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SEASONAL VARIATION IN MOISTURE CONTENT OF EASTERN CANADIAN TREE FOLIAGE AND THE POSSIBLE EFFECT ON CROWN FIRES

by
C. E. Van Wagner

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ABSTRACT

Foliar moisture content was sampled in five eastern Canadian conifers and two hardwoods during 1962-65, and seasonal trends were established. These were basically similar from year to year despite weather differences. The moisture content of new conifer foliage and hardwood foliage was very high (over 300 per cent) at flushing, decreased sharply, and gradually levelled out by late summer. The moisture content of old conifer foliage fell during April, passed through a minimum (ca. 95 per cent) in May and early June, then rose gradually to a maximum (ca. 115 per cent) in late summer. The average composite foliar moisture content of the five conifers rose from about 95 per cent in late May and early June to about 130 per cent in mid-August. Theoretical speculations based on the heat energy required to drive off differing amounts of foliar moisture, as well as the results of laboratory flammability tests with single trees, suggest that the 35-point difference probably has a distinct effect on the behaviour of crowning forest fires.

ERRATA

<u>Dans la 3e phrase de cet extrait</u>

au lieu de: La teneur en humidité du feuillage des jeunes conifères et feuillus était

lisez: La teneur en humidité du feuillage des feuillus et du nouveau feuillage des conifères était

<u>Dans la 4e phrase</u>,

au lieu de: Tandis que celle des conifères âgés décroissait

lisez: Celle du vieux feuillage des conifères décroissait

EXTRAIT

De 1962 à 1965, on a mesuré l'humidité foliaire et noté ses tendances saisonnières sur cinq conifères et deux feuillus de l'est du Canada. D'une année à l'autre, ces données sont demeurées constantes à travers les variations météorologiques. La teneur en humidité du feuillage des jeunes conifères et feuillus était très élevée à la feuillaison (au-dessus de 300 p. 100), baissait brusquement, et graduellement se stabilisait vers la fin de l'été. Tandis que celle des conifères âgés décroissait en avril, passait par un minimum (ca. 95 p. 100) en mai et début juin, et atteignait progressivement un maximum (ca. 115 p. 100) à la fin de l'été.

De 95 p. 100 environ en fin mai et début juin, la moyenne composée pour les cinq conifères est montée à près de 130 p. 100 vers la mi-août. Selon les calculs théoriques basés sur l'énergie calorifique requise pour sécher les feuilles, et les résultats des tests d'inflammabilité effectués au laboratoire sur les arbres pris individuellement, il semblerait que la différence de 35 p. 100 est susceptible d'influencer sensiblement le comportement des feux de cime roulants.

SEASONAL VARIATION IN MOISTURE CONTENT OF EASTERN CANADIAN TREE FOLIAGE AND THE POSSIBLE EFFECT ON CROWN FIRES

by

C.E. Van Wagner[1]

INTRODUCTION

Variations in the moisture content of tree foliage, if large enough, could affect the behaviour of crowning forest fires. If significant seasonal fluctuations occur in tree foliar moisture content, knowledge of them would be useful in studying the incidence of crown fires. The project reported here was undertaken to provide such information for some important species in eastern Canada. Leaf samples from seven tree species were taken for four years at the Petawawa Forest Experiment Station, and the effect of foliar moisture content on crown flammability was briefly investigated.

It is well known that, in Canada at least, only conifer stands will support crown fire, and five of the species chosen for sampling were conifers. Two broadleafed species were included for comparison.

The literature contains a few references to seasonal variations in the moisture content of North American tree foliage. Wright (1932) at the Petawawa Forest Experiment Station found that most tree species attain their highest foliar moisture content during late July and early August. Reifsnyder (1961) describes the annual cycle for mountain laurel (*Kalmia latifolia* L.), an evergreen shrub in the Appalachians; its foliar moisture content has a minimum in spring and a maximum in summer. Dieterich (1963) mentions the same cycle in plantation red pine (*Pinus resinosa* Ait.) in the Lake States. Philpot (1963) found little seasonal variation in ponderosa

[1]Research Officer, Department of Forestry and Rural Development, Petawawa Forest Experiment Station, Chalk River, Ontario.

pine (*Pinus ponderosa* Laws.) on the Sierra Nevada, but Jameson (1966) discovered a distinct minimum in May - June and a peak in July - August while sampling pinyon (*Pinus edulis* Engelm.) and juniper (*Juniperus* spp.) foliage in the Rocky Mountains. In the present paper seasonal trends in foliar moisture are first presented and discussed; their possible effects on fire behaviour are then examined.

PROCEDURE

Seven tree species were selected for sampling, three of them on two sites (Table 1). At each location, a sampling unit comprising three permanently marked trees was set up. The conifers were semi-open grown, aged 20 to 40 years, and from 4 to 9 inches in diameter. The hardwoods were saplings with diameters of 1 to 2 inches.

Samples of all species were collected for three years, 1962 to 1964, from late March to late October. However, the first year's pine samples were disqualified owing to improper separation of the current year's foliage, and sampling of the pines alone was continued in 1965 to obtain three years' valid pine data. Comparison of all species is thus restricted to 1963 and 1964.

TABLE 1. SPECIES SAMPLED AND LOCATIONS OF THE THREE-TREE SAMPLE UNITS

Species	Soil Type		
	Moist sandy loam	Dry sandy loam	Dry Sand
White pine - *Pinus strobus* L.		X	X
Jack pine - *Pinus banksiana* Lamb.			X
Red pine - *Pinus resinosa* Ait.		X	X
Balsam fir - *Abies balsamea* L. Mill.		X	
White spruce - *Picea glauca* (Moench) Voss	X	X	
Sugar Maple - *Acer saccharum* Marsh.	X		
Trembling aspen - *Populus tremuloides* Michx.			X

Sampling was confined to the early afternoon, which marked the minimum in the diurnal variation in foliar moisture content (Kramer and Kozlowski, 1960) and the daily peak in forest fire hazard.

To minimize the effects of daily weather, days of moderate relative humidity and wind speed were chosen, with seasonable temperatures. Suitable days were picked every three weeks on the average, more frequently in spring than in summer and fall. The effect of periodic rain and drought was not consciously taken into account; it was assumed that any variation due to unusual soil moisture conditions would average out during the several years. Monthly rainfalls and May-to-September totals for the sample years are listed for the record in Table 2.

Conifer foliage was sampled in two categories:

1) old foliage, comprising all ages of needles carried over from the previous year, and
2) new foliage, from the current year's growth.

On each sampling day, two samples of old conifer foliage were taken, and, as soon as they became available, one sample of new conifer foliage and two samples of the broad-leaved species. Each sample was a composite from several points about the lower third of the crown.

The samples were collected in covered tins, weighed within an hour, and oven-dried at 100°C for 24 hours. Foliar moisture content (FMC) was calculated in per cent of oven-dry weight, precise to within a few parts in a thousand. It is possible that some non-aqueous volatile matter was lost during oven-drying. However, some trials with the xylene distillation method of Buck and Hughes (1939), as well as the experience of Wright and Beall (1938), suggest that the values obtained are within 2 per cent greater than true water content and are quite consistent in a relative sense.

In the results presented here, all data for each species are pooled. There were some statistically significant differences between individual trees and sites, although within each species all trees exhibited the same seasonal trends. In view of the small number of trees sampled, these differences have little meaning and were judged unimportant to the main purpose of this project. Graphs of the seasonal trends were plotted as FMC against time in days, and the points joined with straight lines.

To prepare composites of several years' data, vertical averages of the annual trends were plotted every 10 days along the abscissa; these average points were similarly linked with straight lines.

A laboratory experiment was performed to show the effect of FMC on the flammability of individual small spruce trees. Its results and some simple theoretical speculation about how foliar moisture variations may influence crown fire are presented in a later section.

SEASONAL TRENDS IN FOLIAR MOISTURE

Results

The main trends found in foliar moisture content are shown in Figures 1 and 2. The curves in Figure 1 are averages for the five conifer species together over a two-year period. The FMC of newly flushed conifer foliage was very high - over 300 per cent. It decreased rapidly to within about 40 percentage points of the old foliage level by early August, then more slowly. The difference between the two classes was down to about 20 points by the end of October.

The old conifer foliage emerged from the winter at a moisture content close to the late autumn values. This is better appreciated if the early spring samples are thought of as composites of the previous year's old and new foliage, treated separately the previous autumn. During April, the moisture content of old foliage dipped sharply, reaching a distinct minimum in May before the new growth flushed; it then gradually increased to a broad maximum in late summer.

Figure 2 contains the FMC trends for the two broad-leaved species separately, each averaged for three years. Foliage of both trembling aspen and sugar maple flushed at a high moisture content that fell rapidly, levelling off by mid-summer. An interesting feature of these curves is the sharp rise observed after the autumn colour change. The final decrease in FMC during the few days just before leaf fall does not appear in Figure 2. Samples of falling leaves collected in October 1964 showed, however, that only a moderate amount of drying takes place on the tree. Each species was sampled on two different days of moderate wind; the moisture contents of falling maple leaves were 94 and 87 per cent, and of aspen 147 and 128 per cent.

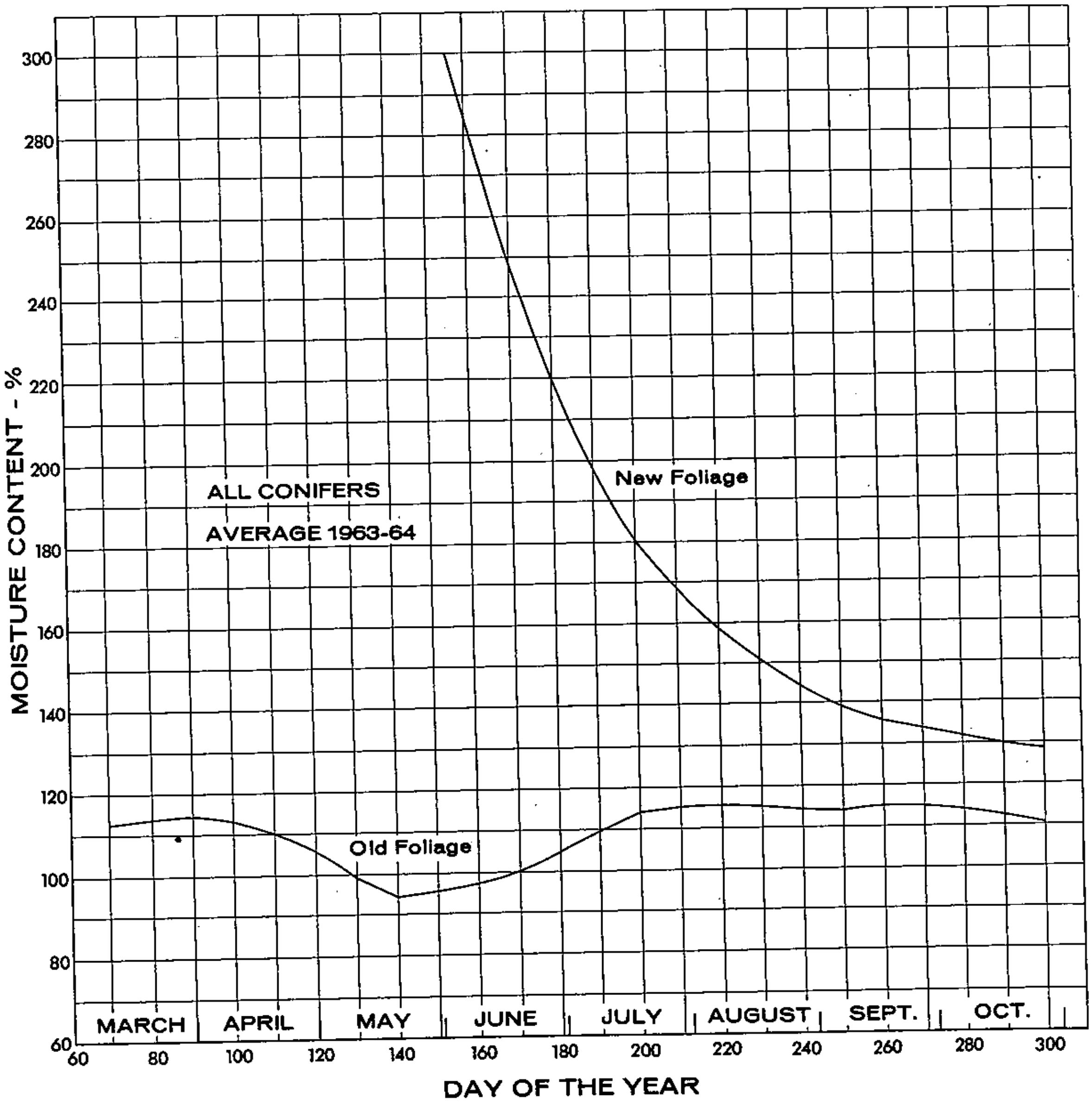

Figure 1. Foliar moisture trend of the five conifers together, averaged for 1963 and 1964.

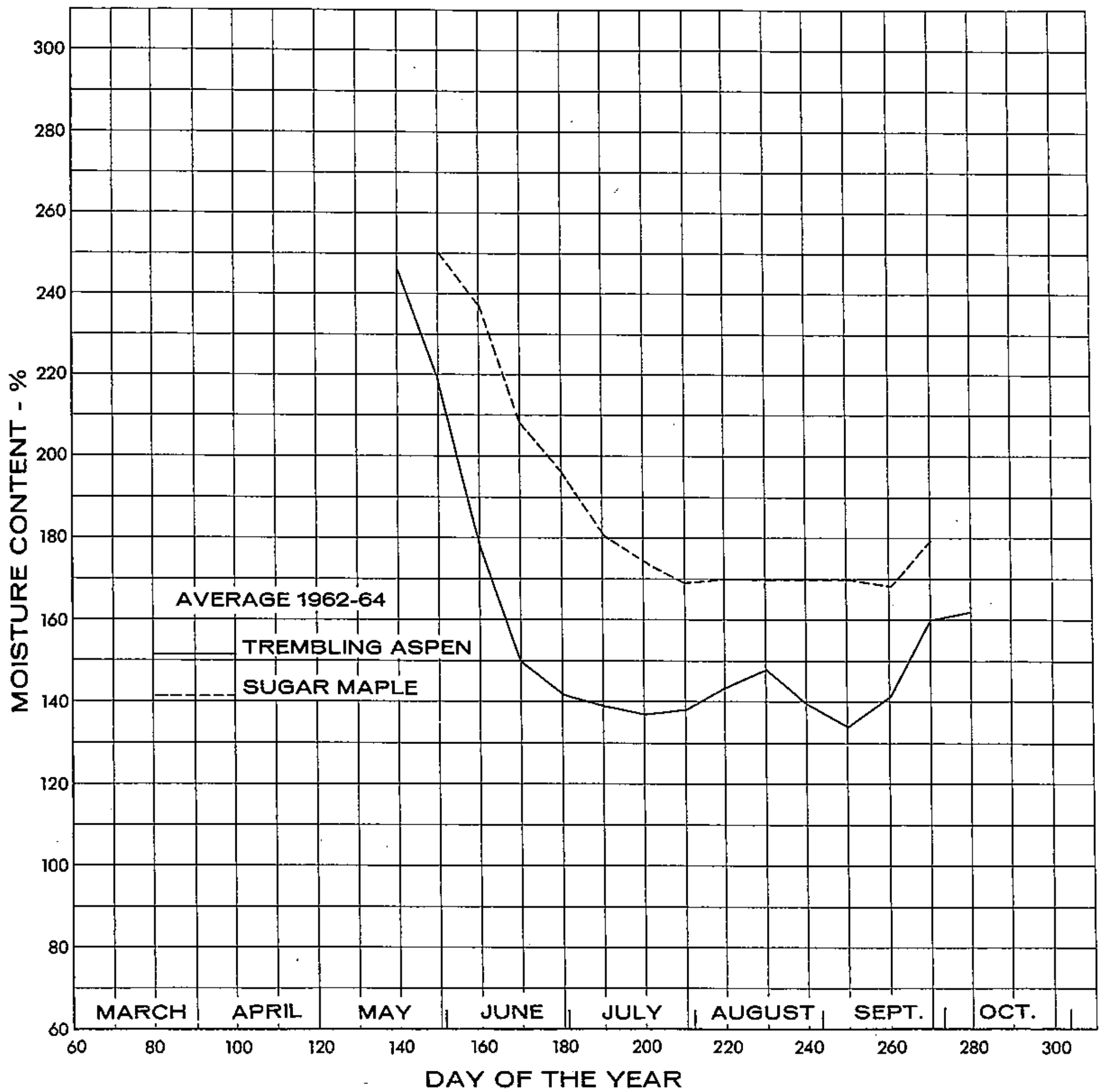

Figure 2. Trends of foliar moisture in sugar maple and trembling aspen, averaged for the years 1962 to 1964.

In all cases of significant difference within a species, the individual trees maintained a fairly constant difference throughout the season, each following the trends already outlined. Differences between species are illustrated in Figures 3 and 4. Among the pines, white pine consistently maintained the highest FMC, with jack pine and red pine following in order (Figure 3). Balsam fir and white spruce were very similar to each other (Figure 4). The annual minimum and maximum old-foliage moisture contents of these two species groups are presented in Table 3. The seasonal trends in these two groups of conifers were much the same but with two noticeable points of difference. First, the pines exhibited a later and longer period of low FMC (mid-May to late June) than did fir and spruce (early May to early June). Second, in fir and spruce the moisture content of new foliage fell more quickly than in the pines, and approached the old foliage level more closely by summer's end. In Table 4 the conifer species are listed in rough order of decreasing FMC.

Discussion

The main features of the seasonal trend in the FMC of old conifer foliage are the marked spring minimum and the less pronounced summer maximum. This trend was sufficiently uniform among all species and individual trees from year to year to warrant the conclusion that it is a characteristic of the conifers of this region.

Some of the year-to-year differences in the FMC's in Table 3 can be tentatively ascribed to annual weather variations. For example, old fir and spruce foliage reached its highest summer maximum in 1962, the only year with near normal rainfall in both June and July (Table 2). Conversely, spring and early summer in 1964 and 1965 were both dry and warm; minimum and maximum FMC's were low in these years.

It is reasonable to suppose that the summer FMC is influenced by both rainfall and evaporation; a very wet year might then produce higher summer FMC's than those of 1962 to 1965. The spring minimum FMC, on the other hand, occurs soon after the soil is recharged by snowmelt. Fraser (1957) determined moisture trends in several soils on the Petawawa Forest Experiment Station and found them always at field capacity in early spring.

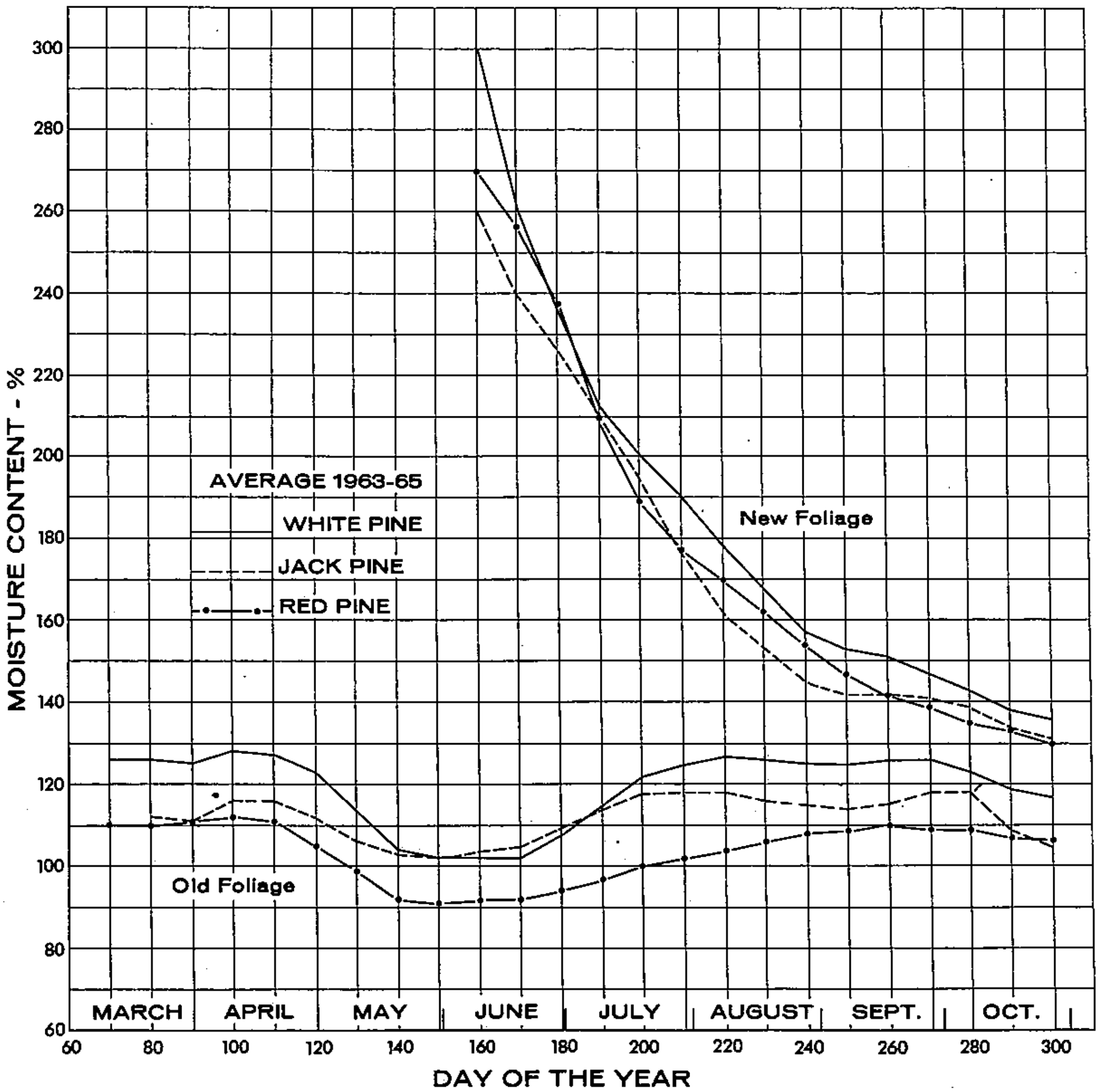

Figure 3. Trends of foliar moisture in white pine, jack pine and red pine, averaged for the years 1963 to 1965.

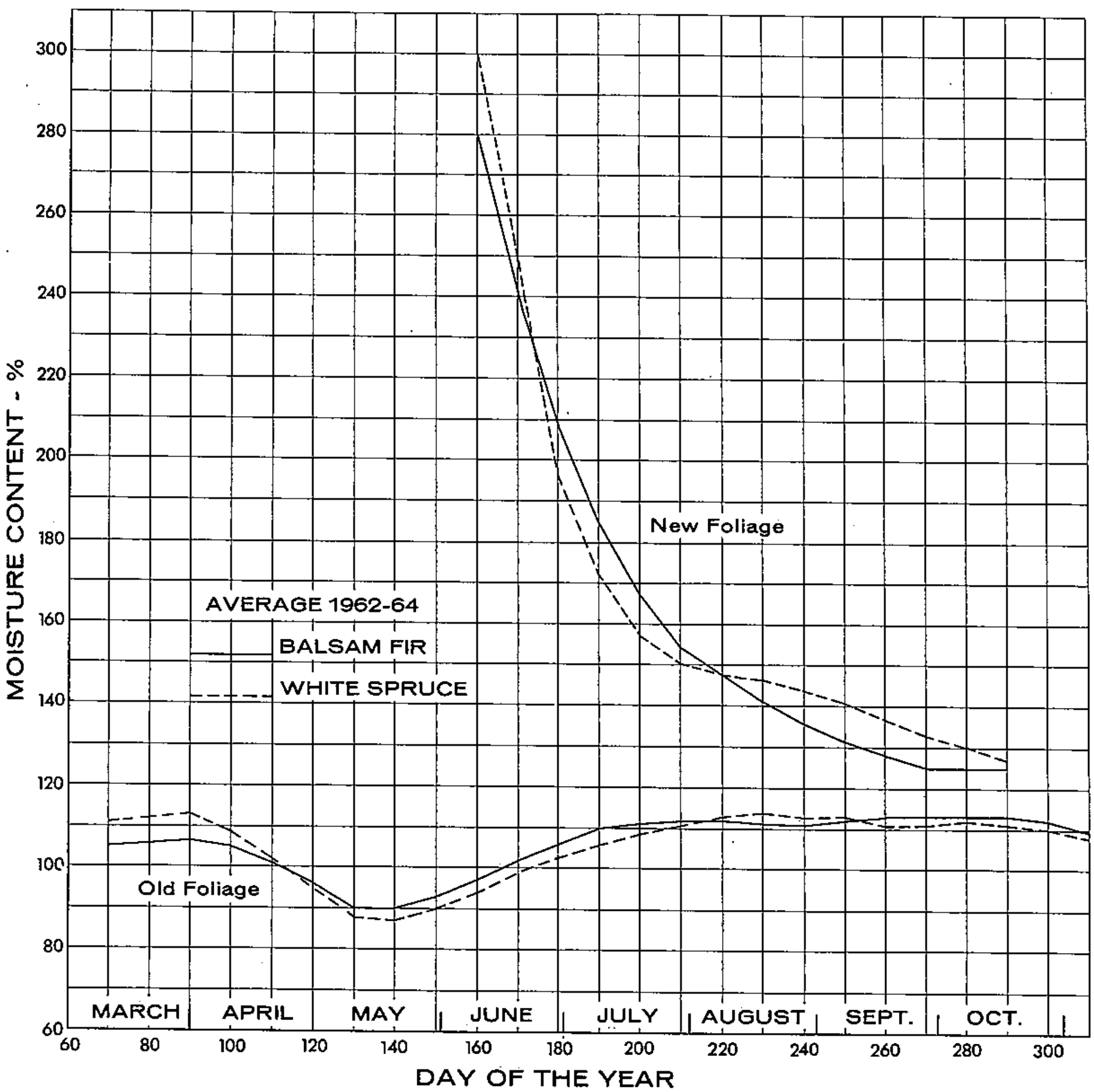

Figure 4. Trends of foliar moisture in balsam fir and white spruce, averaged for the years 1962 to 1964.

TABLE 2. VALUES FOR MONTHLY RAINFALL FOR MAY TO SEPTEMBER, 1962 TO 1965, COMPARED WITH LONG-TERM MEANS

Year	Rainfall (in.)					
	May	June	July	Aug.	Sept.	Total May to Sept.
1962	2.4	3.1	2.5	2.4	3.0	13.4
1963	3.4	1.2	1.5	4.1	4.1	14.3
1964	2.8	1.1	1.5	1.7	2.6	9.7
1965	2.2	0.8	2.4	7.0	3.8	16.2
Mean (1946-65)	2.6	2.9	2.9	3.4	2.9	14.7

Furthermore, the moisture content of old conifer foliage always rose during June and July despite subnormal rainfall in these months. A possible primary reason for the spring minimum is that soil temperature increases more slowly than air temperature as spring progresses; in spite of high soil moisture, the greater viscosity of water and the sluggish activity of root tissues at low temperature could cause water uptake to fall behind the demands of transpiration. This is equivalent to suggesting that the spring

TABLE 3. ANNUAL VALUES OF SPRING MINIMUM AND SUMMER MAXIMUM MOISTURE CONTENT IN OLD CONIFER FOLIAGE, AVERAGED FOR TWO SPECIES GROUPS

Year and Item	Fir and Spruce	Pines	All Conifers
1962 Min.	91.0	-	-
Max.	121.7	-	-
1963 Min.	87.1	101.2	95.5
Max.	114.2	128.8	122.9
1964 Min.	86.6	95.0	91.5
Max.	110.5	119.4	115.8
1965 Min.	-	94.1	-
Max.	-	117.0	-

drop in FMC is caused by evapotranspiration but is independent of soil moisture.

It is obvious that taking a valid composite sample of conifer foliage during early summer is a delicate matter; new and old foliage must be taken in the proper weight proportions, which are continuously changing as the new foliage develops. Furthermore, a single composite FMC hides the large difference between old and new foliage. Although composite samples were not taken, hypothetical values of average FMC were calculated for August 8, when this difference was generally about 40 per cent. These composite FMC's were calculated from the individual trend curves, on the assumption that new foliage makes up a third of the total foliage dry weight in the pines, a quarter in fir, and a fifth in spruce. These fractions are approximations of data given for red pine by Stiell (1962), for balsam fir by Baskerville (1965), and for white spruce by Fraser *et al.* (1964). Table 4 shows these composite FMC's and the average spring minimums and summer maximums for all species of old conifer foliage. Taking the August 8 composite FMC's as typical mid-summer values, Table 4 also lists the differences between these and the spring minimum FMC's in old foliage; it is these differences that are pertinent to a discussion of crown fire behaviour.

FOLIAR MOISTURE CONTENT AND CROWN FIRE

The ranges in conifer foliar moisture content to be expected during the fire season are indicated in the last column of Table 4. The increases during the period May to August average about 34 per cent, and the obvious question is: Are these differences large enough to affect the propagation of crowning forest fires?

A simple laboratory experiment was performed to illustrate how the flammability of one species varies with FMC. Several similar 5-foot white spruce trees were cut in March and brought inside. By standing some in water and allowing others to dry for varying periods, FMC's were obtained ranging from 68 to 124 per cent. Each tree was burned in a flame hood by igniting balls of crushed newspaper arranged around its base. A total hemispheric radiometer was mounted 3 feet from the burning trees and the maximum intensity of thermal radiation observed. Measured in this manner,

TABLE 4. VALUES FOR FOLIAR MOISTURE CONTENT IN THE FIVE CONIFERS COMPARED IN SEVERAL WAYS - COMBINED 1963 AND 1964 AVERAGES

Species	Old foliage moisture content* %		Estimated moisture content on August 8 %			Difference, composite FMC (Aug. 8) minus spring minimum
	Spring minimum	Summer maximum	Old foliage	New foliage	Composite foliage†	
White pine	100	133	131	176	146	46
Jack pine	104	126	121	155	132	28
Red pine	92	117	109	167	128	36
Balsam fir	89	113	108	142	116	27
White spruce	84	115	111	148	118	34
Conifer average	94	121	116	158	128	34

*Vertical bars link averages not significantly different at $p = 0.05$.

†Determined from graph values as explained in text.

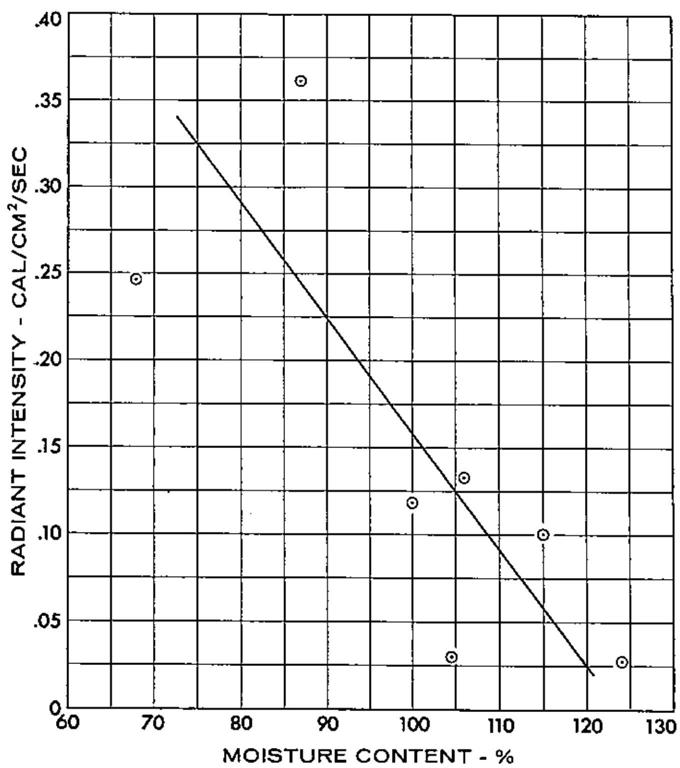

Figure 5. Effect of foliar moisture content on maximum radiant intensity 3 feet from burning 5-foot white spruce trees.

the radiant intensity is primarily a measure of the flame size; it is shown plotted against FMC in Figure 5. Obviously, moisture content variation within the range observed has a marked effect on the flammability of single trees.

The quantitative effect of foliar moisture on crown fire behaviour can be estimated in part by considering how much energy is required to heat live foliage to ignition temperature. Assume that the fire advances by preheating the unburned fuel in its path until it gives off flammable gases that can be ignited by the approaching flame. Suppose that the preheating consists very simply in first driving off the moisture and then heating the dry fuel to 300°C, a commonly accepted ignition temperature. The heat of vaporization of water at 100°C is 540 cal/g, and the specific heat of dry foliage is taken to be 0.35 cal/g/°C. Suppose the initial temperature to be 20°C. Then, if the heat of desorption is ignored, the energy Q required in cal/g of dry foliage is:

$$Q = (100-20)\frac{M}{100} + 540\frac{M}{100} + 0.35\ (300-20)$$

$$= 6.2M + 98$$

where M is foliar moisture content in per cent. From Table 4 the average conifer FMC is 94 per cent at the spring minimum and 128 per cent on August 8; the values of Q at these moisture contents are 680 and 892 cal/g respectively. If the heat were supplied at the same rate, the time required to reach ignition temperature would be a third longer at the higher moisture level.

A second effect of higher moisture content would be a drop in flame temperature and thereby in the intensity of thermal radiation emitted by the flame front. As an example, this effect was calculated for a flame at 1000°C having an emissivity of 0.8 and radiating 2.8 $cal/cm^2/sec$. If the air supply to the flame is assumed to be twice the requirement for complete combustion, then a 34-point rise in FMC could reduce the radiant intensity by 20 per cent.

For each conifer stand there must exist a minimum rate of advance below which the crowning phase of a fire cannot continue to burn; below this critical rate the energy output and flame depth are inadequate to maintain the required horizontal heat transfer rate to ignite the unburned foliage. Thus the level of foliar moisture might in some circumstances be the deciding factor in whether or not a fire crowns.

These speculations and this experiment touch only lightly on a complex phenomenon. Other factors that undoubtedly affect the propagation of crown fire are the height of the live crown above ground, the bulk density of foliage within the crown space, the shape and arrangement of the leaves, and the presence of flammable waxes, oils and resins. When taken together, however, the present results suggest that foliar moisture content is an important factor in crown fire behaviour and that stands of eastern Canadian conifers are most susceptible to crowning in the spring.

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