area o marks unburned patches). Underlining indicates pH values of the samples from the burned areas.

From each site, separate samples of organic (L + F + H) and mineral (B) horizons were collected. During the fall of 1975, 100 samples were collected from the unburned area (hollow circles in Fig. 1), and an additional 20 samples were obtained from the burned area during the spring of 1976. Before analysis, all samples were air dried at room temperature (25° C). Roots, large twigs, large gravel, and stones were removed, the residual soil then being ground to pass a 1-mm sieve. Each sample was analyzed for cation exchange capacity, exchangeable cations, and pH (MacDonald, Marit. Forest Res. Cent. Inf. Rep. M-X-28, 26 pp, 1972).

Results show that the pH values of the organic horizons have decreased because of SO_2 contamination. Values from areas slightly affected and unaffected by SO_2 ranged from 4.2 to 5.7 with an average of 4.6, whereas those from areas severely affected (area encircled in solid line, Fig. 1) were as low as 2.2 with an average of 3.1. The severely affected area lies on the east-southeast side of the SO_2 source. Similar or even more drastic changes in pH due to SO_2 deposition have been recorded in Alberta (Nyborg et al., USDA, Forest Serv. Gen. Tech. Rep. NE-23:767-790, 1976). It should be remembered however, that the acidifying effect of SO_2 is counteracted by the buffering action of the soil and by the cations added by rain and litterfall. It also appears quite reasonable to assume that most of the SO_2 deposition occurred within the first year after emission started, when, in the absence of a stack, the gas was vented at ground level.

Only a very small decrease in the pH values of mineral horizons samples was observed. This may be the result of high-buffering and adsorptive capacity of the overlying organic horizons and the counteracting effects of cations displaced from the organic horizons.

With the acidification of the organic horizons, a concomitant decrease in the cation concentration and percent base saturation (PBS) of their exchange sites was observed. An average of 37% of the exchange sites, in the samples from the areas unaffected or slightly affected by SO_2, were occupied by bases, whereas the corresponding value for the area severely affected by SO_2 was 10%. Theoretically, more than 700 kg SO_2/ ha is required to bring about such a change. This value is in agreement with similar estimates calculated on the basis on the decrease in pH values of the samples.

The organic horizon samples from the burned area did not show any noticeable differences in pH or PBS as compared with the organic samples from unburned areas. At a time when little further SO_2 deposition is taking place, burning of a portion of the organic material would only release more cations, which can move to lower horizons. This explanation is supported by the slightly higher pH and PBS values observed in the mineral horizon samples from the burned area. Presence of new vegetation in the area affected by SO_2 and the results of the chemical analysis of the soil samples suggest that the area is suitable for reforestation. However, it may be wise to determine first which species are best suited for planting in such an area. Because there was little difference in the chemical properties of the soil in the burned and the unburned areas, the burned area should be equally suited for planting.—M.K. Mahendrappa, Maritimes Forest Research Centre, Fredericton, N.B.

ENTOMOLOGY

Rearing the North American Native Elm Bark Beetle.— Many researchers appear to have had great difficulty in rearing the North American native elm bark beetle, *Hylurgopinus rufipes* (Eichh.) in the laboratory. The experience of Thompson and Matthysse (Search 2(1):1-16,1972) seems typical: all attempts at rearing, including holding insects and elm bolts at different temperatures, failed, and led these workers to suspect that this species undergoes diapause, which they were unable to break.

Investigations of Dutch elm disease vectors at Sault Ste. Marie required a serious attempt at rearing *H. rufipes* indoors. Like most workers, we began with a wild population in the fall and got the same results as others before us. The beetles tunnelled into the bark as if to feed or construct overwintering niches, but seemed totally disinclined to breed. Later, in February, we tried again, this time beginning with overwintering adult beetles in the bark of a 30-cm-long block from the base of a living elm 19 cm in diameter. We found that these insects, when they emerged, began quite readily to breed in elm bolts cut in the previous fall and stored at 1°C, and even colonized the block from which they had emerged. This was the beginning of a continuous rearing, which has proceeded without interruption for the past 4 years. In the account of our procedure given below, sizes of cages and elm bolts and numbers of beetles may be modified to suit needs. As described, the method generally produces at least 200 beetles a day.

Elm bolts used in rearing are usually about 35 cm long and 15 to 30 cm in diameter, and when cut from healthy elms they are end-waxed and "aged" for at least 3 weeks at 1°C. Uninfested elm that has been killed by Dutch elm disease is readily used by the beetles for breeding. If material is too fresh, however, they may tend to use it exclusively for feeding instead of breeding. Before being offered for breeding, the bolts are thoroughly soaked with water.

Breeding takes place in wood-frame cages with plywood floors, and sides and back of fine-mesh nylon cloth. The cage fronts are of Plexiglas with sliding doors of the same material. The outside measurements of the cages are approximately 100 x 40 x 40 cm. We have not tried rearing *H. rufipes* in a much larger space, such as a room, and so cannot say whether the narrow confinement is necessary for success. For a rearing, five or six elm bolts are placed upright in a cage and beetles are added daily for 2 weeks. Since more than 100 beetles may be added each day, the bolts are saturated with breeding insects. Breeding activity is soon evidenced by the extrusion of copious boring dust from the bolts. During the time the bolts are held in the breeding cages, they are wetted thoroughly with an atomizer every working day if possible.

Three cages are used and a new rearing is begun every 2 weeks; the bolts are removed from breeding cages at the end of 6 weeks and transferred to emergence cages. For these we use 22-liter grease cans with tops of black polyethylene sheeting held in place with rubber bands. Beetles emerge into glass jars whose metal tops are rivetted to the sides of the cans, with coinciding 2.5-cm holes punched through top and can wall. Some crumpled tissue paper in the jars provides a perching surface for the beetles. Screened holes 7.5 cm in diameter on each side of the jars permit air circulation in the cans and provide extra light to attract emerging beetles to that side of the can.

Both breeding and emergence cages are held at constant 21°C and 45-50% RH, with a 16-h light period. Even under these constant conditions, the 2-week introduction of fresh beetles gives rise to a surprisingly long period of progeny emergence. Emergence becomes appreciable after about 9 weeks from the beginning of the rearing, peaks at about 11 weeks, and continues until about the 19th week. In our rearings we discard the bolts after 22 weeks.

What we call "reemergence" is common in these rearings. For example, on 20 December, 1973, a new rearing was started and no beetles were added to the cage after 25 December. Within 2 days of the last addition, all beetles had disappeared into the bark on the breeding material. On 1 January, 1974, many beetles were flying about in the cage. New rearing material was added; this was promptly attacked and brood developed in it. On 30 January, 1974, beetles were again seen flying about and more wood was added. This, too, was readily infested. These observations show that, under such rearing conditions, the beetle population is active for a lengthy period and capable of breeding at an age greater than 5 weeks. They also suggest that reemergence may be common in the field. If so, and if such beetles feed on healthy trees between sojourns in brood trees, this phenomenon has serious implications for the transmission of the Dutch elm disease fungus. A very high percentage of "reemergents" from trees recently killed by the disease would carry spores, increasing greatly the chance of new infections.

Although these rearings have demonstrated that no obligate diapause exists in *H. rufipes*, it seems certain that late summer and fall adult beetles will not breed after they have been conditioned (by whatever stimuli-falling temperature, shortening day length) to overwinter. To start rearings from such wild populations requires that they be subjected to low temperature for, say, 10 weeks indoors or in the field, after they have entered their overwintering niches in the bark. On the other hand, it should be feasible to begin with wild breeding populations in the spring and early summer.

Without experimentation it is difficult to assess properly the part played by wetting the bolts with an atomizer. However, we have observed that production of beetles diminished during and after periods when water was not applied so assiduously as described. The adults of many wood- and bark-infesting beetles drink water copiously, and it is possible that this also applies to *H. rufipes.*—L.M. Gardiner and D.B. Roden, Great Lakes Forest Research Centre, Sault Ste. Marie, Ont.

Comparison of Germinability of Seed from Insect-infested and Uninfested Cones.—Germination tests were conducted to determine if seeds from infested cones suffered decreased germinability because of insect damage to conductive tissues in the cone.

Seeds from mature cones, collected in late August and early September from Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Engelmann spruce (*Picea engelmannii* Parry), and ponderosa pine (*Pinus ponderosa* Laws.), were extracted on an individual-cone basis from infested and uninfested cones. Both infested and uninfested cones for each test were taken from the same tree, to eliminate intratree variability. The insects involved were *Barbara colfaxiana* (Kft.), in Douglas-fir; *Laspeyresia youngana* (Kft.) and *Lasiomma (Hylemya) anthracina* (Cz.), in Engelmann spruce; and *Laspeyresia piperana* (Kft.), in ponderosa pine. Cones infested by insects other than the foregoing were discarded.

After extraction, the seeds were X-rayed to facilitate separation of filled and hollow seeds. On completion of tests, all seeds that failed to germinate were dissected. Those previously classified incorrectly as "filled" were deleted; thus the reason for totals of fewer than 500 seeds in some tests.

Five replications, each of 100 seeds, were stratified for 3 weeks at 1°C on moist filter paper in petri dishes. Germination tests were conducted at day-night temperatures of 27°C (8 h) and 20°C (16 h). A modified Jacobsen germinator (Edwards and Olsen, Can. J. Forest Res. 3(1):146-148, 1973) was used in conducting the tests. Seed germination commenced within 5 or 6 days and was completed in 10 or 11 days, except in one replication that required 13 days for completion. Seeds were classified as germinated when the radicle length was four times the seed length.

TABLE 1

Germinability of seeds from insect-infested and uninfested Douglas-fir, Engelmann spruce, and ponderosa pine cones

Host	Source of cones*	Insect	Seeds tested Total of 5 reps.	Germinants No.	 %
Douglas-fir	Falkland	*Barbara colfaxiana*	491	450	92.6
		Uninfested	487	462	94.9
	Riske Creek	*B. colfaxiana*	491	451	91.9
		Uninfested	487	454	93.2
Engelmann spruce	Bolean Lake	*Laspeyresia youngana*	502	475	94.6
		Uninfested	489	477	97.5
	Manning Park	*L. youngana*	454	410	90.3
		Uninfested	480	435	90.6
	Little Fort	*Lasiomma (Hylemya) anthracina*	432	426	98.6
		Uninfested	458	449	98.0
	Bolean Lake	*L. anthracina*	470	458	97.4
		Uninfested	489	477	97.5
Ponderosa pine	Lytton	*Laspeyresia piperana*	500	412	82.4
		Uninfested	490	364	74.3

*All cones from each location were obtained from a single tree.

Table 1 shows that more than 90% of seed in all lots except ponderosa pine germinated, with no appreciable difference between seed from infested cones and seed from uninfested cones. This percentage indicated that seed in infested cones does not suffer damage indirectly because of feeding by these insects.—A.F. Hedlin and D.S. Ruth, Pacific Forest Research Centre, Victoria, B.C.

SILVICULTURE

Height and Diameter Growth Response of 10-year-old Jack Pine to Thinning and Fertilization. — Thinning has been used successfully to improve individual tree growth rates and reduce rotation ages of several tree species (Dosen et al., J. For. 55:201-204, 1957; Cayford, Can. Dep. For., For. Res. Branch Publ. 1077, 1964; Berry, Bi-mon. Res. Notes 25:37, 1969; Bella and DeFranceschi, Can. Dep. Fish. For., Inf. Rep. A-X-40, 1971; Bella, Environ. Can., For. Serv. Inf. Rep. NOR-X-102, 1974). Fertilization is also being examined, alone and in combination with thinning, as a tool to stimulate growth and induce self-thinning of young trees of various species, but the author is not aware of any published reports on the effects of combined treatments on juvenile jack pine (*Pinus banksiana* Lamb.).

In 1971 an experiment was established to determine the effect of thinning and fertilization, alone and in combination, on the growth, survival, and development of 10-year-old jack pine in northeastern Ontario. The following is a report on the results obtained after four growing seasons.

The experimental area is in Benneweis Township, Gogama District, Ont. (lat. 47° 31′ N, long. 81° 49′ W), approximately 35 km south of the town of Gogama, within the Missinaibi-Cabonga Section (B.7) of the Boreal Forest Region (Rowe, Environ. Can., For. Serv. Publ. 1300, 1972). The general climate is modified continental, and the area is within the Height of Land Climatic Region (Chapman and Thomas, Can. Dep. Transp., Meteorol. Branch, Climatol. Study 6, 1968). Mean total precipitation, as measured at the nearest weather station (Ruel, Ont.), is approximately 84 cm annually (Anon., Environ. Can., Atmos. Environ. Serv., Can. Norm. 2, Precipitation 1941-1971, 1973).

The experiment was carried out in a dense 10-year-old jack pine stand on a sandy humo-ferric podzol (Anon., Can. Dep. Agric., Publ. 1455, 1974) described by Riley (Environ. Can., For. Serv. Inf. Rep. 0-X-180, 1973) as Site Class 2 (Plonski, Ont. Minist. Nat. Resour., Div. For., Norm. Yield Tables [Metric], 1974) for jack pine. The stand originated from site preparation, followed by aerial seeding, at a rate of 99,000 seeds/ha, in 1960. Sampling by Riley (1973) showed the stand to be 88% stocked (on a mil-acre quadrat basis) with 13,000 trees/ha and an average height of 1.8 m in 1970. Portions of the stand were thinned in 1970 to achieve approximately 1.8 m x 1.8 m spacing between trees, and this resulted in 4,135 stems/ha (Riley 1973).

In May 1971, two areas within the stand, one thinned and one unthinned, were arbitrarily selected to receive fertilizer treatments. Each area was divided into 12 plots (0.04 ha each) for fertilizer treatment. Four fertilizer levels were chosen: $T_1 = 0$ (control), $T_2 =$ N 56 kg/ha, $T_3 =$ N 168 kg/ha, $T_4 =$ N 168 kg/ha + P 112 kg/ha. N was supplied as urea (46% N) and P as triple superphosphate (45% P_2O_5). Each treatment was replicated three times, and all treatments were randomly assigned to a plot in each experimental area.

All plots contained 0.02-ha interior measurement plots. All trees in the measurement plots were numbered with aluminum tags and measured for total height, and all trees greater than 3.8 cm dbh were measured for diameter. Fertilizer was spread by hand in appropriate quantities for the respective treatments of each area.

All plots were remeasured in June 1975, i.e. 4 years after establishment. Height growth measurements were subjected to analysis of variance, and Duncan's Multiple Range Test was used to assess treatment differences.

TABLE 1

Mean total jack pine (10-year-old) tree height in 1971 and 1975, and periodic increment (1971-75) by fertilizer and thinning regime

Fertilizer	Thinned			Unthinned		
	Height 1971 (m)	Height 1975 (m)	Increment (m)	Height 1971 (m)	Height 1975 (m)	Increment (m)
0	2.43^{ab}	3.66^{cd}	1.23^{y}	2.71^{ab}	4.11^{c}	1.40^{y}
B 56	2.43^{ab}	3.63^{cd}	1.20^{y}	2.70^{ab}	4.01^{cd}	1.31^{y}
N 168	2.14^{b}	3.32^{d}	1.18^{y}	2.79^{a}	4.13^{c}	1.34^{y}
N 168 P 112	2.29^{ab}	3.57^{cd}	1.28^{y}	2.67^{ab}	4.01^{cd}	1.34^{y}

Treatments having a common letter and column heading are not significantly different at $P = 0.05$.

TABLE 2

Mean percentage of trees in a diameter class for both 1971 (above line) and 1975 (below line)

Thinning level	Fertilizer level (kg/ha)	Diameter class (cm)						Dead (or missing and presumed dead) (%)
		2.5 (0-3.8)	5.1 (3.8-6.3)	7.6 (6.3-8.9)	10.2 (8.9-11.4)	12.7 (11.4-14.0)	15.2 (14.0-16.5)	
Thinned	0	96/41[a]	3/18	0/33	1/1	0/1	0/0	6
Thinned	N 56	100/39	0/20	0/26	0/9	0/0	0/0	6
Thinned	N 168	97/53	1/14	2/19	0/6	0/1	0/.3	6.7
Thinned	N 168 P 112	100/41	0/16	0/25	0/7	0/0	0/0	11[b]
Unthinned	0	100/55	0/30	0/ 7	0/0	0/0	0/0	8
Unthinned	N 56	100/56	0/28	0/6	0/0	0/0	0/0	10
Unthinned	N 168	94/48	5/31	1/7	0/2	0/0	0/0	12
Unthinned	N 168 P 112	100/38	0/35	0/7	0/.5	0/.5	0/0	19

[a] Read as: In 1971, 96% of original trees were in 2.5-cm diameter class, but in 1975 only 41% of original were in 2.5-cm diameter class.

[b] Bear damage to one plot.

TABLE 3

Mean diameter and height of 10 dominant trees per plot and mean diameter of all trees>3.8 cm dbh at the 1975 remeasurement

Thinning treatment	Fertilizer level	Dominant trees (mean of 10/plot)			All trees > 3.8 cm dbh
		1975			
			Height (m)		
		DBH (cm)	Total	Increment	DBH (cm)
Thinned	0	8.4[a]	4.8	1.2	6.9
	N 56	8.8	5.1	1.3	7.0
	N 168	9.8	5.6	1.6	7.4
	N 168 P 112	9.1	5.1	1.5	7.1
Unthinned	0	6.7	5.3	1.7	5.0
	N 56	6.7	5.3	1.6	5.1
	N 168	7.2	5.6	1.5	5.6
	N 168 P 112	6.9	5.3	1.4	5.2

[a] In 1971 measurement, all trees were less than 3.8 cm dbh.

Height measurements (Table 1) at the time of experiment establishment indicate only one instance of a significant difference between trees in the thinned and unthinned plots. However, no within-plot differences were noted. At remeasurement, periodic height increments for the period 1971-75 were slightly greater (but not significantly so) in the unthinned than in the thinned plots. Mean height increment was not significantly affected by fertilization in either stand condition; however, there was a trend of reduced height increment in unthinned plots with fertilizers.

Trees were ranked by diameter class (dbh) (Table 2) for an evaluation of diameter growth response to thinning and fertilization. In 1971, most trees were in the 2.5-cm diameter class in both thinned and unthinned plots. By 1975, however, several response trends could be noted from the data: (a) *unthinned plots*—(1) the percentage of trees in the 2.5-cm class decreased with increased fertilizer treatment and (2) total mortality (including missing and presumed dead) tended to increase with increased fertilizer levels; (b) *thinned plots*—(1) fertilization appeared to increase the percentage of stems in the 10.2-cm diameter class over thinned control and (2) fertilization did not appear to have any influence on mortality; (c) *a comparison of thinned and unthinned stands*—(1) at the control level, a far greater percentage of stems occurred in the 7.6-cm diameter class in the thinned than in the unthinned plots regardless of fertilizer treatment, (2) combined thinning and fertilization increased the percentage of stems in the 10.2-cm diameter class over unthinned control or unthinned but fertilized, and (3) mortality was generally lower in thinned than in unthinned stands.

Effect on height and diameter growth was evaluated further by selecting the 10 trees with the largest diameters on each plot and comparing mean dbh and height by treatment (Table 3). Mean diameter for these trees was greater in thinned than in unthinned plots and tended to increase slightly with increasing fertilizer levels. Conversely, total height in 1975 and periodic height increment were generally greater in the unthinned than in the thinned plots. A similar response pattern was observed when a larger sample based on the 1975 data and comparing all trees > 3.8 cm was used (Table 3).

The lack of a positive response and the indication of a negative response by jack pine with respect to height increment in the present study is consistent with negative responses reported by Berry (1969) for 10-year-old red pine. Conversely, Chrosiewicz (Bi-mon. Res. Notes 27:6, 1971) reported improved growth of 10-year-old jack pine when stand density was reduced to a moderate density of 4,800 trees/acre (11,856/ha) from an extreme density of 338,700 trees/acre (836,589/ha). Elsewhere, Lotan (USDA Forest Serv. Res. Note INT69, 1967) reported that an initial negative response to thinning in 30-year-old lodgepole pine (*Pinus contorta* Dougl.) became insignificant after 11 years. Such a pattern may be applicable to jack pine and will be determined in future assessments.

Fertilization had no significant effect on height increment in either thinned or unthinned plots, but there was a trend to reduced increment in the unthinned-plus-fertilized plots. This suggests that the reaction of tree height to increased nutrition was similar to its reaction to the increased growing space that resulted from thinning.

The results indicate that diameter growth responded positively to both thinning and fertilization treatments. Lee (Can. J. Forest Res. 4:568-571, 1974) found that 25-year-old Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) responded significantly to fertilization during the first 2 years after treatment but that the effect diminished thereafter. Conversely, response due to thinning was not noticeable during the first 3 years. The results of the present study suggest that juvenile jack pine may make a more rapid response to thinning. The effect of fertilization is apparent and should become more pronounced in the later years of stand development owing to the increased number of trees in larger diameter classes. In terms of diameter-growth increase, the treatments could be ranked as follows: thinning + fertilization > thinning > fertilization > control.

Lee (1974) and DeBell et al. (Crown Zellerback Cent. Res., Camas, Wash., For. Res. Note 5, 1975) have commented on the possibility of inducing self-thinning in dense stands by stimulating dominance with fertilizer applications. Lee (1974) reported an increase in mortality beginning in the fourth year in fertilized stands. In the present study there is an indication, though not a strong trend, of greater mortality of jack pine in unthinned, fertilized plots. Such a trend may become increasingly important as the stand develops.

In the thinned stand, the diameter response (Table 2) to N at the lowest level (56 kg/ha) was not improved by the higher N levels. This suggests that the thinning itself provided sufficient increase in photosynthetic space and/or reduction in competition for available nutrients and moisture, to permit near-maximum growth. A small dosage of nutrients improved growth, but higher application rates were wasted on most trees; however, as Table 3 suggests, dominant trees may be able to capture extra nutrients.

Diameter assessments of young stands should be utilized more closely in future research as a sensitive assessment of treatment responses.—D.A. Winston, Great Lakes Forest Research Centre, Sault Ste. Marie, Ont.

Culture of Detached Branches for Controlled Pollinations in Western Hemlock.—Tree-improvement programs, in general, are dependent on the development of controlled-pollination procedures. Because of their size and remoteness, most parent or plus trees selected for breeding programs are usually vegetatively propagated and placed in breeding orchards to enable making the desired crosses.

Several years could be saved if vegetative propagation and establishment of breeding orchards, for the first phase of breeding programs, could be circumvented. One approach would be to make the crosses in the laboratory on detached branches or cuttings, which are removed from the trees after floral buds have been initiated but before the buds have opened. This approach has been commonly used for many years with several hardwood genera, e.g. *Populus, Salix, Ulmus,* and *Acer* (Johnson, For. Chron. 21:130-136, 1945), and has met with some success in two conifers, *Cryptomeria japonica* (Chiba, J. Jap. For. Soc. 34:278-281, 1952) and *Sequoia sempervirens* (Linhart and Libby, Silvae Genet. 16:168-172, 1967; Libby et al., Silvae Genet. 21:17-20, 1972). In 1975, the Pacific Forest Research Centre began testing this approach for western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) in support of a newly developed tree-improvement program.

Branches bearing enlarged, but unopened, seed-cone buds were collected from three 45- to 50-year-old trees on southern Vancouver Island in late March, about 3 weeks before natural pollination would

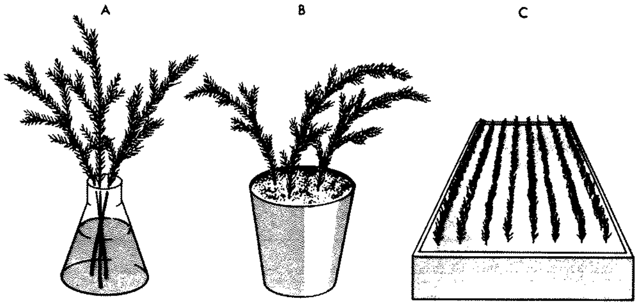

Figure 1. Treatments used to culture detached branches and cuttings. All treatments included material from all three trees. A and B treatments comprised detached branches, 50 cm in length, each branch bearing 16 seed-cone buds. Each flask or pot contained one branch per tree. C treatments comprised cuttings 6-10 cm in length, each cutting bearing a single seed-cone bud.

AQUEOUS TREATMENTS (A)
- A.1 - H_2O only, basal end of detached branch recut weekly. One detached branch per tree.
- A.2 - H_2O + IBA (5 ppm). Three detached branches per tree.
- A.3 - H_2O + IBA (5 ppm) + fertilizer solution A (FA) (Ingested, Rep. Res. Inst. Sweden 51:1-131, 1963. Control solution for pine adjusted here to 5 ppm N.) Three detached branches per tree.
- A.4 - H_2O + IBA (5 ppm) + fertilizer solution B (FB) (van den Driessche, Can. J. Bot. 46:531-537, 1968. Standard solution adjusted here to 5 ppm N.) One detached branch per tree.

SOIL ROOTING-MIX TREATMENTS (B & C) - soil consisting of equal parts perlite, peat moss, and coarse sand.
- B.1 - soil + FA + 24-h presoak of basal end of detached branch in IBA solution. (100 ppm). Three detached branches per tree.
- B.2 - soil + FB + IBA presoak (as per B.1). One detached branch per tree.
- C.1 - soil + 24-h presoak of basal end of cuttings in IBA solution (100 ppm). Forty-eight (3 blocks of 16) cuttings per tree.
- C.2 - soil + FA + IBA presoak (as per C.1). Forty-eight (3 blocks of 16) cuttings per tree.

normally commence. Detached branches 50 cm in length and cuttings 6-10 cm in length, were placed in plywood boxes (1.2 x 0.8 x 0.6 m) covered with clear polyethylene sheeting (to maintain high humidity) within a controlled-environment room and cultured under a series of treatments (Fig. 1). Culture media were either aqueous solutions or a soil rooting-mix, with or without nutrients and IBA (3-indolebutyric acid). Treatments A.2, A.3, B.1, C.1, and C.2 were replicated three times; the remaining treatments were of lower priority and were not replicated because of space limitations in the growth room. To test the effects that pollen, or the absence of it, had on subsequent seed-cone development, half the cone buds in each treatment were designated for pollination. Growth-room conditions were seasonally adjusted to simulate normal outdoor conditions, with early-spring temperature and photoperiod settings at 13°C and 12 h, respectively, and early-summer settings at 18°C and 16-h photoperiod. Light intensity was maintained at approximately 183 lux (600 ft-c) throughout the study.

Seed cones on detached branches and cuttings were pollinated with a single-tree pollen lot during mid-April, with a fine brush. Relatively few cones (approximately 10% of the seed-cone buds) developed normally enough to permit effective pollination. While most cones continued to grow after emerging from the bud scales, there was little reflexing or opening of the ovuliferous scales, a process essential for pollen to pass to the micropyle to enable fertilization. Seed cones on the ortets (trees in the field from which branches were collected) were pollinated from late April to early May with a syringe and the same pollen lot as that used in the growth room. Cone development during and after pollination was normal on these trees.

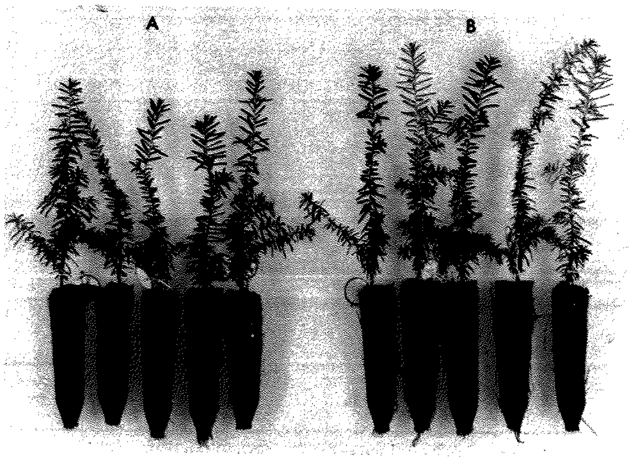

Figure 2. Representative 6-month-old seedlings from seeds produced on detached and intact branches from one of the western hemlock study trees.
A. Seedlings derived from seeds of detached-branch cultures. Mean height = 137 mm.
B. Seedlings derived from seeds of intact branches on the ortet. Mean height = 161 mm.

Cones in the rooting-mix treatments did not continue to develop beyond the initial bud-burst stage. These treatments also suffered heavy-to-total needle loss by late summer. Roots did not develop on any cuttings or detached branches in either the rooting-mix or the aqueous treatments.

In the aqueous treatments, 20% of the branches had total needle loss by late summer, and all cones on these branches became shrivelled and dry. This response, while occurring in all treatments, was more prevalent for one tree. On branches, not suffering such serious needle drop, about 75% of the cones developed to "maturity" by late summer, as judged by the brown cone color. However, the cone scales did not open normally and the cones had to be dissected to remove the seeds. Both cones and seeds averaged 50-60% the size of those produced on the ortets. There was some reduction in the total seed yields per cone, with averages of 15-25 for detached branches and 20-30 for branches left intact on the ortets. However, filled seed yields, as determined by radiography, were considerably reduced. Of the 105 cones that were pollinated and survived to maturity, 85 bore filled seeds. From these, 143 filled seeds were produced, the yield being 1.7 filled seeds per cone. For branches left intact on the ortets, the yield was 23.2 filled seeds per cone. All aqueous treatments and some detached branches of all three trees yielded some filled seeds. Treatments A.1 through A.4 yielded totals of 26, 37, 71, and 29 filled seeds, respectively. Differences in yields of filled seeds from the aqueous treatments were slight, considering that treatments A.1 and A.4 had one-third the number of potential seed cones that treatments A.2 and A.3 had at the outset.

All filled seeds were tested for germination potential, and all germinants were planted in styroblock growing containers. The numbers of germinants for treatments A.1 through A.4 were 0, 10, 34, and 21, respectively. The reduced number of germinants, as compared with filled seeds, probably reflects poorly developed embryos. The reduction was most striking in treatment A.1, none of the 26 filled seeds having germinated. While seedlings from the detached branches were initially two to three times smaller than those from intact branches, height differences decreased with age. At 6 months, average seedling heights for seeds produced on detached branches from the three trees were 85, 84, and 78% those of seedlings derived from intact branches (Fig. 2). This supports other data (Piesch, unpublished), which suggest that seed size has little effect on the growth potential of western hemlock seedlings.

While water culturing detached branches for controlled pollinations appears promising in western hemlock, much research is still needed. Further testing of the system is continuing.—R. F. Piesch, Pacific Forest Research Centre, Victoria, B.C.

MENSURATION

Metric Site Index Formulae for Major Canadian Timber Species.—Site index curves are used widely to estimate potential site productivity. In North America site index curves have been prepared for most major timber species. Construction of these site index curves has generally been based on graphical methodology; hence, to utilize them it is necessary to read and/or interpolate from a given set of curves for desired site index or height values. This is a time-consuming operation that often produces inconsistency in repeated readings for the same points.

Expressing site index curves by formulae makes possible direct computation of site index from tree height/age data, and eliminates the slow and error-prone process of reading and interpolating site index values from graphs. On large sets of data, this saves time and allows site index determination to be integrated into computerized data-processing systems.

Various mathematical equations have been fitted recently to several previously published site index curves. Using exponential growth functions Payandeh (Forest Sci. 20:143-144, 1974a; Bi-mon. Res. Notes 30:4, 1974b; For. Chron. 50:194-196, 1974c) gave equations for major Canadian timber species, expressing height as a function of site index and age (model 1) and also site index as a function of stand height and age (model 2):

$$H = b_1 S^{b_2} (1-e^{b_3 A})^{b_4 S^{b_5}} \qquad (1)$$

$$S = b_1 H^{b_2} (1-e^{b_3 A})^{b_4 H^{b_5}} \qquad (2)$$

where: H = height of dominant and codominant trees in feet
S = site index (height in feet at a base age, e.g. 50 years)
A = stand total age in years
e = base of natural logarithms
b's = constant parameters of the model

The estimated parameters for the foregoing models are valid for English units of measure only, i.e. when both stand height and site index are measured and/or estimated in feet. In computerized data-processing these estimated parameters may still be used, the resulting calculations being converted to metric units. Nevertheless, with metric conversion already in progress in Canada, and for the sake of simplicity

TABLE 1

Estimated parameters of model 1[a] expressing height as a function of site index and stand age for major Canadian timber species

Species	Parameters b_1	b_2	b_3	b_4	b_5	Standard error (m)	Maximum error[b] (m)
Black spruce [c]	6.183	.515	-.0211	5.958	-.5657	.40	1.00
Jack pine [c]	1.818	.883	-.0381	6.756	-.4997	.15	.52
Aspen [c]	2.556	.794	-.0335	9.296	-.6060	.21	.46
White birch [c]	1.215	1.006	-.0503	4.329	-.1823	.18	.52
White pine [c]	5.6095	.6442	-.0244	5.5377	-.3386	.43	.98
Red pine [c]	1.5987	.9682	-.0275	2.3660	-.2063	.18	.40
Tolerant hardwoods [c]	3.1045	.7586	-.0293	6.5510	-.4838	.18	.40
Balsam fir [c]	1.2906	1.0096	-.0401	2.0034	.0182	.24	.49
White spruce [c]	1.8041	.9591	-.0230	1.2841	.0050	.30	.79
Red spruce [c]	2.0169	.8856	-.0561	7.4114	-.0813	.46	1.00
Western white pine [c]	2.8885	.9746	-.0203	2.2089	.0002	.33	.91
Lodgepole pine [d]	1.1931	1.0064	-.0276	1.5427	.0311	.24	.43
Ponderosa pine [e]	2.5280	.9126	-.0060	1.7196	-.2290	.70	1.55
Douglas-fir [e]	1.1600	1.0011	-.0230	1.3164	.0134	.58	1.58
Sitka spruce and western hemlock [e]	1.1610	1.0018	-.0114	1.0976	.0072	.70	1.98

[a] Height = b_1 (Site Index)^{b_2} $(1\text{-}e^{\,b_3 A})^{b_4 \,(\text{Site Index})^{b_5}}$

[b] Maximum difference (±) between observed and predicted height.

[c] Site index based on index age of 50 years.

[d] Site index based on index age of 80 years.

[e] Site index based on index age of 100 years.

TABLE 2

Estimated parameters of model 2[a] expressing site index as a function of stand height and age for major Canadian timber species

Species	Parameters b_1	b_2	b_3	b_4	b_5	Standard error (m)	Maximum[b] error (m)
Black spruce [c]	.0250	1.7509	-.00296	-2.0354	-.3212	.34	.73
Jack pine [c]	.5023	1.1094	-.02099	-2.2764	-.3298	.27	.43
Aspen [c]	.3078	1.2123	-.01385	-2.3153	-.3591	.43	.64
White birch [c]	.9261	.9883	-.03961	-2.6707	-.1609	.24	.52
White pine [c]	.1432	1.3333	-.02073	-3.1710	-.1055	.43	.88
Red pine [c]	.5876	1.0396	-.02095	-1.8281	-.2241	.17	.33
Tolerant hardwoods [c]	.4152	1.1090	-.02276	-2.0767	-.1221	.30	.61
Balsam fir [c]	.8133	.9685	-.03810	-1.7186	.0562	.30	.67
White spruce [c]	.5221	1.0550	-.02400	-1.8757	-.0922	.27	.76
Red spruce [c]	.5217	1.0872	-.06120	-6.9357	.0751	.49	1.16
Western white pine [c]	.3459	1.0244	-.02190	-2.3118	.0210	.34	1.04
Lodgepole pine [d]	.8781	.9797	-.02840	-1.5107	.0549	.43	.82
Ponderosa pine [e]	.0357	1.3582	-.00020	-1.0305	-.1922	.55	1.77
Douglas-fir [e]	.7665	1.0307	-.02320	-1.0850	-.0960	1.04	2.07
Sitka spruce and western hemlock [e]	.5322	1.0499	-.01150	-1.6205	-.1028	1.04	1.89

[a] Site Index = b_1 (Height)^{b_2} $(1\text{-}e^{\,b_3 A})^{b_4 \,(\text{Height})^{b_5}}$

[b] Maximum difference (±) between observed and predicted site index.

[c] Site index based on index age of 50 years.

[d] Site index based on index age of 80 years.

[e] Site index based on index age of 100 years.

and computational cost considerations, it is best to derive a new set of metric parameters as follows:

Let H' and S' be stand height and site index in meters and k (3.28084) be the conversion factor from meters to feet. By replacing H with H' and S with S', model 1, for example, may be written as

$$kH' = b_1 (kS')^{b_2} (1-e^{b_3A})^{b_4 (kS')^{b_5}}$$

When the constant is taken out and both sides are divided by k,

$$kH' = b_1 k^{b_2} S'^{b_2} (1-e^{b_3A})^{b_4k^{b_5}S'^{b_5}}$$

$$H' = b_1 k^{(b_2-1)} S'^{b_2} (1-e^{b_3A})^{b_4k^{b_5}S'^{b_5}} \qquad (3)$$

Now, if $b_1' = b_1 k^{(b_2-1)}$ and $b_4' = b_4k^{b_5}$, equation 3 (above) may be written as

$$H' = b_1' S'^{b_2} (1-e^{b_3A})^{b_4'S'^{b_5}} \qquad (4)$$

Equation 4 (above) expresses stand height (meters) as a function of site index (meters) and stand total age. Similar conversion was done for model 2. It is noted that the metric conversion affects only the two parameters b_1' and b_4' of the model as defined above. Tables 1 and 2 summarize the metric parameter values for both models along with standard error amd maximum error in meters.

Scientific and common names of tree species and the sources of data relating to them are as follows: *Picea mariana* (Mill.) B.S.P., black spruce, *Pinus banksiana* Lamb., jack pine, *Populus tremuloides* Michx., aspen, *Betula papyrifera* Marsh., white birch, *Pinus strobus* L., white pine, and *Pinus resinosa* Ait., red pine (Plonski, Ont. Dep. Lands Forests, Silvic. Serv. Bull. 2, 1960); *Abies balsamea* (L.) Mill., balsam fir (Bakuzis and Hansen, a monograph review, Univ. Minn. Press, Minneapolis, 1955); *Picea glauca* (Moench) Voss, white spruce (Kabzems, Sask. Dep. Nat. Resour., For. Branch Tech. Bull. 5, 1971); *Picea rubens* Sarg., red spruce (Meyer, USDA Bull. 12, 1929); *Pinus monticola* Dougl., western white pine (Haig, USDA Tech. Bull. 323, 1932); *Pinus contorta* Dougl., lodgepole pine (Smithers, Can. Dep. For. Bull. 127, 1961); *Pinus ponderosa* Laws., ponderosa pine (Meyer, USDA Tech. Bull. 630, 1938); *Pseudotsuga menziesii* (Mirb.) Franco, Douglas-fir (McArdle, USDA Tech. Bull. 20 [revised 1941]); and *Picea sitchensis* (Bong.) Carr., Sitka spruce, and *Tsuga heterophylla* (Raf.) Sarg., western hemlock (Meyer, USDA Tech. Bull. 544).—B. Payandeh, Great Lakes Forest Research Centre, Sault Ste. Marie, Ont.

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