Potential hazard rating system for fir stands infested with budworm using cambial electrical resistance

WESTON DAVIS
University of New Hampshire, Durham, NH, U.S.A. 03824

AND

WALTER SHORTLE AND ALEX SHIGO
United States Forest Service Northeastern Forest Experiment Station, Durham, NH, U.S.A. 03824

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Cambial electrical resistance (CER) of more than 10 000 trees, predominantly balsam fir (*Abies balsamea*) and red spruce (*Picea rubens*) was measured in 90 stands in northern Maine, New Hampshire, and Vermont, U.S.A. CER index values (mean CER, kiloohms per stand) ranged from 9 to 13 for fir in nonoutbreak situations, and 9 to 18 in outbreak situations with moderate to heavy budworm infestation, whereas values for red spruce remained essentially constant at 7 to 13 in both situations. Balsam fir trees in stands with an index value of 9 grew almost three times faster (diameter growth) than in stands with an index value of 13. An increase of index values from 13 to 18 in outbreak situations indicated no further reduction in growth, but may indicate impending mortality of trees with lower vitality. Such index values may be useful in developing a hazard rating system for fir stands infected with spruce budworm.

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La résistance électrique cambiale de plus de 10 000 sapins baumier (*Abies balsamea*) ou épinettes rouges (*Picea rubens*) fut mesurée dans 90 peuplements du nord de l'Etat de Maine ainsi qu'au New Hampshire et Vermont, E.U. La valeur moyenne de la résistance électrique cambiale des peuplements variait de 9 à 13 chez le sapin exempt de défoliaison par la tordeuse des bourgeons de l'épinette, tandis que cette même valeur atteignait 9 à 18 lorsque le sapin avait subi des attaques variant de modérées à sévères. Chez l'épinette rouge par contre, les valeurs de la résistance cambiale étaient les mêmes (entre 7 et 13) dans les deux situations. La croissance radiale du sapin présent dans des peuplements dont la résistance cambiale moyenne atteignait 9, était presque trois fois plus élevée que lorsque cette même valeur était de 13. Par contre, dans les peuplements soumis aux attaques de la tordeuse, une augmentation de 13 à 18 ne correspondait pas à une diminution supplémentaire de la croissance radiale, mais pourrait fort bien indiquer la mort imminente des arbres les plus faibles. La résistance électrique cambiale pourrait jouer un rôle utile en vue de développer un système de calcul du risque pour les peuplements de sapins attaqués par la tordeuse des bourgeons de l'épinette.
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Introduction

A method of estimating relative vitality of balsam fir stands would be very helpful in planning forest management operations. Electrical resistance measurements made in the cambial zone are inversely related to tree vitality; as electrical resistance increases tree vitality decreases (Shortle et al. 1977, 1979; Smith et al. 1976; Wargo and Skutt 1975). Electrical resistance measurements were used to predict Dutch elm disease in elm trees before visible symptoms are observed (Blanchard and Carter 1980). A fast nondestructive sampling technique such as electrical resistance measurements could provide useful information about the overall physiological health of a forest stand. The purpose of this study was to determine the potential use of cambial electrical resistance measurements as a means of assigning a spruce budworm hazard index to balsam fir stands, assuming greater mortality will occur in stands of lower vitality.

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Materials and methods

This study, funded through the CANUSA Spruce Budworm Program, was conducted on paper company lands in northern Maine, New Hampshire, and Vermont, U.S.A. Cooperators included the U.S. Forest Service and Brown, St. Regis, International Paper, Scott, Great Northern, Georgia-Pacific, and Seven Islands paper companies.

Stands of balsam fir (*Abies balsamea* L.) mixed with red spruce (*Picea rubens* Sarg.) were sampled on a broad range of sites. Other species measured on these sites were eastern hemlock (*Tsuga canadensis* L.), northern white cedar (*Thuja occidentalis* L.), eastern white pine (*Pinus strobus* L.), yellow birch (*Betula alleghaniensis* Britton), paper birch (*Betula papyrifera* Marsh), red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh), and American beech (*Fagus grandifolia* Ehrh).

Sampling was conducted at prism points along a transect, using a 10-factor prism. All trees which appeared displaced, looking through the wedge prism, were sampled. Diameter at breast height, species, and electrical resistance values were recorded for each tree. Each stand of balsam fir was represented by a minimum of 100 trees (8–10 sample points). The stands ranged in spruce budworm (*Charistoneura fumiferana* Clem) infestation from none to heavy. The individual stands were classified according to a combination of factors; forester's infestation estimates, percent of brown foliage, dead stems, and general appearance of the stand. The four classifications used were as fol-

TABLE 1. Stand distributions and standard deviations for balsam fir for each electrical resistance mean, at four levels of spruce budworm infestation

Mean electrical resistance per stand (kΩ)	Spruce budworm infestation							
	None		Light		Moderate		Heavy	
	No. stands	SD	No. stands	SD	No. stands	SD	No. stands	SD
9	2	2.511	1	2.640	2	2.660	0	—
10	4	2.632	4	5.728	0	—	2	2.504
11	3	3.322	2	3.337	7	3.182	0	—
12	2	2.874	3	3.249	16	3.993	3	2.734
13	2	3.200	3	3.560	6	3.625	7	3.260
14					2	2.851	0	—
15					2	3.310	4	3.384
16					4	4.361	3	3.924
17					0	—	2	4.477
18					2	3.454	2	3.452
Total	13		13		41		23	

TABLE 2. Mean electrical resistance values and average annual growth for balsam fir stands for the 1979 growing season and the last 5 years

Vitality index CER[a] (kΩ/stand)	Mean increment, diameter growth (mm) at DBH[c]				Mean increment, diameter growth (mm) of stem[d]			
	Nonoutbreak[b]		Outbreak[b]		Nonoutbreak		Outbreak	
	1979	1975-1979	1979	1975-1979	1979	1975-1979	1979	1975-1979
9	3.0	3.2			3.5	3.9		
~~10~~ 13	1.1	1.3	1.3	1.5	1.3	1.7	1.4	1.8
18			1.0	1.6			1.2	2.0

[a]CER, cambial electrical resistance at breast height.
[b]Nonoutbreak situations refer to stands with no or light infestation without mortality; outbreak situations refer to stands with serious damage and mortality.
[c]Growth measured at DBH: 20 observations/mean LSD ($P < 0.05$) (0.7, 0.6).
[d]Growth measured on three discs; base of live crown, DBH, and at stump height: 60 observations/mean LSD ($P < 0.05$) (0.7, 0.7).

lows: none, no spruce budworm present; light, no mortality, some brown foliage, no serious damage; moderate, scattered mortality, 50-65% of the stems contain brown foliage; and heavy, several dead stems, 66% or more of the stems contain brown foliage and a general ragged appearance. In the course of the summer 90 different stands were sampled. Stands were indexed for vitality by calculating the mean electrical resistance for balsam fir trees and for red spruce trees in each stand.

Electrical resistance readings were made with a model 7950 Shigometer® using a No. 2E Delmhorst moisture detector electrode with 54-mm (2¼-in.) stainless steel contact pins in a No. 522/A-106 retainer.[2] Two readings were taken on opposite sides of the stem at 1.4 m above the ground. The pins were inserted in a vertical orientation, holding them perpendicular to the bole of the tree (Shortle et al. 1977). On thick barked trees pins were pushed through fissures in the bark. Previous work has shown seasonal pattern can also be detected with the meter; therefore when comparing groups of trees they must be measured during the same season (Davis et al. 1979).

After all 90 stands had been indexed for vitality, a sample of 8 stands was selected to test the relationship of index values to growth rates. In stands classified as having light or no infestations, two stands with mean index values of 9 kΩ (predicting good growth) and two stands with values of 13 kΩ (predicting poor growth) were sampled for increment growth analysis. In stands classified as having moderate to heavy infestations, two stands with index values of 13 kΩ were selected for comparison with the nonoutbreak situation, and two stands with mean index values of 18 kΩ (predicting further growth reduction and(or) impending mortality) were also chosen for growth analysis. In each of these stands 10 balsam fir trees were selected at random, felled, and 5-cm-thick discs were cut from the bole at stump height, 1.4 m above the ground (breast height) and at the base of the live crown. The discs were sanded and the width of each annual ring for the last 5 years, along two radii, was measured. Mean growth rates were calculated for each index value for each of the eight stands, then compared by analysis of variance.

[2]Trade, firm, or corporation names are included for information purposes only and do not imply endorsement by the Canadian Journal of Forest Research and the United States Forest Service.

Results

Balsam fir and red spruce were the most frequently observed species, with 5851 balsam fir and 3865 red spruce sampled. The mean electrical resistance per stand for balsam fir ranged from 9 to 18 kΩ (Table 1). Stands with an index value of 9 kΩ were found on sites in New Hampshire, Vermont, and Rangeley, Maine, which were below the 45° latitude line. These stands had no spruce budworm damage. Stands with a mean electrical resistance of 9 kΩ had the greatest annual growth (Table 2).

TABLE 3. Stand distributions and standard deviations for red spruce for each electrical resistance mean, at four levels of spruce budworm infestation

Mean electrical resistance per stand (kΩ)	Spruce budworm infestation							
	None		Light		Moderate		Heavy	
	No. stands	SD	No. stands	SD	No. stands	SD	No. stands	SD
7	1	1.436	1	1.564	1	0	0	—
8	1	1.512	0	—	2	1.986	0	—
9	2	2.319	2	1.935	10	4.1473	5	2.523
10	3	3.178	3	3.525	13	3.119	5	3.050
11	2	3.333	4	3.234	9	3.278	7	2.677
12	3	3.354	2	3.979	4	2.891	4	3.393
13	1	3.387	1	0.707	2	4.229	2	3.510
Total	13		13		41		23	

Balsam fir in stands with index values of 13-18 kΩ were all growing at a slower annual rate than those with an index value of 9 kΩ.

The mean electrical resistance for all the red spruce observed was about 10 kΩ, ranging from 7 to 13 kΩ per stand (Table 3). Electrical resistance of red spruce did not increase with increased spruce budworm infestation, as it did for the balsam fir.

The least significant difference (LSD) values were calculated for all the stands at each of four levels of spruce budworm infestation, none, light, moderate, and heavy (Table 4). Values ranged from 0.8 to 2.0 so that a difference of 2 kΩ between stand means was significant.

Discussion

Cambial electrical resistance index values (mean CER, kiloohms per stand) for balsam fir appeared to predict growth differentials among stands in nonoutbreak situations where stands with lower electrical resistance were growing at a faster rate than similar stands with higher electrical resistance values. In the outbreak situation, stands had a higher range of index values (85% of stands >12 kΩ) than in the nonoutbreak situation (35% of stands >12 kΩ) indicating either an impact on growth caused by the infestation or poor growth predisposing these stands to infestation or a combination of both. Stands with electrical resistance means of 9 kΩ in outbreak areas indicate that the budworm has not caused any serious growth reduction at this time. Stands with the highest index values showed no further reduction in growth, but mortality was beginning to occur in such stands. Continued increases in the cambial electrical resistance beyond the range where growth is lost may indicate impending mortality.

Index values for red spruce did not increase in outbreak areas indicating that spruce are maintaining their vitality since fir is the preferred food of the budworm.

If it can be shown that poor growing stands have a higher risk of mortality during outbreaks of spruce budworm, then indexing by cambial electrical resistance may be useful in a long-range hazard rating system. Furthermore, if it can be shown that continued increase in the index values of heavily infested stands predicts impending mortality, then indexing may be useful in short-range hazard rating system.

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TABLE 4. Least significant differences in mean CER[a]/stand for 90 stands containing 20-120 balsam fir trees, at four levels of spruce budworm infestation

Spruce budworm infestation	No. stands	Mean no. observations	LSD ($P < 0.05$)[b] (kΩ)
None	13	23-120	1.75-0.77
Light	13	52-100	1.25-0.90
Moderate	41	21-130	2.00-0.81
Heavy	23	28-115	1.83-0.90

[a]CER, cambial electrical resistance.
[b]Error: df, 800-2400; $t = 2$, conservative.

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