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ENTOMOLOGY

Calibration of the Spray System on a Four Engine DC-4G Aircraft for Dispersing *Bacillus thuringiensis*

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Aerial dispersions with *Bacillus thuringiensis* "3a3b" against spruce budworm, *Choristoneura fumiferana* Clem. (Lepidoptera : Tortricidae), were more efficient and economical when concentrated suspensions of this entomopathogen were used (Smirnoff, Can. Entomol. 112:857–859, 1980). In the field, the efficiency of a suspension depends on the distribution and quantity of active material reaching the target. Thus, spray systems should be properly calibrated to assure the quality and efficiency of aerial treatments. In the past, aircraft spray systems were adjusted for flow rate without considering the number of nozzles and their distribution on the booms. Then, evaluation of the spray system was *a posteriori* and indirectly based on evaluation of defoliation. Because these figures are affected by other factors such as outbreak level, temperature, and stand conditions, it was impossible to obtain precise data on spray system calibration.

The Insect Pathology Unit of the Laurentian Forest Research Centre (LFRC) developed an original method to determine accurately the quantity of active material of *B. thuringiensis* reaching ground level during aerial treatment. The method evaluates the number of viable spores deposited per square centimetre (Smirnoff, Can. J. Microbiol. 26:1364–1366, 1980). During the last 5 years, the method was tested following aerial treatments with a Grumman AgCat aircraft and the results indicated that it can and should be used for deposit assessment and calibration of the spray system.

During the summer of 1982, tests were carried out, in cooperation with the Service of Entomology and Pathology of the Quebec Department of Energy and Resources, to calibrate the spray system on a four engine DC-4G aircraft chosen to disperse different *B. thuringiensis* suspensions for the control of *C. fumiferana*. The calibration was carried out by varying several factors such as the number and distribution of nozzles, pressure, and volume dispersed. This note describes the results obtained.

The *B. thuringiensis* formulas tested were (1) Futura, recently developed by LFRC's Insect Pathology Unit, which when diluted (60/40) with water, provided dispersion of the required *B. thuringiensis* dosage (20×10^9 I.U.) in a final volume of 2.5 L/ha (Smirnoff, Juneau, and Valéro, Can. J. For. Res. 12:105–107, 1982). Futura is composed of *B. thuringiensis* primary powder at 80 000 I.U./mg:15%; sorbo (an aqueous 70% sorbitol solution): 44.8%; and water: 40.2%. (2) Thuricide 32LV[a]® and (3) Dipel 88[b]®. The last two formulas were dispersed undiluted at 4.7 L/ha (40×10^9 I.U./ha).

A DC-4G aircraft was used for calibration tests. It flew at 272 km/h and was equipped with a boom and open nozzle spray system. The booms were designed for a maximum of 154 nozzles (77 on each side of the fuselage) and the desired swath width was 333 m.

The nozzle distributions tested were (1) 110 open nozzles evenly distributed (55/55) on each side of the fuselage on the full length of booms; (2) 110 open nozzles (55/55) close to fuselage; (3) 110 open nozzles (55/55) on wing tips.

Because the maximum of 154 nozzles had to be used with Dipel 88 and Thuricide 32LV to assure dispersion of the required volume, the only possible distribution was an even number (77/77) on each side of the fuselage over the full length of the booms. Thus, results are not presented in terms of nozzle distribution on wings.

Deposit was assessed by placing jars containing

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[a] Sandoz Inc., San Diego, California, USA
[b] Abbott Laboratories, North Chicago, Illinois, USA

2.5% peptonized water at every 30 m line perpendicular to the flight lines. The number of viable spores/cm^2 in the containers was determined using Smirnoff's method (Environment Canada, Can. For. Serv., LFRC, Inf. Rep. LAU-X-54, 1982).

Pressure in the booms was 0.9 kg/cm^2 to disperse Futura at 2.5 L/ha and 1.4 and 1.7 kg/cm^2 for Thuricide 32LV and Dipel 88 for dispersion at 4.7 L/ha respectively. All calibration tests were carried out under satisfactory meteorological conditions. Temperatures ranged from 8 to 12°C, relative humidity was over 70%, and winds were below 6 km/h.

The best spray system for dispersing *B. thuringiensis* was 110 nozzles close to the fuselage, 55 on each side with Futura (Table 1). Futura also gave the best dispersal results (Table 2). During calibration tests (Table 1) the aircraft made only one pass and deposit drifted over each side of the pass. During operational treatments with *B. thuringiensis*, flight lines were 333 m apart. Thus, deposit on a given flight line is the sum of the deposit on this line plus the overlaps of the drift from the neighboring lines. This is why a simulation of an operational dispersion with Futura at 2.5 L/ha (20 × 10^9 I.U./ha) carried out by making successive aircraft passes 333 m apart, gave a deposit of 348 000 viable spores/cm^2, i.e. 80% of the emitted number of viable spores (Table 2). A similar dispersion of Futura carried out in the spring of 1982 with a DC-4G aircraft adjusted for flow rate only, provided a deposit of 220 000 spores/cm^2. Calibration of the DC-4G aircraft spray system increased the deposit by 50% with the same *B. thuringiensis* formula and flow rate.

TABLE 1

Deposit with Futura, *Bacillus thuringiensis* formula, during calibration tests with a DC-4G® aircraft

Distribution of open nozzles on booms	Viable spores/cm^2*
110 nozzles evenly distributed on the booms (55/55)	86 200
100 nozzles on wing tips (55/55)	191 800
110 nozzles close to fuselage (55/55)	233 100

* Deposit of a single pass, no overlap.

Dipel 88 and Thuricide 32LV contain no anti-evaporant and are not suitable for dispersion with a DC-4G aircraft. Deposit at ground level after dispersion of these formulas at 2.35 L/ha (20 × 10^9 I.U./ha) was insufficient and did not exceed 60 000 viable spores/cm^2. Dispersion of Dipel 88 and Thuricide 32LV at 4.7 L/ha (40 × 10^9 I.U./ha) yielded only 10% and 40% of emitted number of spores respectively (Table 2). Futura contains sorbitol, an anti-evaporant which prevents loss of active material during dispersion, resulting in a much higher deposit at ground level in terms of viable spores/cm^2.

TABLE 2

Dispersion of different *Bacillus thuringiensis* formulas with a DC-4G® aircraft; booms and open-type nozzle spray system

Formulas	Activity (× 10^9 I.U./ha)	Volume (L/ha)	Swath width*	Number of viable spores deposited/cm^2	Deposit at ground level** (%)
Futura†	20	2.5	333 m	348 000	80
Dipel 88® ††	40	4.7	100 m	81 400	10
Thuricide 32LV®	40	4.7	333 m	278 000	40

* Swath width: 333 m. Simulation of an operational dispersion.

** Percent deposit is estimated according to the emitted number of viable spores.

† 110 open nozzles evenly distributed (55/55) close to fuselage.

†† 154 open nozzles evenly distributed (77/77) on each side of fuselage over the full length of booms.

ENTOMOLOGY

Field Tests with Semiochemicals for the Mountain Pine Beetle in the Cypress Hills, Alberta

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Following the discovery of the mountain pine beetle, *Dendroctonus ponderosae* Hopk., in the Cypress Hills of southeastern Alberta in 1979 (Hiratsuka et al., Can. Dep. Environ., North. For. Res. Cent., Inf. Rep. NOR-X-225, 1980), a control program of sanitation cutting and burning of beetle-infested trees was initiated in 1980 to prevent spread and intensification of this infestation. This program has been continuing since and has proven both costly and labor-intensive because of the difficulty in locating all of the widely distributed "pocket infestations" for the control treatment (Moody and Cerezke, Can. Dep. Environ., North. For. Res. Cent., Inf. Rep. NOR-X-248, 1983).

Recent field tests with semiochemicals (behavior-modifying chemicals) for the mountain pine beetle in British Columbia have resulted in the identification of chemical components that induce strong aggregation behavior of the beetle to its host tree, lodgepole pine, *Pinus contorta* Dougl. var. *latifolia* Engel. (Borden et al., Can. J. For. Res. 13:325–333, 1983a; Borden et al., For. Chron. 59:235–239, 1983b; Borden et al., J. Econ. Entomol. 76:1428–1432, 1983c; Conn et al., Can. J. For. Res. 13:320–324, 1983). In 1982, extension of these tests were conducted in Cypress Hills Provincial Park in Alberta to take advantage of the isolated populations of the mountain pine beetle in this area which uniquely represented the most easterly distribution of both the beetle and its host, lodgepole pine in Canada. These investigations provided data for evaluation of semiochemicals for control of the beetle, and for comparative attractiveness of two semiochemical blends.

The two semiochemical blends were placed as bait on "trap trees" and in multiple funnel traps (Lindgren, Can. Entomol. 115:299–302, 1983) located within two sites where most of the bark beetle population had been removed by sanitation cutting, and in another site that received little control but contained a resident beetle population.

One bait (M/tV/eB) consisted of the host tree monoterpene, myrcene (M), and two beetle-produced compounds, *trans*-verbenol (tV) and *exo*-brevicomin (eB), released at laboratory-determined rates of 17, 1, and 0.5 mg/day, respectively (Conn et al. ibid). The second bait consisted only of myrcene and *trans*-verbenol (M/tV), but with the same release rates.

Ten plot sites with dominant mature lodgepole pine trees were selected. Plots 1 to 3 were within the general area where control treatment (by cutting and burning of infested trees) was considered nearly complete. Plots 4 and 5 were in a second control area, from which most infested trees were removed. Plots 6 to 10 were located in a separate valley where little control work had been done.

At each site the positions for three multiple funnel traps and three lodgepole pines of above-average diameter (Table 1) were approximately 50 m apart in a rectangular pattern. The choice of bait for each trap or tree and baited trap and tree positions along a transect were decided randomly so that each plot site contained:

- three traps, one baited with M/tV, one with M/tV/eB, and the other an unbaited control
- three trees, one baited with M/tV, one with M/tV/eB, and the other an unbaited control

TABLE 1

Diameters and *Dendroctonus ponderosae* attack densities on baited and adjacent unbaited lodgepole pine trees.

	M/tV-baited	M/tV/eB-baited	Control (unbaited)
Avg. diameter (cm)	34.3(10)[a]	36.9(10)	36.4(10)
Proportion of trees attacked in 1982	6/10	10/10[b]	0/10
Avg. attack density (m^2/tree)	39.6	51.6[c]	—
No. attacked trees within 10 m of baited trees	17	23	0
Avg. diameter (cm) of attacked trees adjacent to baited trees	28.5(14)	29.7(9)	0
Avg. attack density/m^2/tree of trees adjacent to baited trees	32.8(14)	35.0[d](9)	0

[a] Numbers in brackets indicate number of trees used in computing average or in t–test comparisons.
[b] Difference in proportion attacked significant; Chi-square test, $p < 0.05$.
[c] Means significantly different at $p < 0.01$.
[d] Means not significantly different, $p > 0.05$.

Baits were suspended at mid-height within the funnel traps. Each trap hung freely from a 1.5 m stake driven into the ground. On all trees baits were placed on the north aspect of stems, about 1.5 m above ground and within small aluminum envelopes nailed to the tree (Borden et al., 1983a, ibid).

The experiment was initiated July 16 and terminated August 31, 1982, when all beetles caught in the traps were counted and preserved for sex determination. All baited trees were examined at the end of August for new (1982) mountain pine beetle attacks. Attack density was counted within two 20 × 40 cm areas of bark surface, centered at bait-attachment height on north and south aspects of the tree, and expressed as number of beetle strikes/m^2 of bark surface per tree. In addition, the numbers of 1982 beetle-attacked trees, mostly within a 10-m radius of each baited tree and trap, were also tallied, and attack densities on trees within a 5-m radius were estimated as on baited trees.

All 10 trees baited with M/tV/eB and 6 of the 10 trees baited with M/tV were attacked by *D. ponderosae*, while no attack was observed on any of the 10 control trees. One of the M/tV-baited trees had only one new attack. Mean attack density of the six attacked M/tV-baited trees was 39.6/m^2, significantly less (t−test; $p < 0.01$) than the 51.6/m^2 recorded on M/tV/eB-baited trees (Table 1). These results indicate that beetles were more strongly attracted to M/tV/eB-baited trees than to M/tV-baited trees, similar to those results obtained from British Columbia (Borden et al. 1983a, ibid.).

Average density of beetle attacks on trees adjacent to each of the two bait formulations was tallied separately. The densities on trees adjacent to the two bait formulations were not statistically different from each other, but were both less than densities on the respective baited trees (Table 1). However, densities on those trees adjacent to the M/tV baits and those adjacent to M/tV/eB baits did not differ significantly ($p > 0.20$ and $p > 0.10$, respectively) from the respective densities on M/tV-baited and M/tV/eB-baited trees.

Twenty-three trees, attacked in 1982 were observed within a 10-m radius of the M/tV/eB-baited trees and 17 around the M/tV-baited trees. Thus both types of baits influenced immigration and colonization by the beetles. Elsewhere in the vicinity of plots, 1982 attacks were observed on one recently fire-scorched tree near an M/tV/eB-baited tree in Plot 1, on two wind-blown trees some 15 m from an M/tV-baited tree in Plot 3, and on two trees 12−15 m from an M/tV-baited trap in Plot 6. Beetle attraction to these trees may have been influenced by factors other than the nearby baits. Within all plot areas there is evidence that the two bait formulations on trees influenced mass attacks (i.e., >31.2/m^2 of bark) on at least 50 trees, including both baited and adjacent unbaited trees. This result suggests that semiochemical baits could be used effectively within the park to help contain infestations (Borden et al. 1983b, ibid). Comparison between controlled and uncontrolled areas indicates that the average number of trees per plot apparently influenced by baited trees was 1.3, 1.0, and 9.2, respectively, for plots 1 to 3, 4 and 5, and 6 to 10. These data correlate well with the relative population levels within the three general areas, and corroborate the results of Borden et al. (1983c, ibid), that demonstrated that baited trees can be used to assess the effectiveness of silvicultural controls and to mop up residual infestations.

In comparison to the baited trees, baited traps collected relatively few mountain pine beetles (Table 2), and variability between plots and bait formulations was considerable. One explanation is that the baited trees, with subsequent enhancement from mass attacks, provided a stronger attraction than baited traps and attracted beetles away from the traps. Additionally, the concentration of chemicals on attacked baited trees may have varied from that in baited traps because of natural release of host odors; the beetles may also have oriented more strongly to the tree silhouettes.

TABLE 2

Numbers and sex of *Dendroctonus ponderosae* captured in funnel traps baited with two semiochemical formulations.

Treatment	No. beetles captured	
	Males	Females
M/tV	83	31
M/tV/eB	17[a]	24
Control	0	0

[a] Number of males attracted to M/tV/eB significantly less (t−test, $p = 0.05$) than to M/tV.

The numbers of female beetles caught with the two bait formulations are similar (Table 2) while the numbers of males caught in M/tV/eB-baited traps were significantly less (t−test; $p < 0.05$) than the numbers caught in M/tV-baited traps. This reduction in numbers of males may have resulted from an inhibitory effect of *exo*-brevicomin (Ryker and Rudinsky, J. Chem. Ecol. 8:701−707, 1982; H. Wieser, E.A. Dixon, and H.F. Cerezke, 1982, unpublished report). The data, however, are somewhat contradictory to those of Conn et al. (1983 ibid), which indicated that *exo*-brevicomin had no apparent affect on males but rather enhanced the response of females.

The results of this study demonstrated that the M/tV/eB bait formulation influenced a greater number of attacked "trap trees", each with higher (about 30% more) average attack densities than did the M/tV bait formulation. Thus the trap trees, in addition to the large numbers of attacked adjacent unbaited trees, suggest a useful method to focus large numbers of beetles within designated areas for efficient subsequent sanitation control. The M/tV/eB bait shows the best potential to maximize the numbers of attracted beetles and should therefore be used in any future mountain pine beetle control programs.

FOREST DESCRIPTION AND MENSURATION

Dimensional Relationships for Several Tree Species from the Spruce-fir Forest Types of Northwestern Ontario

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Over 3 million hectares of Ontario's productive forest lands are classified in the spruce-fir forest types. A spruce-fir forest stand is at least 60% coniferous by volume (mainly white spruce (*Picea glauca* (Moench) Voss), black spruce (*P. mariana* [Mill.] B.S.P.), and balsam fir (*Abies balsamea* [L.] Mill.). Forty percent or less is hardwood, essentially white birch (*Betula papyrifera* L.), balsam poplar (*Populus balsamifera* L.), trembling aspen (*Populus tremuloides* Michx.), and other species. The gross volume of these cover types is estimated at about 700 million m^3. At present, the annual harvest is below the calculated allowable cut for these forest types. However, as wood supplies diminish in Canada and as forests are used more and more for recreational purposes, greater demands will be placed on the spruce-fir forest types in Ontario.

Because of the complexity of the spruce-fir forest types and a lack of research resources, very little information is available about the extent, species composition, growth, yield, and other mensurational characteristics of these types. Such information is essential in the determination of management potential; hence, a preliminary assessment was undertaken to provide basic mensurational information. This note presents dimensional relationships for the principal tree species of the spruce-fir forest types of northwestern Ontario. Knowledge of such relationships is essential for growth and yield studies and simulation modelling.

Measurements were taken from 526 trees on 193 semipermanent growth plots established from 1970 to 1974 at three main locations: the Black Sturgeon Lake area northeast of Thunder Bay, the Beardmore area north of Nipigon, and the Searchmont area north of Sault Ste. Marie. All plots were located within stands 2 ha in area or larger without significant gaps in the canopy. The plots covered a wide range of stand ages, species composition, densities, and site indexes. Most of the sample trees were dominants and codominants. A few trees were from the intermediate crown class. It is believed that all trees were of natural origin.

Tree diameter (DBH) was measured to the nearest 2.5 mm with a diameter tape. Total tree height (HT) was measured to the nearest 30 cm with sectional measuring poles for trees less than 10 m and a Spiegal relascope for taller trees. Crown diameter (CD) was estimated to the nearest 30 cm. Crown length (CL), the distance from the tip of the tree to the general level of live branches, was also measured to the nearest 30 cm, with either a height-measuring pole or a Spiegal relascope. Tree age (A) was determined from increment borings taken at 30 cm stump height. Total (TV) and merchantable (MV) tree volumes were calculated according to Honer's (Can. Dep. For. Rur. Devel., Ottawa, Ont. Inf. Rep. FMR-X-5, 1967) tree volume equations. Merchantable volume was based on a stump height of 15 cm and a minimum top diameter of 7.5 cm. Plot site indexes were calculated on the basis of existing site index equations (Payandeh, Can. For. Serv. Bi-mon. Res. Notes 33:37–39, 1977) for important Canadian timber species. When a site index equation for a species was not available, an equation for another species similar in growth pattern was employed, for example, the site index equation for balsam poplar was used for both trembling aspen and balsam poplar. The site index for an average plot was calculated and assigned to each of the two or three trees within that plot used for dimensional relationships.

Table 1 provides a statistical summary of species for which data on 30 or more trees were available. Nonlinear regression analysis was employed to establish dimensional relationships for white spruce, black spruce, balsam fir, balsam poplar, and white birch. Model forms were similar to those employed earlier (Payandeh, Can. For. Serv. Bi-mon. Res. Notes 34:11, 1978) for peatland black spruce (Table 2). Inclusion of site index in the later models improved the fits significantly in nearly all cases. In each case plotting of residuals against predicted and independent variable(s) was examined carefully to detect unexpected trends, outliers, and variance heterogeneity. In a few cases, weighting would have improved the fit slightly, but not significantly, and hence was not employed to maintain model uniformity across the species. The final equations were chosen on the basis of their values of R^2, standard errors, % bias, and functional forms. Table 2 gives the regression models used for various dimensional relationships. The resulting parameter estimates along with values of R^2, standard error, and % bias for different species and dimensional relationships are given in Table 3. These equations will provide preliminary but essential mensurational information for further growth and yield studies of the spruce-fir forest type in Ontario.

I would like to thank G. Kubik for his patience in doing the numerous regression runs required for this analysis.

TABLE 1

Statistical summary of tree data used for establishing dimensional relationships for several tree species from the spruce-fir forest type of northwestern Ontario[a]

Tree data	Species	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation (%)
DBH (cm)	White spruce	8.9	54.0	24.61	7.90	32.1
	Black spruce	8.0	31.3	19.83	5.18	26.1
	Balsam fir	6.7	37.3	17.29	6.35	36.7
	Balsam poplar	7.6	49.8	21.08	10.53	50.0
	White birch	6.7	44.7	21.87	11.34	51.9
Age (years)	White spruce	24.0	138.0	55.43	17.80	32.1
	Black spruce	28.0	120.0	64.97	23.28	35.8
	Balsam fir	22.0	98.0	45.18	15.94	35.3
	Balsam poplar	23.0	148.0	52.13	31.60	60.6
	White birch	25.0	140.0	71.31	41.16	57.7
Height (m)	White spruce	7.0	26.8	16.17	3.55	22.0
	Black spruce	8.2	28.0	15.35	3.29	21.4
	Balsam fir	7.9	24.1	13.85	3.60	26.0
	Balsam poplar	10.7	32.3	18.86	5.25	27.8
	White birch	9.1	24.4	15.44	4.09	26.5
Crown diameter (m)	White spruce	1.5	8.5	3.55	1.27	35.7
	Black spruce	0.9	7.3	2.55	1.14	44.7
	Balsam fir	1.2	6.1	3.08	1.07	34.7
	Balsam poplar	1.5	7.6	4.26	1.44	33.8
	White birch	1.8	7.6	4.47	1.65	36.9
Crown length (m)	White spruce	3.4	17.1	9.23	2.83	30.7
	Black spruce	4.0	16.8	8.45	2.59	30.7
	Balsam fir	4.0	16.2	8.66	2.77	32.0
	Balsam poplar	2.1	11.3	6.47	2.18	33.7
	White birch	3.7	11.3	6.84	2.07	30.3
Total volume (m^3)	White spruce	.042	2.277	.423	.353	83.5
	Black spruce	.037	1.090	.261	.176	67.4
	Balsam fir	.037	.975	.217	.197	90.8
	Balsam poplar	.038	2.855	.524	.669	127.7
	White birch	.049	1.241	.421	.309	73.4
Merchantable volume (m^3)	White spruce	.029	2.178	.398	.340	85.4
	Black spruce	.025	1.037	.241	.170	70.5
	Balsam fir	.024	.928	.199	.190	95.5
	Balsam poplar	.023	2.730	.492	.643	130.7
	White birch	.029	1.185	.395	.298	75.4

[a] 220 white spruce, 70 black spruce, 117 balsam fir, 59 balsam poplar, and 32 white birch, respectively.

TABLE 2

Nonlinear regression models used to establish dimensional relationships for several tree species from the spruce-fir forest type of northwestern Ontario

Dimensional relationship	Regression model
DBH – age	$DBH = B_1 S^{B_2}(1 - e^{B_3 A})^{B_4} + \epsilon$
Height – age	$HT = B_1 S^{B_2}(1 - e^{B_3 A})^{B_4} + \epsilon$
Crown diameter – height	$CD = B_1 S^{B_2} H^{B_3} + \epsilon$
Crown length – height	$CL = B_1 S^{B_2} H^{B_3} + \epsilon$
DBH – height	$DBH = B_1 S^{B_2} H^{B_3} + \epsilon$
Crown diameter – DBH	$CD = B_0 + B_1 S^{B_2} D^{B_3} + \epsilon$
Crown length – DBH	$CL = B_0 + B_1 S^{B_2} D^{B_3} + \epsilon$
Height – DBH	$HT = B_0 + B_1 S^{B_2} D^{B_3} + \epsilon$
Total volume – DBH	$TV = B_1 S^{B_2} D^{B_3} + \epsilon$
Merchantable volume – DBH	$VM = B_1 S^{B_2} D^{B_3} + \epsilon$

TABLE 3

Estimated regression coefficients for dimensional relationships for several tree species from the spruce-fir forest type of northwestern Ontario

		Coefficients							
Relationship	Species	B0	B1	B2	B3	B4	R^2	Standard error	Bias (%)
DBH − age	White spruce		2.984	.996	−.020	1.543	.624	4.647	−.010
	Black spruce		2.250	.906	−.074	11.029	.614	3.304	.009
	Balsam fir		1.706	1.111	−.021	1.545	.792	2.826	.091
	Balsam poplar		23.812	.651	−.002	.916	.881	4.051	−.264
	White birch		36.381	−.024	−.023	1.695	.827	4.188	−.108
Height − age	White spruce		1.868	.917	−.028	1.502	.770	1.689	−.021
	Black spruce		2.865	.759	−.025	1.292	.768	1.424	−.051
	Balsam fir		1.683	.908	−.034	1.562	.803	1.607	.048
	Balsam poplar		2.644	.814	−.023	.979	.886	1.813	−.016
	White birch		1.957	.847	−.031	1.352	.902	1.427	.042
Crown diameter − height	White spruce		.647	−.287	.884		.410	.729	.028
	Black spruce		.176	−.292	1.351		.574	.542	−.097
	Balsam fir		.060	.614	.843		.615	.672	.126
	Balsam poplar		.390	−.168	.982		.659	.857	−.148
	White birch		.576	−.499	1.257		.838	.689	.230
Crown length − height	White spruce		.721	−.318	1.239		.580	2.028	.101
	Black spruce		1.693	−.305	.908		.412	1.678	−.006
	Balsam fir		.454	.115	.998		.723	1.467	−.040
	Balsam poplar		.180	.646	.578		.515	1.298	.100
	White birch		.731	−.046	.866		.707	1.096	−.082
DBH − height	White spruce		1.225	−.259	1.339		.750	4.040	.048
	Black spruce		1.014	.331	.770		.625	3.048	.007
	Balsam fir		.607	−.0005	1.274		.852	2.446	−.012
	Balsam poplar		.382	−.381	1.733		.916	2.916	.092
	White birch		16.265	−1.395	1.487		.785	4.409	−.315
Crown diameter − DBH	White spruce	12.644	−14.504	.084	−.211		.524	.667	−.851
	Black spruce	16.535	−18.606	.064	−.138		.595	.595	2.105
	Balsam fir	8.037	−12.613	.052	−.386		.517	.701	−.046
	Balsam poplar	43.654	−45.018	.027	−.072		.766	.764	.001
	White birch	47.972	−48.365	.023	−.060		.759	.881	.473
Crown length − DBH	White spruce	1.372	.349	.013	.962		.723	1.497	.045
	Black spruce	1.372	1.170	−.713	1.224		.630	1.601	.170
	Balsam fir	1.372	.342	.217	.854		.779	1:321	−.033
	Balsam poplar	1.372	.087	.934	.438		.463	1.454	.102
	White birch	1.372	.109	.745	.614		.630	1.304	−.014
Height − DBH	White spruce	1.372	.701	.419	.590		.857	1.294	−.015
	Black spruce	1.372	1.404	.317	.477		.663	1.549	−.003
	Balsam fir	1.372	1.180	.157	.674		.880	1.172	.012
	Balsam poplar	1.372	1.280	.326	.549		.907	1.555	.038
	White birch	1.372	.269	.906	.472		.824	1.737	.118
Total volume − DBH	White spruce		.000094	.073	2.490		.986	.042	−.402
	Black spruce		.000066	.231	2.470		.940	.044	4.352
	Balsam fir		.000131	.064	2.411		.986	.023	−.486
	Balsam poplar		.000066	.339	2.387		.928	.183	17.789
	White birch		.000092	.264	2.323		.969	.057	3.787
Merchantable volume − DBH	White spruce		.000079	.118	2.485		.987	.039	.679
	Black spruce		.000036	.267	2.615		.945	.040	1.903
	Balsam fir		.000067	.031	2.616		.985	.024	1.626
	Balsam poplar		.000041	.627	2.330		.987	.075	−3.731
	White birch		.000039	.280	2.531		.954	.067	8.454

FOREST PRODUCTS TECHNOLOGY

Temperature Effects on Pilodyn Pin Penetration

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Specific gravity, or wood density, is a timber characteristic commonly used to evaluate wood quality for tree improvement programs (Zobel, B.J. 1964. Unasylva 18:89–103). Wood density is an especially useful parameter because it is closely linked to overall timber strength and net pulp yields. This parameter is becoming increasingly acknowledged as an important characteristic for routine inclusion in breeding programs of many operational forest tree improvement schemes. Reasons for this interest center around the expectation that wood harvested from more rapidly grown and younger second rotation forests will, on the average, be less dense.

Conventional methods used to estimate specific gravity or wood density in standing trees are usually time-consuming and require repeated sampling to resolve variability in estimates. They are limited to samples removed from trees and analyzed in a laboratory, and may require felling, especially of trees in smaller diameter classes. The Pilodyn wood tester provides a reliable, quick, and nondestructive estimate of wood density (Cown, D.J. 1978. N.Z.J. For. Sci. 8:384–391.; Micko, M.M. et al. 1982. For. Chron. 58:178–180.; Taylor, F.W. 1981. Forest Sci. 27: 59–61). Because of these advantages the instrument has been proposed for use as a preliminary screening tool when selecting plus trees, as well as for an index of selection in a breeding program (Cown, 1978; Micko et al. 1981.; Taylor 1981).

The Pilodyn wood tester is powered by a constant force tension spring, which injects a blunt pin into the wood sample. The principle is similar to a shock resistance test but, instead of measuring the load required to cause a constant surface deformation, the penetration from a constant load is measured by the Pilodyn tester. The distance (read in mm) that the pin penetrates the wood sample is inversely proportional to wood specific gravity or density, within limits of sampling accuracy. To test the possibility of using the instrument year-round for evaluation of plus tree candidates, the effect of changes in ambient air temperature on pin penetration was studied.

Two jack pine (*Pinus banksiana* Lamb.) trees in each of a 10, 20, 30, and 50-cm diameter class at the Petawawa National Forestry Institute, Chalk River, Ontario were selected for this study. A thermometer was mounted adjacent to each of the eight trees in the study. Two diametrically opposite readings were made at 1.3 m (breast height) at 0900 and 1500 on each of 10 days during early December, 1982. Ambient air temperature at each tree was also recorded at these times on each day of the experiment. Maximum and minimum daily temperatures were obtained from the permanent weather station at the Institute as a standard measure of diurnal fluctuation.

The four observations recorded in each diameter class for each measurement time were pooled to provide a mean which was used for subsequent analysis. Data were analyzed, separately for each diameter class, by calculating a nonparametric correlation coefficient (Spearman, C. 1904, Amer. J. Psych. 15:88–94) between pin penetration and a standard temperature from the weather station.

Mean values of pin penetration for the four diameter classes were quite similar (Table 1). However, the standard deviation of the 10 and 50-cm diameter classes was considerably less than the 20 and 30-cm classes. These differences in total variability can be attributed not only to temperature differences, but to differences inherent within the section of stem of candidate trees themselves. Variability of this sort can be induced, for example, by differences in bark thickness or amounts of compression wood. While every attempt was made to visually remove these sources of variation by sampling midway between branch whorls, it was impossible to ensure that each section of bole within each candidate tree was identical.

TABLE 1

Summary statistics for Pilodyn pin penetration observed over a period of ten days on several different diameter classes of jack pine

Diameter class (cm)	Mean	Standard deviation	Minimum	Maximum	r_s
10	19.15	4.83	11.8	25.0	0.68**
20	19.61	6.47	8.8	25.5	0.86***
30	21.39	6.17	11.0	27.0	0.84***
50	20.65	4.07	13.5	24.5	0.88***

r_s Spearmans rank correlation coefficient with temperature at the weather station. There are 17 degrees of freedom associated with each diameter class.

* nominal levels of significance; ** = 0.05; and *** = 0.001

The pattern of pin penetration was strongly related to patterns of temperature variation (Fig. 1, a-d). Spearman rank correlation coefficients calculated between temperature recorded at the weather station and pin penetration were significant for all diameter classes (Table 1). A nonparametric correlation coefficient was used because of the conspicuously nonlinear distribution of the observations (Fig. 1, a-d). As well, the authors were primarily interested in the patterning and response of pin penetration to changes in temperature.

It is obvious from Figures 2, a-d that decreasing temperature results in a dramatic drop in the penetrability of wood, especially between zero and −10°C. Beyond these values, the response is essentially constant with no slope. Although temperature can, and does, have a drastic impact on pin penetration, it is not the only factor that affects estimation of specific gravity. Hoffmeyer (The Pilodyn instrument as a non-destructive tester of the shock resistance of wood. Paper presented at Non-Destructive Testing Meeting, Vancouver, Wash. Aug. 1978) demonstrated that moisture content has a significant effect on pin penetration. Although living trees are not expected to show absolute differences in moisture content, differences in proportion of frozen and thawed wood can be caused by differences in tree mass. These differences will change the response time of trees of different mass to fluctuations in temperature. In fact, the smaller diameter classes tended to be more erratic in pin penetration through temperature gradients (Fig. 1, a-d).

Several observations can be made from these results. The first and most important is that temperatures at or below freezing have a significant influence on the penetration depth of the pin. These effects are most pronounced in the 0° to −10°C temperature range. However, frozen wood reduces the penetrability and thus decreases absolute differences among trees. Measures of penetrability are highly erratic when ambient temperatures are fluctuating above and below freezing. Although the smaller range in penetration values can be partially rectified by using a more powerful force, problems with pin breakage increase.

These observations indicate that studies using the Pilodyn wood tester as a means of estimating wood density should be carried out at ambient temperatures consistently above 0°C. Penetration does not appear to be temperature-dependent over the range of above-freezing temperatures reported here (0° − 15°C). As has been observed in several other studies previously mentioned, this instrument has considerable potential for application in tree improvement programs. However, several factors, including ambient air temperature, must be taken into account in order to minimize error in estimation.

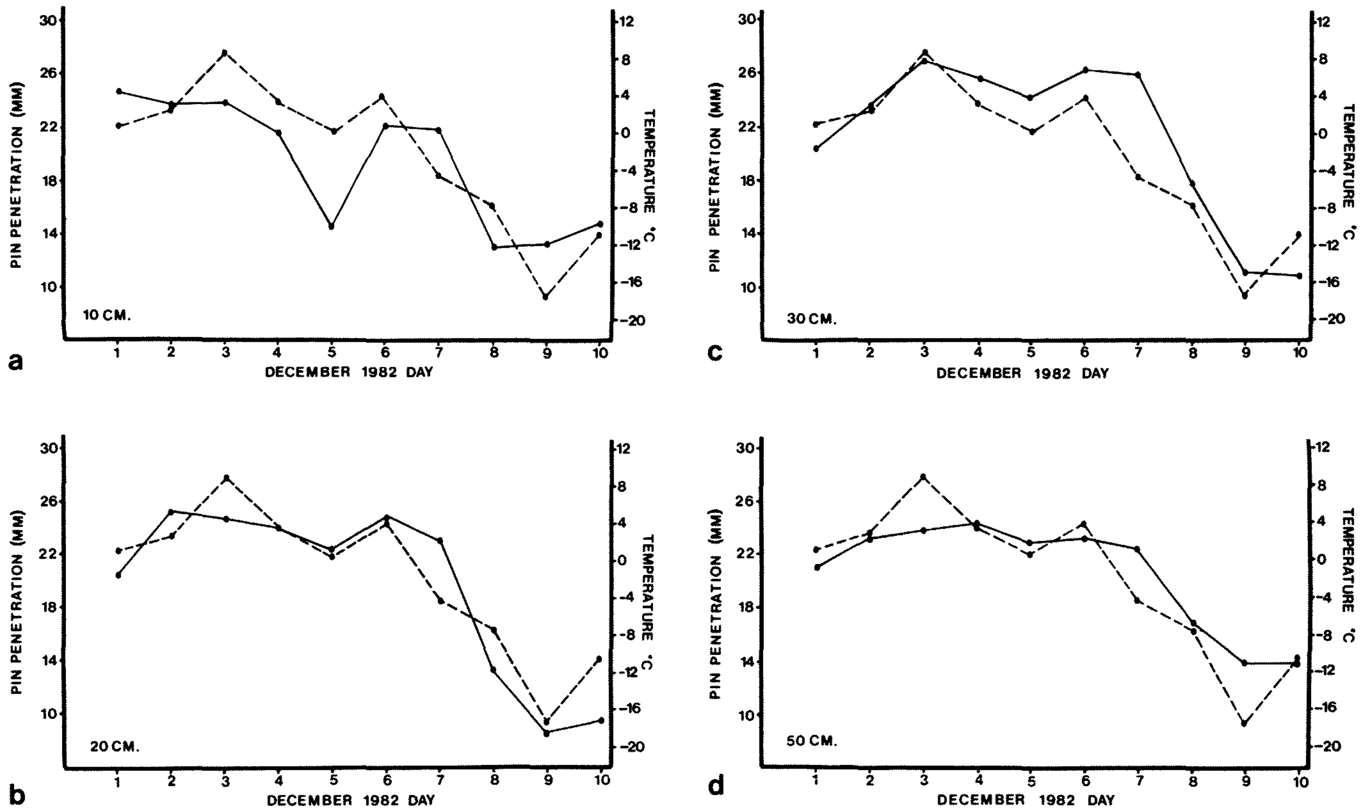

Figure 1. Mean Pilodyn pin penetration versus mean standard temperature by day for each of four diameter classes of jack pine. The dashed line represents the mean standard temperature; the solid line represents mean response of trees in various diameter classes: a = 10 cm; b = 20 cm; c = 30 cm; d = 50 cm.

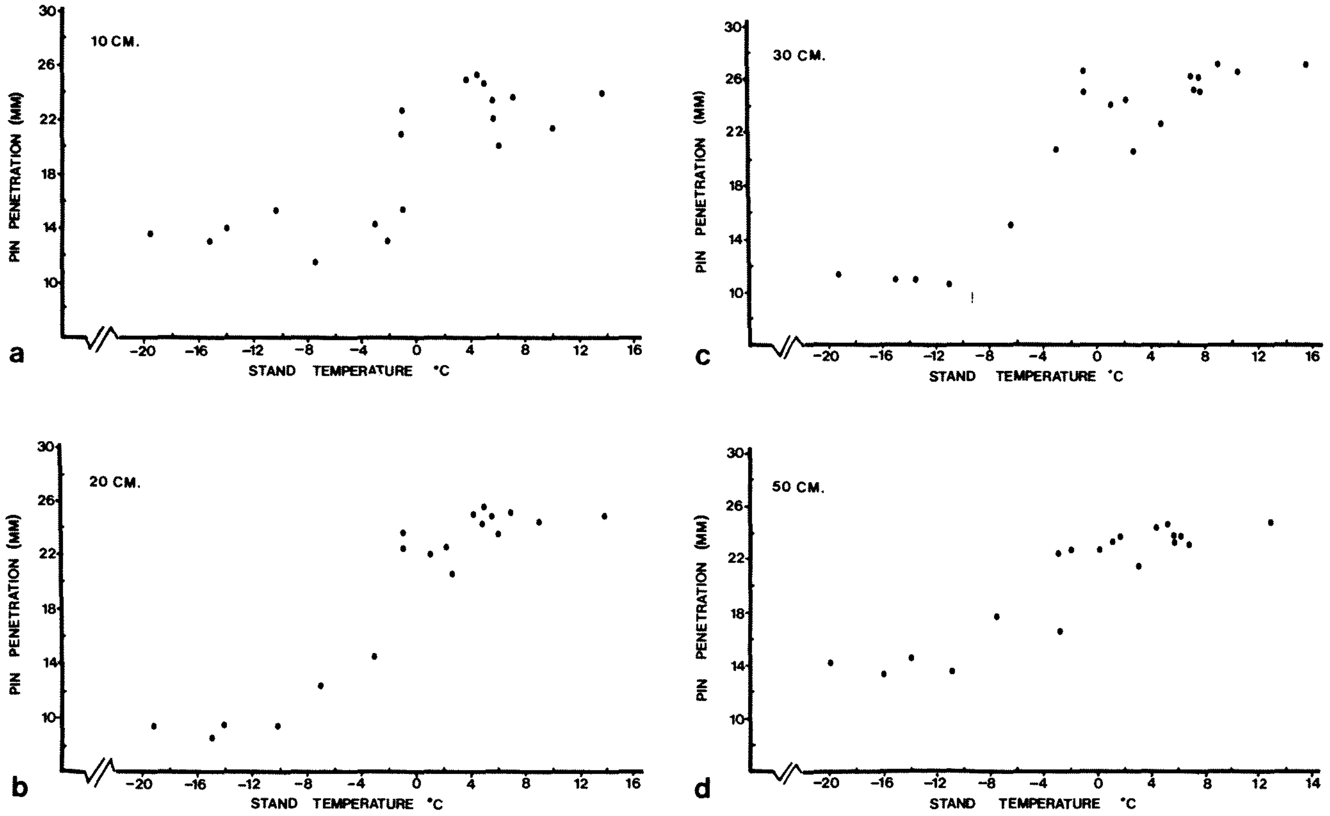

Figure 2. Relationship between mean Pilodyn pin penetration versus ambient air temperature for four diameter classes of jack pine: a = 10 cm; b = 20 cm; c = 30 cm; d = 50 cm.

MISCELLANEOUS TECHNIQUES

Individual Rearing of Spruce Budworm Larvae

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In ecological studies of spruce budworm, *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae), it is often necessary to rear thousands of larvae to determine precisely the cause and timing of mortality throughout development. The usual method of rearing budworm larvae in groups of 25–40 (Grisdale, Can. Entomol. 102:1111–1117, 1970) or in groups of 5 (Fast and Dimond, Can. Entomol. 116:131–137, 1984) often results in many larvae dying, possibly through cannibalism and disease contagion. To eliminate this problem, larvae must be reared individually and to determine timing of mortality, larvae must be observed daily. A new rearing method was therefore designed considering space and ease of observation.

Rearing large numbers of larvae individually on foliage is not practical; artificial meridic diet (McMorran, Can. Entomol. 97:58–62, 1965) is ideal. Grisdale's (loc. cit.) method could be modified by using clear plastic containers instead of translucent creamer cups and by rearing one larva per container. However, in such containers, about 10 mL of diet is necessary, otherwise dehydration of the diet can interfere with larval development and survival. Furthermore, one larva can complete its development on 2 mL of diet; therefore, using 10 mL is wasteful. Also, several thousand 45-mm-diameter creamer cups occupy significant space. The method described here uses 7.4-mL shell vials (17 mm diameter, 60 mm high) stored in clear acrylic trays (Fig. 1).

Artificial diet is poured into 100 × 15-mm petri dishes to a depth of about 10 mm. When cooled, the diet is sprayed with an antifungal solution consisting of 15 g sorbic acid and 6 g methyl para-hydroxybenzoate in 1 L of absolute ethyl alcohol (Grisdale, loc. cit.). After the alcohol has evaporated, diet is transferred to the shell vials by using the open end of each vial as a cutter and punching out a disc of diet. Because the diet forms an airtight seal, the air in the vial is compressed and the first disc of diet is pushed back out of the vial to remain in the petri dish as the

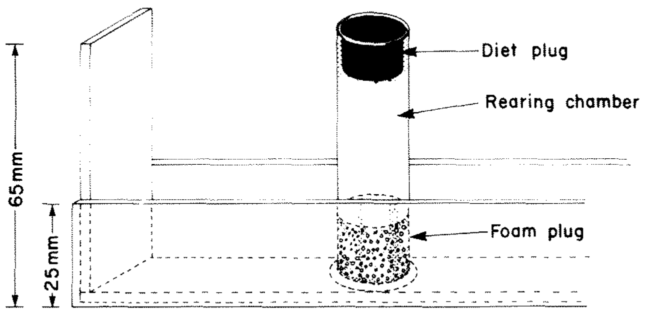

Figure 1. Acrylic tray with vial for rearing individual spruce budworm larvae.

vial is lifted. It can be removed from the petri dish with forceps and discarded. When punching out the second disc, the vial opening is positioned such that it slightly overlaps the space left by the removed disc; this disc is thus not a perfect circle. Air escapes through the imperfection and the disc remains flush with the top of the vial when the vial is lifted from the petri dish. The immediate result is a vial plugged at the top with a disc of diet. This procedure is repeated until about 100 vials have been plugged with diet, at which time the exposed surface of the diet is sprayed with fungicide. When the alcohol has evaporated the diet discs are pushed to the bottom of the vials using a wooden dowel; the air escapes through the slight imperfections at the edges of the discs. Such vials can be stored for several weeks in plastic bags at <5°C.

One larva is placed in each vial, which is then plugged with a plastic foamlike plug, 20 × 19 mm, made by cutting in half a standard 38-mm-long diSPo® plug. Vials are placed in an acrylic tray with the plug down. The ends and bottom of each tray are cut from a 3-mm acrylic sheet; the sides are cut from a 2-mm sheet. The inside width of the tray is designed so that the vials fit snugly but the length of the trays can be adjusted to the width of the shelves upon which the larvae are to be reared. In a fully loaded tray, the vials remain inverted with the diet at the top; this is standard rearing practice even for larvae reared in creamer cups. In a partially filled tray, vials may tilt at various angles. Such tilting can be prevented by forcing a full length, 20 × 38 mm, diSPo® plug horizontally into the tray abutting the last vial.

Foam plugs are suitable for all but second-instar larvae that have recently emerged from hibernacula. These larvae tend to wander and will frequently chew their way into the foam plug, become trapped, and die. Thus, if recently emerged larvae are to be reared it is best to place 5 mm of washed, autoclaved, white silica sand in the bottom of the tray and insert the open end of the vials into the sand. Such sand, obtained locally from a building supply store, will pass through a standard No. 30 sieve, opening 0.6 mm. Larvae will often wander on top of the sand and may even dig into it but they rarely become trapped. Once the larvae have moved upward into the diet and established feeding sites, usually within 48 h, and invariably between the glass wall and the diet, the vials can be stoppered with a foam plug and the sand discarded. Larvae can be reared entirely over sand but it has several drawbacks: it tends to spill and be messy; large larvae transport sand particles from the bottom of the vial and incorporate them into the webbing, often to such an extent that it interferes with observation; and it can interfere with the spinning of cocoons by hymenopterous parasites that issue from budworm and drop onto the sand.

One second-instar larva can be reared through to an adult in one vial without needing to change the diet but, because of space limitations within the vial, the moth's wings fail to expand normally. If live adults are required, it is advisable to remove the pupae from the vials and place them in larger containers for moth emergence.

When ambient humidity is low, the diet may dry and shrink. This can be prevented by raising the ambient humidity of the room or by dampening the foam plug.

In 1982, 1042 field-collected second-instar larvae were forced from hibernacula in mid-April and reared using this method. Three temperature regimes were used, each based on a 24-h sine curve. These were 10–16–22°C, 15–20–25°C, and 22–26–30°C. Time to 50% pupation was 45 days, 25 days, and 19 days, respectively. The data are summarized in Table I which shows that overall survival, corrected for parasitism by *Apanteles fumiferanae* Vier. and *Glypta fumiferanae* (Vier.), ranged from 52% at the cool temperature regime to 80% at the high. Second-instar larval mortality at the two cooler temperature regimes was mostly due to the larvae becoming trapped in droplets of condensation which formed when the temperature dropped. This problem was overcome in a subsequent experiment by placing

TABLE 1

Survival of *Choristoneura fumiferana* second-instar larvae reared individually in vials at three temperature regimes

	Temperature regime, °C		
	10–16–22	15–20–25	22–26–30
Larvae on diet	354	337	351
Dead 2nd instars	57	31	24
Dead 3rd instars	10	12	3
Dead 4th instars	45	2	19
Dead 5th instars	32	4	0
Dead 6th instars	14	34	16
Pupae	170	218	247
Parasites	26	36	42
Survival, %	52	72	80

vials, containing newly-emerged second-instar larvae, at a constant 22° C for 48 h before placing them in the fluctuating temperatures. This allowed time for the larvae to establish feeding sites. In this experiment, with similar larvae forced from hibernacula in early-May, survival to pupae, corrected for parasitism, ranged from 97% at the cool temperature regime to 89% at the high temperature regime.

This method has been used successfully to rear larvae of all instars, collected in the field throughout the larval feeding period. Dipterous parasite larvae which emerge from these field-collected larvae may escape through the foam plugs. The rate of survival is higher if Diptera larvae are removed and allowed to burrow into milled sphagnum moss to pupate. (E. Eveleigh, MFRC, pers. comm.).

RECENT PUBLICATIONS

Source of these recent publications is indicated by the code number on the left of each description. Requests for copies should be addressed to the Canadian Forestry Service office identified by the code and listed on the back cover.

7 **Barclay, H.; Van Den Driessche, P. 1983.** Pheromone trapping models for insect pest control. Res. Popul. Ecol. 25(1):105 – 115.

7 **Barclay, H.J. 1984.** The estimation of fitness in iteroparous species during population replacement experiments. Can. J. Genet. Cytol. 26:91 – 97.

4 **Blais, J.R. 1983.** Predicting tree mortality induced by spruce budworm: a discussion. For. Chron. 59:294 – 297.

2 **Dobesberger, E.J.; Lim, K.P.; Raske, A.G. 1983.** Spruce budworm (Lepidoptera: Tortricidae) moth flight from New Brunswick to Newfoundland. Can. Ent. 115:1641 – 1645.

3 **Eidt, D.C.; Sosiak, A.J.; Mallet, V.N. 1984.** Partitioning and short-term persistence of fenitrothion in New Brunswick (Canada) headwater streams. Arch. Environ. Contam. Toxicol. 13:43 – 52.

7 **Gray, T.G.; Slessor, K.N.; Grant, G.G.; Shepherd, R.F.; Holsten, E.H.; Tracey, A.S. 1984.** Identification and field testing of pheromone components of *Choristoneura orae* (Lepidoptera: Tortricidae). Can. Ent. 116:51 – 56.

5 **Great Lakes Forest Research Centre 1983.** Mechanization of silviculture newsletter. Fall 1983, 1 (2).

7 **Hedlin, A.F.; Weatherston, J.; Ruth, D.S.; Miller, G.E. 1983.** Chemical lure for male Douglas-fir cone moth, *Barbara colfaxiana* (Lepidoptera: Olethreutidae). Environ. Entomol. 12: 1751 – 1753.

2 **Hew, Choy L.; Kao, Ming Hsiung; So, Ying-Peng; Lim, Kiok-Puan 1983.** Presence of cystine-containing antifreeze proteins in the spruce budworm, *Choristoneura fumiferana*. Can. J. Zoo. 61:2324 – 2328.

3 **Kettela, E.G. 1983.** A cartographic history of spruce budworm defoliation 1967 to 1981 in eastern North America. Environ. Can., Can. For. Serv. Inf. Rep. DPC-X-14.

9 **Kingsbury, P.D., editor. 1983.** Permethrin in New Brunswick salmon nursery streams. Environ. Can., Can. For. Serv. Inf. Rep. FPM-X-52.

7 **Miller, G.E. 1983.** When is controlling cone and seed insects in Douglas-fir seed orchards justified? For. Chron. 59:304 – 307.

3 **Park, Y.S.; Fowler, D.P. 1983.** A provenance test of Japanese larch in eastern Canada, including comparative data on European larch and tamarack. Silvae Genetica 32:96 – 101.

7 **Sahota, T.S.; Farris, S.H.; Ibaraki, A. 1983.** Timing of initiation of pharate adult development in *Barbara colfaxiana* (Kft.) (Lepidoptera: Olethreutidae). Can. J. Zoo. 61:2305 – 2306.

7 **Shrimpton, D.M.; Thomson, A.J. 1983.** Growth characteristics of lodgepole pine associated with the start of mountain pine beetle outbreaks. Can. J. For. Res. 13:137 – 144.

4 **Smirnoff, W.A.; Valéro, J.R. 1983.** Estimation du spectre de la dispersion aérienne de *Bacillus thuringiensis*. Can. J. Microbiol. 29:1277 – 1279.

4 **Smirnoff, W.A.; Valéro, J.R. 1983.** Preserving *Bacillus thuringiensis* concentrates and formulations without xylene. J. Invertebr. Pathol. 42:415 – 417.

3 **Van Groenewoud, H. 1983.** Cluster analysis of simulated vegetation data. Tuexenia 3:523 – 528.

3 **Wall, R.E. 1984.** Effects of recently incorporated organic amendments on damping-off of conifer seedlings. Plant Disease 68:59 – 60.

7 **White, Eleanor E. 1983.** Biosynthetic implications of terpene correlations in *Pinus contorta*. Phytochemistry 22:1399 – 1405.

ERRATUM

In Vol. 4, No. 1, "Prescribed fire behavior and impact in an eastern spruce-fir slash fuel complex", on page 7, column 1, line 37 – 38 should have read "underestimation by Muraro's (1971) table remains unexplained." Also Table 2, which refers to the footnote on page 5, was mistakenly included in the article.

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