GROWTH FLUCTUATIONS OF VIRGIN HEMLOCK FROM NORTHERN PENNSYLVANIA

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When studying the influence of weather on the growth of trees, it is necessary to segregate the variation in the width of the annual rings which is due to changing weather conditions from the variation due to other factors influencing the annual growth. By segregating the influence of factors other than weather, we are able to construct a tree-ring calendar showing the responses of diameter growth to weather alone, that is to say, a calendar in which all disturbing factors other than weather have largely been eliminated. The methods used for such an investigation can represent an application of the analysis of variance.

Cross sections of old hemlock trees were collected in two virgin stands of the beech, birch, maple, hemlock association in northern Pennsylvania. The first of the stands, now logged off, was about five miles north of Sheffield in Warren County and the second stand, an old farm woodlot belonging to Messrs. Rightmeier, was located five miles to the north of the little town of Estella in Sullivan County. This second stand has also been cut since the collection of our data. In both localities the cross sections were cut at the upper end of the first log. Ten cross sections have been secured from Sheffield and six from Estella.

The ring measurements were made on three radii to the nearest 1/200 of an inch and the results averaged for each year. The average age of the trees from Sheffield was somewhat below 300 years; the trees from Estella were 200 years old. The last 50 years of the Sheffield trees and the last 45 years of the Estella trees have been subjected to a detailed analysis of tree-ring variation. It was intended to correlate the variation in ring width for this period of years with the available meteorological data. Since the results so far obtained were negative, we shall not discuss them at any length. Without making a detailed analysis, the method described for the isolation of the variation of ring width due to weather was finally applied to the entire sequence of data.

The ring widths of the ten trees from Sheffield are graphically represented in Figure 1. Each tree reveals a more or less typical individual growth trend during this period of years. In most cases this trend could be adequately represented by a straight line. Tree five was the only one requiring a parabola to represent its individual growth trend. The trend line of tree eight runs parallel to the X—axis and thus represents the arithmetic average of the 50 measurements.

The total variation of the 500 (10 times 50) rings may be measured by computing the sum of the squared deviation of each ring measurement from the average ring width of all ten trees. Calculating in units of 0.005 inches, we obtain 2,676.55. The total sum of squares may now be apportioned to a variation between trees and within trees by the usual methods of the analysis of variance, with the result shown in Table I.

Table 1. Division of the total sum of squares into portions between and within trees. Hemlock, Sheffield, Pa.

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between trees	1061.13	9	117.9
Within trees	1615.42	490	3.30
Total	2676.55	499	

It is evident that the different growth rates of the ten trees account for a large portion of the total sum of squares.

The variation within trees will now be further subdivided into a portion due to the individual growth trend of each tree, a portion due to the influence of weather, and a residual portion due to errors of sampling, errors of observation, etc. The trends shown in Figure 1 have all been fitted by the method of least squares and it was therefore an easy matter to calculate the sum of the squared residuals from the respective curves. By subtracting this sum of squared residuals from the sum of squares within trees, we obtain 1615.42 — 1586.52 = 28.90 which is the sum of squares due to trend. The sum of the squared residuals may finally be subdivided into a sum of squares between years and a residual variation; the results of this final analysis are summarized in Table 2.

Table 2. Division of sum of squares within trees into portions due to trends, years, and remaining variation, and pertinent mean squares.

Source of variation	Sum of squares	Degrees of freedom	Mean square
Tree trends	28.90	10	2.89
Years	882.8	49	18.02
Residual variation	703.72	431	1.63
Total	1615.42	490	

The residual mean square of 1.63 is small compared with the mean square between years. It affects, of course, the calculated variance between years and it is necessary to subtract 1.63 from 18.02 in order to find the mean square residual which may be entirely ascribed to the influence of weather. The difference 18.02 — 1.63 must finally be divided by 10 in order to find the mean square of the average residuals due to weather; the root mean square is therefore equal to 1.28, or 19.5 per cent of the average ring width. If the residual mean square of Table 2 had been zero, the variance between years would have been 18.02/10 or 1.802 and it would have been concluded, after eliminating the differences between trees and individual trends, that fluctuations of weather account for the whole of the remaining variance. Actually, fluctuations in weather account for 1.639/1.802 or 91.0 per cent of the remaining variance. A tree-ring calendar made up from the average residuals of the individual trends reflects therefore surprisingly well the net influence of weather on the annual growth of trees, the influence of unaccounted for "disturbing" factors amounting to only 9 per cent of the variance between years.

The last 45 rings of the trees from Estella have been analyzed in the same way, and very similar results have been obtained. The individual growth trends of the trees from Estella were more irregular than those from Sheffield. It was necessary to fit second and third degree curves to the original data which explains the relatively larger number of degrees of freedom assigned to the trend. From Table 3 where the complete results of the analysis of variance are listed, it is seen that we have to subtract 13.16 from 63.17 in order to find the mean square of the average residuals which is due to weather. Dividing the difference by six, taking the square root, and finally, expressing the quotient in per cent of the average ring width of the six trees, we find that the root mean square error of the average residuals is equal to 17.5 per cent of the average growth. The variance due to weather alone amounts therefore to 50.01/63.17 or 79.2 per cent of the variance between years.

Table 3. Division of sum of squares into portions due to assignable causes. Hemlock, Estella, Tioga County, Pennsylvania.

Source of variation	Sum of squares	Degrees of freedom	Mean square
Between trees	5023.69	5	1004.74
Tree trends	4888.95	12	407.41
Years	2779.44	44	63.17
Residual variation	2738.00	208	13.16
Total	15430.08	269	

The annual variations in ring width are very much alike for the trees from Sheffield and Estella, although the two localities are more than 100 miles apart. Surprisingly enough, no significant correlation between growth and rainfall could be established. Since (in one case) 90 per cent of the calculated average variation in ring width was actually shown to be due "to years," it remains an unsolved question what meteorological factors or combination of factors influence the annual growth of trees in northern Pennsylvania, where rainfall is not a limiting factor.

The entire sequence of tree-ring data of the ten trees from Sheffield has finally been used to construct a tree-ring calendar covering a period of 237 years. A third degree curve was fitted to the average ring widths of the ten trees and the deviations from this trend were expressed in per cent of the average growth (see Table 4, page 22).

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