reduces herbage production up to 20 to 30 feet away from the forest wall.

Weight of tree litter was closely associated with herbage production. The linear regression is highly significant, statistically, and accounts for 21 per cent of the variation in herbage production.

Three major upland soil groups were recognized in this study. The mean herbage production per acre (adjusted to average litter weight) by soil groups was: soils with clay subsoils—860 pounds, soils with loam subsoils—680 pounds; and deep sands—470 pounds. Soil groups and litter weight together account for 31 per cent of the variation in herbage production. Herbage production was highest on moist sites favorable to slender bluestem.

Uplands produced about 2.75 times as much grass as did the bottomlands. Since bottomland soils are basically more productive than upland soils, the difference is attributed to heavy brush and tree competition in the bottoms.

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THE RECURRENCE OF SPRUCE BUDWORM INFESTATIONS IN THE PAST CENTURY IN THE LAC SEUL AREA OF NORTHWESTERN ONTARIO[1]

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Introduction

The abundance of balsam fir, *Abies balsamea* (L) Mill., a climax constitutent of the boreal forest in North America, varies in different parts of eastern Canada (Halliday 1937). In recent years, epidemics of the spruce budworm, *Choristoneura fumiferana* (Clem.), have occurred in many areas supporting widespread stands of mature balsam fir. One of these areas is in the vicinity of Lac Seul in Northwestern Ontario, where an outbreak has been in progress for approximately the last 12 years; in 1952, this outbreak covered close to 10,000 square miles.

Although the spruce budworm feeds on both white spruce, *Picea glauca* (Moench) Voss., and balsam fir, the latter is more vulnerable, and usually succumbs after five years of severe defoliation (Belyea 1952), whereas white spruce may withstand an additional one to two years of attack (Swaine, Craighead, and Bailey 1924). In the wake of a spruce budworm outbreak most of the balsam fir trees of commercial size are usually destroyed, whereas a relatively large number of white spruce trees survive (Turner 1952).

In the course of studies on the current outbreak in the Lac Seul area, indications of a disturbance about 85 years ago were gained from a consistent ring suppression pattern at that time in old white spruce, and from the age-class distribution of balsam fir in the present stands. This paper presents evidence that the disturbance is attributable to spruce budworm. The conditions of the forest preceding and following the past infestation, the area of origin and of spread, and the geographical relationship between the past and present infestations are described.

Evidence That the Past Disturbance Was Caused by Spruce Budworm

Methods

Swaine *et al.* (1924) showed that the characteristic retardation of the annual rings caused by spruce budworm defoliation can be used to trace

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earlier outbreaks. Almost without exception, white spruce trees one hundred years of age or older growing in the general region of Sioux Lookout in northwestern Ontario show a characteristic ring suppression pattern about 85 years ago (Fig. 1).

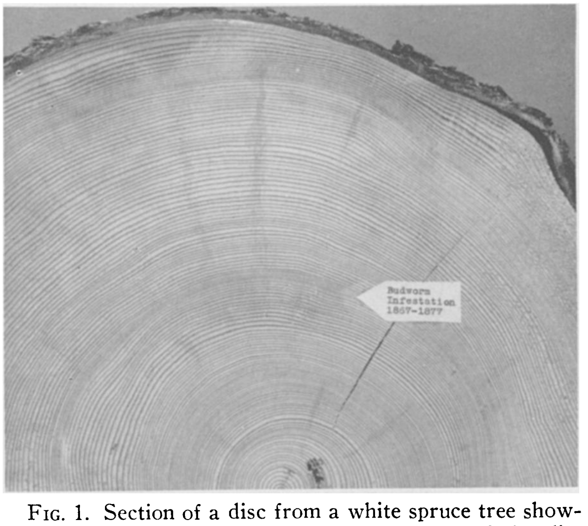

FIG. 1. Section of a disc from a white spruce tree showing the suppressed ring pattern at the time of the disturbance of 1867-1877.

Increment cores were obtained from old white spruce trees in 81 localities over an area of approximately 20,000 square miles in northwestern Ontario. In most localities, cores were obtained from at least 10 trees, but, owing to the scarcity of old white spruce trees, fewer cores were obtained in some localities. Supplementary discs were taken from some of the more accessible points. Each core was examined for a suppression pattern between 1850 and 1885. Ring widths during this period were measured with the aid of a binocular microscope equipped with an ocular micrometer, the average ring width for each year for all trees from each locality was computed and the results were plotted. Only living trees were sampled so that the outside ring could be dated. The 1857 growth was nearly always a narrow ring throughout the area studied and this "marker ring" provided an additional check.

Five plots were studied intensively near the geographical centre of the past disturbance for the purpose of reconstructing stand histories. Plot 1 was one-fifth acre while the others were one-tenth. The plots were more or less evenly distributed along a 20-mile stretch of the Red Lake Road. All the plots were located in overmature coniferous stands varying between 150 and 175 years of age. In all cases the stands were established after fire.

Records are available of the soil type and the ground vegetation for each plot. Windthrown trees were recorded as to species, diameter, and degree of decay. All the standing trees were cut and records taken of the species, diameter at breast height (four and one-half feet from the ground), diameter at stump height 85 years ago, present total height, total height 85 years ago, age at ground level, and time and number of years of suppression if suppression occurred. The diameter, 85 years ago, was calculated by measuring the distance from the centre of the tree to the 1867 year of growth, and the total height 85 years ago was obtained by cutting through the stem at various levels and counting the annual rings until that point was reached where the number of rings was exactly 85.

RESULTS

Table I gives the individual and average width of the rings over the years 1852 to 1882 for the increment cores for each of ten trees from Wapesi Lake, a locality about 30 miles northwest of Sioux Lookout. This shows that there is a certain amount of variability in the width of rings between cores but that the trends are fairly uniform, especially during the years of suppression. For instance, 1867 appears as the first year of suppression in all trees and 1871 as the year of the severest suppression in each tree. This constancy of pattern within the same locality did not hold in all localities studied. By obtaining the average yearly ring width for each locality, these differences tended to be minimized.

Figure 2 shows the average yearly radial growth from 1850 to 1880 based on 13 white spruce, 15 white pine, *Pinus Strobus* L., and 15 red pine, *Pinus resinosa* Ait., at Cedar Lake, 55 miles west of Sioux Lookout. It can be seen that the growth patterns of the three species are in fairly good accord, except for the marked suppression in white spruce that began about 1867 and reached its greatest severity in 1871. Unlike the decline that began in the latter part of the 1850 decade, this period of suppression in the spruce was not reflected in the growth of the other species, and therefore was not the result of an overriding factor, such as weather.

The first year of suppressed growth in the sequence of continuous growth decline is considered as the first year of suppression. The year of initial suppression varies from one area to the next, indicating that the disturbance had spread from a centre. Figure 3 shows the average yearly radial growth from 1850 to 1880 for 10 white spruce trees in each of six different localities.

TABLE I. *Width of rings and average width of rings in mm. from 1852 to 1882 of increment cores from ten different white spruce trees from Wapesi Lake.*

Year	Core Number										Average
	1	2	3	4	5	6	7	8	9	10	
1852....	2.0	1.8	1.5	3.2	3.7	1.8	2.1	2.9	2.8	5.0	2.7
1853....	1.9	1.7	1.5	3.0	3.5	1.5	2.2	3.0	2.5	4.8	2.6
1854....	1.7	1.4	1.6	3.1	3.0	1.6	2.0	3.0	2.0	3.9	2.3
1855....	1.8	1.8	1.9	2.8	2.2	2.0	1.8	2.0	2.1	4.0	2.2
1856....	1.6	1.5	1.8	2.8	3.2	2.0	1.5	2.7	2.4	4.2	2.4
1857....	1.2	1.1	1.4	2.1	2.3	1.5	1.0	2.0	1.8	3.0	1.7
1858....	1.5	1.5	1.5	2.3	3.0	1.7	1.7	2.9	2.2	3.0	2.1
1859....	1.3	1.5	1.9	2.2	2.5	1.5	2.0	2.5	2.3	2.8	2.1
1860....	1.2	1.9	1.9	2.3	3.3	1.6	2.0	3.2	2.1	3.1	2.3
1861....	2.1	2.4	2.3	2.7	3.0	2.0	2.5	3.2	2.8	3.2	2.6
1862....	2.0	2.0	2.1	2.8	3.0	2.1	2.5	2.8	2.7	3.6	2.6
1863....	2.0	1.9	1.7	3.1	2.7	1.7	2.5	2.2	2.4	2.7	2.3
1864....	1.6	1.6	1.5	2.5	2.5	1.6	2.5	2.5	2.1	2.7	2.1
1865....	1.6	1.7	1.7	2.7	2.7	1.9	2.3	2.5	2.3	3.3	2.3
1866....	1.7	2.0	1.8	2.7	2.4	2.0	2.3	2.5	2.6	2.7	2.3
1867....	1.2	1.4	1.4	1.5	2.0	1.5	2.0	2.3	1.6	2.0	1.7
1868....	0.9	1.3	1.5	1.7	2.2	1.3	1.6	2.4	1.5	2.0	1.6
1869....	0.9	1.2	1.4	1.5	1.5	1.1	1.5	1.5	1.3	2.0	1.4
1870....	0.7	0.8	0.8	1.2	1.2	0.7	1.3	1.7	1.1	1.3	1.1
1871....	0.3	0.4	0.5	1.0	1.0	0.7	1.1	1.4	0.9	1.3	0.9
1872....	0.3	0.5	0.7	1.4	1.8	0.8	1.2	1.8	1.0	1.6	1.1
1873....	0.4	0.6	1.4	1.5	1.8	1.2	1.4	1.8	1.3	1.9	1.3
1874....	0.3	0.7	1.3	1.7	1.9	1.0	1.6	1.9	1.3	1.9	1.4
1875....	0.6	1.0	1.7	1.7	2.2	1.4	1.8	1.9	1.6	1.7	1.6
1876....	0.9	0.9	1.5	1.5	2.0	2.0	1.8	2.2	1.7	2.0	1.7
1877....	1.0	1.0	1.8	1.5	2.2	1.5	1.8	2.7	1.6	1.8	1.7
1878....	1.0	1.2	2.0	1.7	2.5	1.8	2.3	3.0	2.1	1.9	2.0
1879....	1.3	1.2	1.7	1.5	1.6	1.6	1.7	2.2	1.9	1.4	1.6
1880....	1.0	0.7	1.5	1.4	1.5	1.1	1.4	2.0	1.7	1.7	1.4
1881....	1.3	1.1	1.5	1.4	1.7	1.2	1.8	2.5	1.8	1.8	1.6
1882....	1.1	1.1	1.5	1.7	2.2	1.4	2.1	2.5	1.9	2.2	1.7

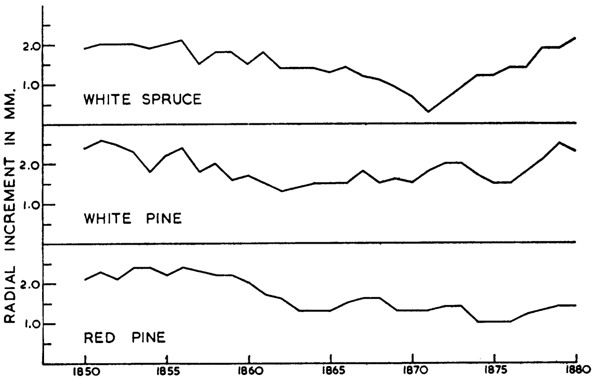

FIG. 2. Average yearly radial growth from 1850 to 1880 for 13 white spruce *Picea glauca* (Moench) Voss., 15 white pine, *Pinus Strobus* L., and 15 red pine, *Pinus resinosa* Ait., at Cedar Lake. The white spruce show a distinct suppression for the period 1867-1874.

Minnitaki Lake and Tully Lake are near the centre of the past disturbance, Basket Lake and Canyon Lake are at intermediate points east and west of the centre, Cobble Lake and Sowden Lake are at the eastern and western boundaries of the disturbance.

Table II gives the basal area of living trees, by species, for the lines cruised at each of the six plots studied. In the case of plots 3, 4 and 5, a

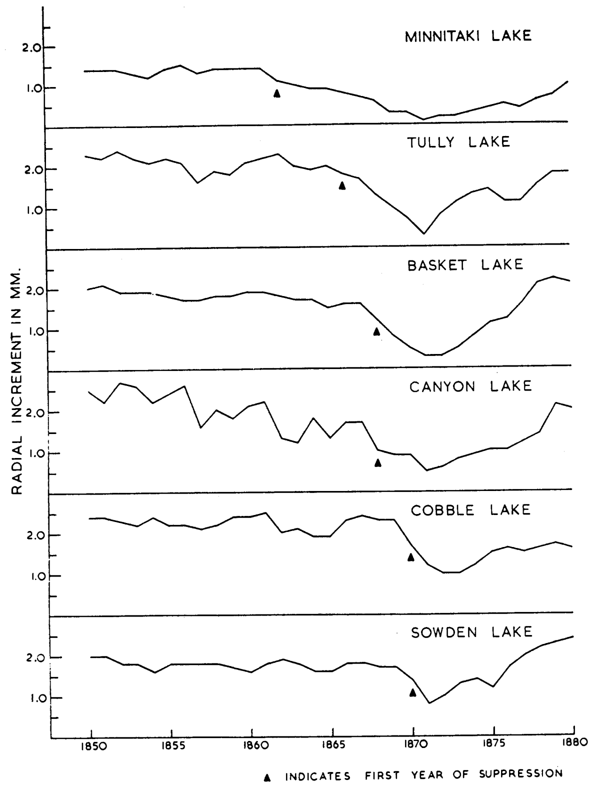

FIG. 3. Average yearly radial growth from 1850 to 1880 for 10 white spruce trees from each of six different localities indicating that the first year of suppression varied from one locality to the next. Minnitaki Lake and Tully Lake are near the centre of the past disturbance, Basket Lake and Canyon Lake are at intermediate points east and west of the centre, Cobble Lake and Sowden Lake are at the eastern and western boundaries of the disturbance.

TABLE II. *Basal area in square feet per acre of living trees,* and per cent of total basal area for lines cruised at each plot.*

Plot Number		Tree Species†							
		Bf	SW	Sb	Pj	Po	Bw	Cw	Total
1	B. A./Acre.......	50	17	13	10	19	5	0	114
	% of B. A........	43.8	14.9	11.4	8.8	16.7	4.4	0	100
2	B. A./Acre.......	50	11	0	0	3	22	0	86
	% of B. A........	58.1	12.8	0	0	3.5	25.6	0	100
3	B. A./Acre.......	19	13	1	10	12	8	13	76
	% of B. A........	25.0	17.1	1.3	13.2	15.8	10.5	17.1	100
4	B. A./Acre.......	66	17	17	0	13	5	0	118
	% of B. A........	55.9	14.4	14.4	0	11.0	4.3	0	100
5	B. A./Acre.......	25	12	45	6	1	6	0	95
	% of B. A........	26.4	12.6	47.4	6.3	1.0	6.3	0	100

*In the case of balsam fir and white spruce, the basal area of trees recently killed by the spruce budworm was included.
† Bf - Balsam fir, *Abies balsamea* (L.) Mill.
Sw - White spruce, *Picea glauca* (Moench) Voss.
Sb - Black spruce, *Picea mariana* (Mill.) BSP
Pj - Jack pine, *Pinus Banksiana* Lamb.
Po - Trembling aspen, *Populus tremuloides* Michx.
Bw - Paper birch, *Betula papyrifera* Marsh.
Cw - White cedar, *Thuya occidentalis* L.
La - Larch, *Larix laricina* (Du Roi) K. Koch.

number of balsam fir and white spruce trees had recently been killed as a result of current spruce budworm defoliation. For the purpose of determining the stand composition prior to recent budworm damage, these trees were included in the calculations of basal area. Table II shows that the stands were essentially coniferous with balsam fir and white spruce being the predominant species, except for plot 5 where black spruce, *Picea mariana* (Mill.) BSP, was predominant.

In Table III, the number of stems of all species is given by diameter classes for living and dead trees and the total number of stems per acre on the lines cruised. Most of the dead balsam fir and white spruce trees in plots 3, 4 and 5 were recently killed by budworm. In the case of other species, mortality resulted from suppression or overmaturity. Table III shows that in plots 1, 2, 3, and 4, balsam fir was predominant, especially in the lower diameter classes that form the understories. In plot 5, balsam fir was next in abundance to black spruce. A much greater percentage of the jack pine and poplar trees were dead than is shown by the ratio of dead stumps to living trees, since many of the dead trees were windthrown. In this area, fires are usually followed by the sub-climax species—poplar on the deep clay soils and jack pine on the shallower or sandy soils. These give way to the climax stands of balsam fir and white spruce. In all the plots the transition to a climax forest was almost complete, with relatively few remnants of the sub-climax still surviving.

Table IV gives the time at which balsam fir

TABLE III. *Number of stems of all species by diameter classes and total number of stems per acre on lines cruised for each plot.*

Plot Number	D. B. H. in inches*	Bf		Sw		Sb		Pj		Po		Bw		Cw		La†	
		L.‡	D.	L.	D.	L.	D.	L.	D.	L.	D.	L.	D.	L.	D.	L.	D.
1	1-5	777	68	26	1	80	5	..	..	3	..	4	1	..	..	..	..
	6-10	213	19	11	4	63	5	19	41	2	3	21	9	..	..	..	..
	11-15	13	1	15	4	4	..	12	15	13	9	2	..	..	..	..	..
	16-22	..	..	9	..	..	..	2	..	13	9	..	..	..	..	..	..
	Total stems tallied	1003	88	61	9	147	10	33	56	31	21	27	10	..	..	..	..
	Total stems per acre	501	44	30	4	73	5	16	28	15	10	13	5	..	..	..	..
2	1-5	675	57	36	1	..	..	..	..	2	1	12	2	..	..	..	..
	6-10	202	16	13	7	..	2	..	..	3	4	65	32	..	..	..	..
	11-15	12	..	11	1	2	..	..	..	5	11	29	3	..	..	..	..
	16-22	..	..	5	..	..	..	..	..	..	1	..	2	..	..	..	..
	Total stems tallied	889	73	65	9	2	2	..	..	10	17	106	39	..	..	..	..
	Total stems per acre	444	36	32	4	1	1	..	..	5	8	53	19	..	..	..	..
3	1-5	575	267	4	3	1	..	..	..	3	1	28	22	36	..	..	..
	6-10	15	36	11	21	8	..	9	18	9	18	35	26	59	..	..	..
	11-15	..	..	7	8	1	..	18	21	12	4	3	2	3	..	..	..
	16-22	..	..	1	..	..	..	4	..	5	3	..	..	..	..	..	..
	Total stems tallied	590	303	23	32	10	..	31	39	29	26	66	50	98	..	..	..
	Total stems per acre	295	151	11	16	5	..	15	19	14	13	33	25	49	..	..	..
4	1-5	21	419	..	..	26	8	..	..	..	..	..	..	..	..	..	..
	6-10	4	292	..	12	107	16	..	2	1	1	8	6	..	..	..	..
	11-15	..	20	2	9	2	..	..	3	12	6	8	..	..	..	..	..
	16-22	..	..	1	8	..	..	..	..	8	4	..	..	..	..	..	..
	Total stems tallied	25	731	3	29	135	24	..	5	21	11	16	6	..	..	..	..
	Total stems per acre	12	365	1	14	67	12	..	2	10	5	8	3	..	..	..	..
5	1-5	197	32	3	2	282	12	..	..	..	..	2	1	..	..	10	90
	6-10	54	35	2	11	161	13	2	17	1	1	10	8	..	..	1	50
	11-15	10	8	4	3	16	2	7	24	1	2	8	4	..	..	..	..
	16-22	2	1	4	3	..	..	4	7	1	1	..	..	..	..	..	..
	Total stems tallied	263	76	13	19	459	27	13	48	3	4	20	13	..	..	11	140
	Total stems per acre	131	38	6	9	229	13	6	24	1	2	10	6	..	..	5	70

*Diameter at breast height, *i.e.* at 4½ feet from the ground. †See footnote Table II. ‡L - Living. D - Dead.

trees over one-half inch in diameter at breast height became established in the plots studied. In plots 1 and 3 all balsam fir trees over one-half inch in diameter were over 85 years old. This indicates that no balsam fir trees became established in these plots for many decades after 1867. In the other three plots, 50 per cent or more of the balsam fir trees were found to antedate the time of the disturbance. The remainder of the balsam fir trees became established in the ten years that followed the disturbance; after that, no fir trees became established until recent times.

A large number of balsam fir trees less than one-half inch in diameter (seedlings) occur on each of the five plots. Regeneration studies that are being carried out in the immediate vicinity of these five plots show a range of from 3,000 to 7,000 balsam fir seedlings per acre. Over 96 per cent of the specimens encountered were less than 20 years and very few were more than 35 years old.

Table V shows the 1861-67 distribution by height class of the balsam fir trees that were studied in each plot. Of a total of 144 trees that survived the past infestation, 68 per cent were two feet in height or less, only 3 per cent were over 11 feet high, and none were over 24 feet high 85 years ago.

TABLE IV. *Time at which balsam fir trees over one-half inch D.B.H.* became established for each plot studied.*

Plot Number	1800-1850	1851-1860	1861-1867	1868-1880	1881-1890	1891-1900	1901-1950
1	21 45%	14 30%	12 25%	0	0	0	0
2	0	1 3%	16 44%	19 53%			
3	18 56%	5 16%	9 28%	0	0	0	0
4	0	1 3%	20 55%	14 42%			
5	1 2%	11 27%	16 40%	13 31%	0	0	0

*Diameter at breast height, *i.e.*, at 4½ feet from the ground.

DISCUSSION

Since the radial growth patterns for the different species of trees in the Sioux Lookout area are similar except for a period starting about the year 1865 when white spruce trees show a marked suppression, this indicates that for a number of years some factor was affecting the growth of this species adversely, while not affecting the growth of the pines. Furthermore, the age-class distribution of balsam fir trees shows that no additional trees of this species became established for some forty years following the time of the radial growth suppression in white spruce, indicating that all or nearly all the seed-bearing balsam fir trees were destroyed at that time. Only a severe and prolonged spruce budworm outbreak can logically be held responsible. In plots 1 and 3, no balsam fir trees over one-half inch in diameter were found to be younger than 85 years but in the other three plots mortality of at least some of the seed bearing trees was delayed for approximately 10 years, as shown by the fact that some balsam fir became established in that interval of time (Table IV). Swaine *et al.* (1924) found that weakened trees may die as late as five to ten years after a budworm epidemic.

TABLE V. *Distribution by height class of currently standing balsam fir trees at the time of the past disturbance.*

Plot Number	Height in feet					
	0-2′	3′-5′	6′-8′	9′-11′	12′-14′	21′-24′
1	24	12	5	4	2	0
2	17	0	0	0	0	0
3	9	8	9	2	0	3
4	21	0	0	0	0	0
5	26	2	0	0	0	0
Total..	97	22	14	6	2	3
Per Cent.	68	15	10	4	1	2

The height-class distribution of balsam fir trees, at the time of the past infestation, indicates that those trees that survived the past infestation were mostly in the seedling stage (Table V).

Conditions similar to those found in the wake of several recent outbreaks seem to have prevailed 85 years ago, namely, that all, or nearly all, the balsam fir trees of merchantable size were killed, but that many of the seedlings and some of the saplings survived. Present conditions in plot 4 may be taken as typical of conditions existing in the areas where heavy mortality of balsam fir has resulted from recent budworm defoliation. In this plot, about 97 per cent of the balsam fir trees of merchantable size have been killed by the budworm in the last few years (Table III), yet over 3,000 living balsam fir seedlings per acre were found.

EXTENT, AREA OF SPREAD, AND THE GEOGRAPHICAL RELATIONSHIP OF THE PAST INFESTATION TO THE PRESENT INFESTATION

Figure 4 shows the localities where the suppressed ring pattern in white spruce trees was observed and where it was absent. The east, north and west boundaries of the past infestation

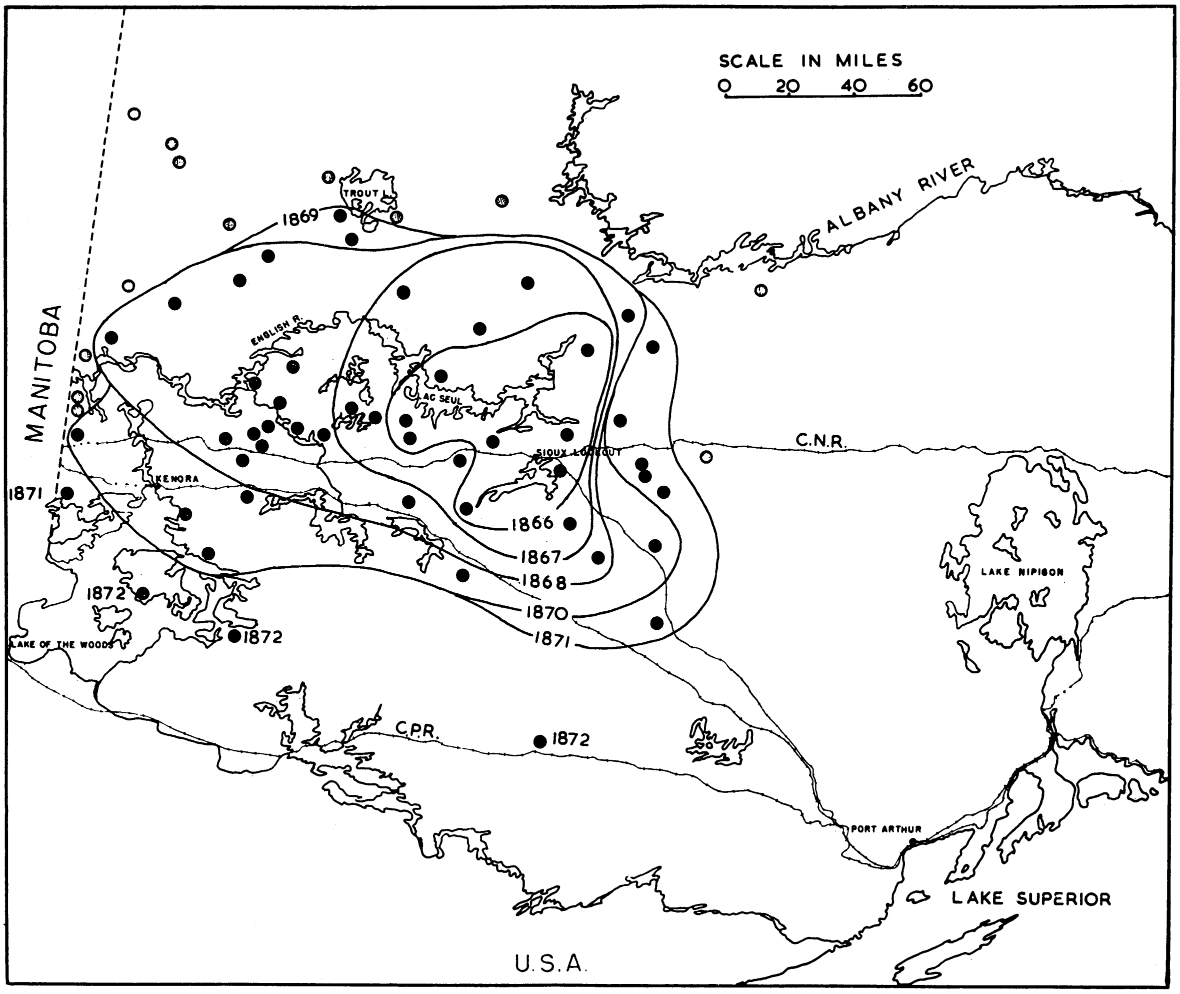

FIG. 4. Area in northwestern Ontario where a severe spruce budworm outbreak occurred about 1866. The solid dots indicate localities where a ring suppression pattern in white spruce trees was observed and the other dots indicate the localities where no pattern was observed. These localities having the same first year of suppression are enclosed within isolines.

are determined by a number of points where no suppression pattern occurred. Several days of aerial exploration failed to reveal any mature stands of white spruce to the south, where stands of jack pine, poplar or younger spruce and fir following relatively recent fires are predominant. The southern boundary of the infestation is therefore not accurately defined. Ring suppression patterns in old white spruce trees were obtained from two points on the east shore of the Lake of the Woods and from one point considerably farther south. These indicate that budworm defoliation occurred, at least in some isolated pockets, almost as far south as the international boundary.

The area encompassed by the old infestation covered approximately 10,000 square miles. However, the outbreak was probably not equally heavy throughout this entire area since spruce budworm outbreaks are confined to stands of spruce and balsam fir. Owing to topographic and edaphic conditions, such stands do not form a continuous forest over this area.

In Figure 4, all localities having the same first year of suppression are enclosed within isolines. These cannot be considered as absolute lines of demarcation for the successive years of defoliation; they are but approximations. Several points in the neighbourhood of Sioux Lookout and the eastern portion of Lac Seul show 1866 as the first year of suppression, indicating that the infestation had its origin in this vicinity. Within this area, the first apparent year of suppression was as early as 1862 in two localities. However, in both these localities the white spruce trees sampled were very old and showed poor diameter growth for approximately the last 100 years, thus obscuring to some extent the initiation of suppression caused by the spruce budworm (see data for Minnitaki Lake, Fig. 3). From this area of origin the infestation spread mostly westward until by 1870 and 1871 it reached points close to the Manitoba boundary.

The relationship between defoliation and reduction in diameter growth in white spruce was studied in two localities where budworm defoliation has been carefully recorded since the beginning of the present infestation. Increment cores were taken from 25 white spruce trees from each locality and the last 20 years of radial growth were measured in the manner described earlier. The computed averages show the first year of ring suppression, for one locality, as having occurred three years after the beginning of the infestation, and, for the second locality, one year later. Though more work is required to determine the exact relationship between spruce budworm defoliation and reduction in increment in white spruce, it can be reasonably assumed that the first year of ring suppression may occur three or four years after the budworm has reached epidemic proportions. Thus the past infestation quite possibly started three or four years earlier than is indicated by the first year of ring suppression in the white spruce trees studied in the different localities.

The fact that there is an interval of a few years between the beginning of an outbreak and the beginning of suppression permits the use of subsidiary data to support foregoing arguments for a major infestation. Since general suppression in spruce began about 1866-67, the outbreak presumably began about 1862-64, or even earlier. Previous work (Wellington *et al.* 1950; Wellington 1952) has demonstrated that there is a preoutbreak period in which summer droughts recur. This period usually amounts to three or four years,

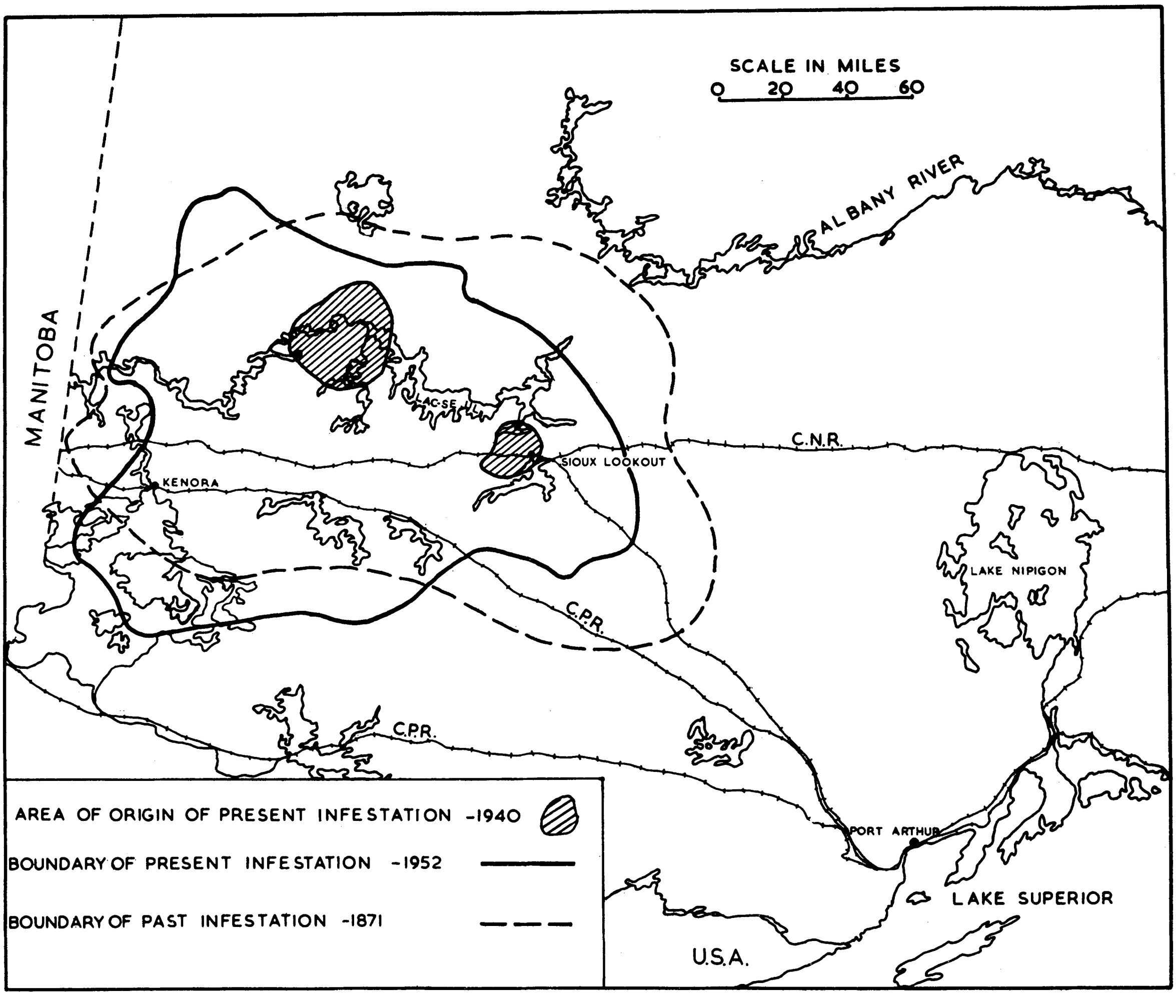

FIG. 5. Area in northwestern Ontario where a past spruce budworm infestation has occurred and where a current infestation is taking place.

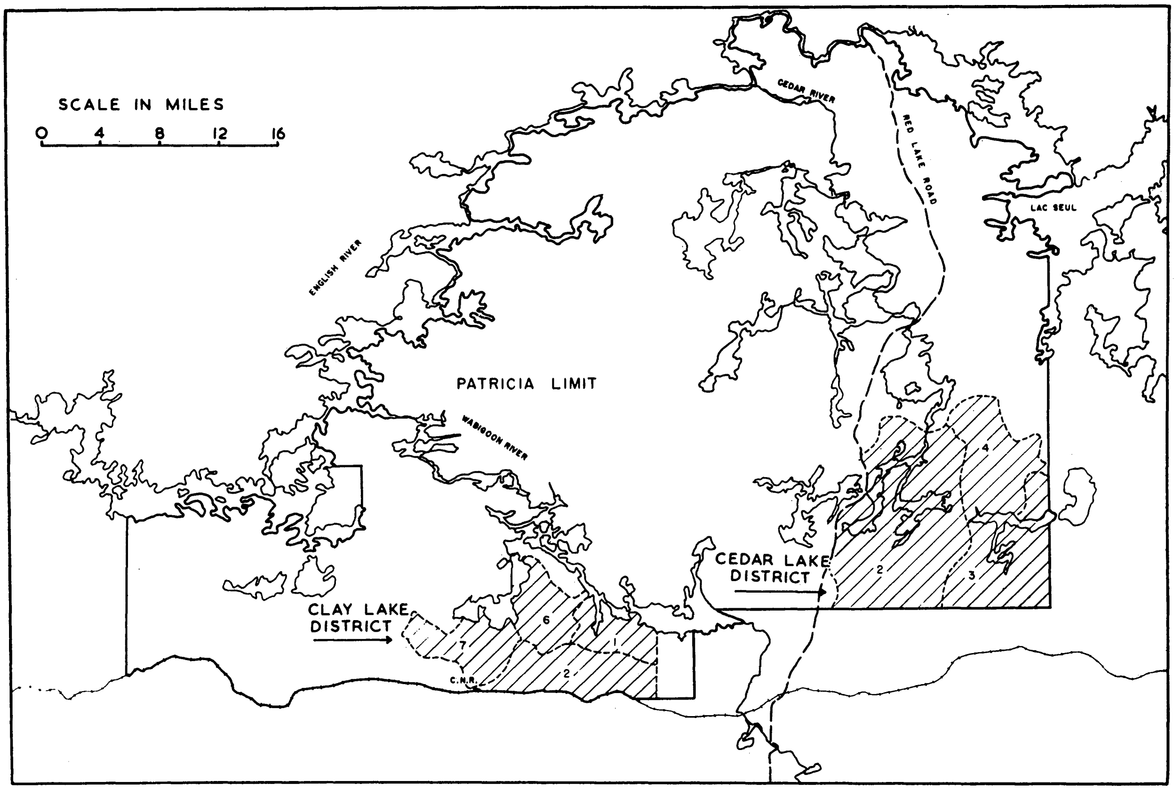

FIG. 6. The Patricia Concession in northwestern Ontario, showing the Clay Lake District and the Cedar Lake District watersheds (cross hatched) where timber surveys were carried out in 1926 and 1948.

and further adjustment of the tentative dates above by this amount gives 1858-60 as the possible beginning of such a pre-outbreak period. Figure 2 shows clearly that there was a decline in the growth of both spruce and pines from the latter half of the 1850's through the early 1860's, and such prolonged general declines result chiefly from climatic change. Consequently, there is good evidence for a climatic trend during this period similar to that which preceded several more recent spruce budworm outbreaks.

Figure 5 shows the areas of origin, the present boundary of the current infestation, and the boundary of the past infestation. The present infestation had two centres of origin, one near Sioux Lookout, in the same vicinity as the apparent centre of origin of the old infestation, and the other about 60 miles farther west near Wabashkang Lake and the English River.

The boundaries of the current infestation have been mapped every year since 1945. Until 1951, the infestation had spread mostly westward and southward from the western centre of origin and had by then covered approximately 5,000 square miles. In 1952, the area was greatly increased, mostly to the east and to the south, and now covers close to 10,000 square miles. The area currently infested is remarkably similar to that of the old infestation.

CHANGES IN THE BALSAM FIR CONTENT OF THE FOREST IN THE LAST 25 YEARS IN RELATION TO THE PAST AND PRESENT SPRUCE BUDWORM OUTBREAKS

A timber survey of a section of the infested area known as the Patricia Concession (Fig. 6) was carried out about 25 years ago and, more recently, parts of the Cedar Lake and Clay Lake Districts of this concession were resurveyed. Data from these surveys provided an excellent opportunity of assessing changes of forest composition in the last 25 years.

Table VI gives the amount in cords of merchantable spruce and balsam fir for the different watersheds in the Cedar Lake and Clay Lake Districts, as assessed during the surveys of 1926 and 1948. In the Clay Lake District, which comprises over 45,000 acres in land area, the volume of spruce increased by 1 per cent and the volume of balsam fir by 265 per cent over a period of 22 years. In the Cedar Lake District, which comprises over 80,000 acres in land area, spruce decreased in volume by 16 per cent and balsam fir increased by 366 per cent during the same period.

The reduction in spruce in the Cedar Lake District might be explained by the fact that one-half of the land area is occupied by overmature or decadent stands where natural mortality is high and windthrow of large trees is prevalent. Grouping the two districts, spruce shows a reduction of 12 per cent and balsam fir an increase of 337 per cent over an area of approximately 125,000 acres. It is evident that the increase in the merchantable volume of balsam fir in the last 25 years has been very considerable.

TABLE VI. *Amount in cords of merchantable* spruce and balsam fir for the periods of 1926 and 1948 in the Clay Lake and Cedar Lake District watersheds.*

District	Watershed	Land Area in Acres	White and Black Spruce		Balsam fir		
			1926	1947	1926	1947	
Clay Lake	1......	12,900	35,600	46,900	2,900	13,000	
	2......	16,877	56,200	62,900	4,800	14,900	Spruce increased by 1%
	6......	7,239	33,000	28,000	1,900	3,100	
	7......	8,749	51,600	40,500	1,700	10,200	Balsam fir increased by 265%
	Total..	45,765	176,400	178,300	11,300	41,200	
Cedar Lake	2......	39,562	333,500	251,300	16,500	66,000	Spruce decreased by 16%
	3......	21,451	90,600	97,800	7,800	31,500	
	4......	19,366	107,600	95,700	3,500	32,100	Balsam fir increased by 366%
	Total..	80,379	531,700	444,800	27,800	129,600	
Grand Total..		126,144	708,100	623,100	39,100	170,800	Spruce decreased by 12% Balsam fir increased by 337%

*Trees 5 inches and over in diameter at breast height.

Previous studies (Blais 1952) have shown that mature or flowering balsam fir trees are important in providing conditions favourable to the increase of populations of the spruce budworm and that, thereby, they contribute to the initiation and spread of spruce budworm epidemics. The large percentage of balsam fir trees that became established prior to the infestation of 1865 provides evidence that there were extensive stands of seed-bearing fir trees at that time. These mature trees succumbed to the old infestation, and it was not until recent years, when the surviving seedlings reached maturity, that spruce budworm populations were again able to reach epidemic proportions. The passing of approximately 70 years (the interval between the past and present infestations) was required for the development of a new forest capable of supporting another destructive outbreak of the spruce budworm. Since the exploitation of the timber resources of this portion of Ontario has begun only very recently, any changes in forest composition that have taken place, and any phenomena connected with these changes can be considerea as being completely natural.

In addition to stating that spruce budworm epidemics can develop only when there is sufficient balsam fir, Swaine *et al.* (1924) suggests that the older epidemics followed the course of logging operations, becoming more extensive as exploitation proceeded farther into virgin forests. The present studies do not support this view since they indicate that severe and widespread spruce budworm infestations occurred in virgin forests. They are more in agreement with the suggestion of Graham and Orr (1940) that outbreaks of the spruce budworm have occurred in the past at intervals of from 40 to 70 years and that such intervals represent the period required for a generation of balsam fir to reach a dominant position in the forest stands.

Summary and Conclusions

Evidence that a widespread and destructive spruce budworm outbreak occurred in the latter half of the nineteenth century in northwestern Ontario was gained from the characteristic reduction of the annual ring increment in old white spruce and by the age-class distribution of balsam fir. The past outbreak had its centre of origin in the Sioux Lookout area and spread over a territory encompassing 10,000 square miles in a period of about 7 years.

The same conditions that were found in the wake of several recent outbreaks seem to have prevailed 85 years ago, namely, that all or nearly all the balsam fir trees of merchantable size were killed, but many of the seedlings and some of the saplings survived.

The large number of balsam fir trees that became established prior to the infestation of 1865 give evidence that there were extensive stands of seed-bearing fir trees at that time. These parent trees were destroyed during the past infestation and it was not until recent years, when their progeny reached maturity, that spruce budworm populations again reached epidemic proportions.

Since the forests in this area had never been subjected to exploitation, all changes in the forest composition and all related phenomena are entirely natural. Spruce budworm outbreaks, therefore appear to be a phase in a natural cycle of events associated with the maturing of balsam fir.

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SOME RELATIONSHIPS OF EVAPORATION RATE TO VAPOR PRESSURE DEFICIT AND LOW WIND VELOCITY

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Introduction

Standardized evaporimeters are commonly used in approximating relative evaporation potentials in plant environments (Fuller 1911, Weaver 1914, Bode 1920, Gates 1921, Cain and Friesner 1929, Costello 1931, Livingston, B. E., 1935, Aikman and Smelser 1938, Livingston, R. B., 1949). Since this potential is a measure of atmospheric conditions as a whole, rather than of factors interpreted separately, water loss data are an expression of sum effects.

The vapor pressure deficit, as a measure of atmospheric humidity, is an indirect measure of evaporation. This function, also called the saturation deficit, is equal to the difference between the saturation vapor pressure at a given air temperature and the actual vapor pressure at the same temperature. As the air approaches saturation, the atmospheric deficit decreases, as does the possible water loss from the immediate plant and soil environment. With increasing aridity of the air, calculated values of the vapor pressure deficit assume greater magnitude indicating greater evaporation stresses. Since surface temperatures and corresponding vapor pressures are an important consideration in equating the evaporation rate, the accuracy of the vapor pressure deficit as a correlative function depends on the degree of temperature correspondence between the air and evaporating surface. Seldom are these values the same under most conditions. Penman (1948) determined evaporation from bare soil, grass, and open water relative to vapor pressure differences, in which he proposed a method of eliminating the difficult measurement of surface temperature. The limitations of the vapor pressure deficit have been discussed by Leighly (1937) and Thornthwaite (1940). Under certain conditions evaporation may be independent of the calculated deficit. For small surfaces, however, whose temperatures would follow closely those of the air, Gordon (1940) proposed that a high correlation is possible between evaporation and the vapor pressure deficit of the atmosphere.

Considering these points of view, it is the purpose of this study to determine the statistical relationship of evaporation rate to the vapor pressure deficit.[1] Included also in this study is the component effect of air movement as an evaporation factor.

Procedures

The study was conducted during July and August, 1951, for a period of five weeks. Two stations were selected, one in an open bluegrass pasture in full sunlight at all times during the day, the other beneath the canopy of a nearby hickory (*Carya*) grove. The latter station was placed so as to be in constant shade as much as possible, thus tending to eliminate rapid temperature changes due to sun flecks. Stand density averaged 41 trees per 100 M^2, or approximately 200 per

[1] The author expresses his appreciation to the University of Missouri Research Council in making available funds for this study, URC Project No. 304, 1951, and to Professor B. H. Frame who reviewed some of the data.