INTER-CORRELATIONS BETWEEN GROWTH RATES OF CONIFERS IN NORTHERN NEW ENGLAND

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On the basis of ring measurements obtained from thirteen forest sites, chiefly in northern New Hampshire, it is now possible to compare hemlock, white pine, and red spruce for their growth responses to variations in dominant climatic factors, year by year. The effects of soil, age of tree, exposure, suppression, and specific differences in rates of growth have been practically eliminated by random choice of sites and the use of appropriate statistical methods. The point to be demonstrated is the extent to which the three types of softwood trees reflect climatic changes in spite of pronounced differences in absolute growth rates between species and between scattered groups of trees of the same species.

For the purposes of this study the question of detailed yearly cross-identification between species is avoided. For the hemlocks (Ecology *17*, 457-478, 1936) and for most of the pines used in this analysis (Ecology *18*, 406-415, 1937) the point has already been considered. Spruce shows it to about the same degree as the white pine. In the present paper the relations between the growth curves as a whole are studied, by means of correlation coefficients.

CALCULATION OF CORRELATION COEFFICIENTS

Each of the thirteen lots of tree sections has been treated as a unit source of data for the computations. For each site the mean growth increments of all trees measured were plotted as a line graph of annual growth rates. These graphs for hemlock and pine have been published (*loc. cit.* and Ecology *21*, 425-437, 1940). The three for spruce showed the same growth characteristics though differing among themselves. The Franconia group of 5 trees covered a period of over 150 years, the Warren lot (10 trees) included none less than 200 with the two oldest over 300 years of age, while the Dorchester group of 10 trees gave only an 85-year record.

The correlations between species and between groups of the same species of tree were estimated on the basis of annual deviations of ring width from a trend line or normal curve of growth rate. Each trend line was drawn to give a balance of plus and minus departures of the plotted points from the line. One of them appears as a text figure in the October, 1940 issue of Ecology.

Each correlation coefficient r was calculated from the annual departures of the two variants from their respective normal curves. Since data from 13 tree groups were used in the complete analysis, a total of 78 coefficients were computed. They are not directly comparable, however, because a variable number of years were involved in computing them. In the following table each one has therefore been entered by a symbol of its significance:

The significance of each r has been indicated according to the usage of Snedecor and others, supplemented by an original device for distinguishing between values in which the odds are much higher than 999 to 1 against a chance agreement. If there is objection to the use of the terms "very highly significant" and "extremely significant" for values that have elsewhere been taken as equivalent to "practically certain" or merely included in the upper 0.1% level (odds 999 to 1), the grades 3 and 4 may be read as identical in meaning but with a significance well above the 0.1% level that is sometimes termed "very highly significant" (see Deuber and Farrar in Jour. of Forestry *38*, 581, 1940).

CORRELATIONS IN DEVIATIONS OF GROWTH RATE FROM TREND

	Sites	Hemlock					White Pine					Spruce	
		Ben	Fair	Han	Wake	Wol	Enf	Han	Har	N.C.	Nor	Dor	Fran
Hemlock	Benton, N. H.												
	Fairlee, Vt.	4											
	Hanover, N. H.	3	4										
	Wakefield, N. H.	3	4	3									
	Wolfeboro, N. H.	3	4	4	4								
White Pine	Enfield, N. H.	2	2	2	1	1							
	Hanover, N. H.	0	1	1	0	0	1						
	Hartland, Vt.	0	2	1	0	0	2	1					
	No. Conway, N. H.	0	0	0	0	0	0	1	2				
	Norwich, Vt.	0	0	1	0	0	2	2	1	2			
Spruce	Dorchester, N. H.	0	0	0	2	1	0	0	0	1	0		
	Franconia, N. H.	2	2	2	1	2	0	0	0	1	0	1	
	Warren, H. H.	2	2	1	2	1	0	0	0	0	0	2	2

Key to symbols indicating nature of correlations, all positive if significant

4 Extremely significant i.e. at least 3 times highly significant
3 Very highly significant i.e. at least 2 times highly significant
2 Highly significant i.e. odds better than 99 to 1 (above 1% level)
1 Significant i.e. odds better than 19 to 1 (above 5% level)
0 Not significant i.e. odds lower than 19 to 1 (below 5% level)

In order to provide generalized statements of relations among the growth rate responses of the three species of trees, the mean correlation coefficient has been calculated for each of the six sections of the table, representing the six possible comparisons among the three species. These mean values for r, together with the nature of relationship expressed by each, are as follows:

Hemlock vs Hemlock	.523	Extremely significant
White Pine vs White Pine	.371	Highly significant
Spruce vs Spruce	.320	Highly significant
Hemlock vs Spruce	.249	Highly significant
Hemlock vs White Pine	.215	Not quite significant
Spruce vs White Pine	practically zero	Not significant

DISCUSSION

From the table of correlations among the individual forests, the differences among the thirteen sites are evident but they are not so revealing as the general consistency within a section of the table. For example, when it is a matter of hemlock vs hemlock, pine vs pine or spruce vs spruce, the differences due to site are almost negligible. The situation is not much different for spruce vs hemlock or spruce vs pine, with only the Dorchester young spruce giving a group of correlation coefficients with hemlock that are contrary in significance to the close agreement of the others in that section of the table. It is only when hemlock and pine sites are compared that we find a lack of consistency in site effects. Even here it is probably not primarily a difference in site that is responsible but the imperfect and variable cross-identification between hemlock and white pine, noted by Goldthwait and Lyon (Ecology *18*, 406-415, 1937).

The questions of inter-correlation between growth responses of tree species, as measured by r, are given direct, unequivocal answers by the mean values of the correlation coefficients. White pine fails completely to respond

as spruce does, even though the Dorchester sample of spruce was growing at essentially the same altitude as the pines. The general reactions of hemlocks and white pine are somewhat alike, probably because of the fair cross-identification already noted; in the years with small departures of one or both species from their normal growth rates, the signs of the departures may be evenly balanced and there may then be less tendency to respond alike to environment.

The one pair of species (spruce and hemlock) to agree consistently in growth response has a highly significant value for its generalized correlation coefficient. These species show unexpected agreement, considering the differences in the plant communities in which they normally grow. The relationship is less close than that between trees of the same species of conifers but it is statistically far beyond the expectancy of chance agreement.

SUMMARY

Except for the differences in the growth responses of red spruce and white pine to the climate of northern New England, the variations in annual growth rates of hemlock, white pine, and red spruce, year after year, tend to be alike in their departures from normal curves of growth for the individual forests. The tendency is especially strong between forests of the same species, assuming a selection of trees dependent upon the dominant factors of the climate and specifically with reference to the water supplies for the root systems. Hemlock definitely shows the best agreement between forest sites but both spruce and pine are reliable in work with any one species. In general, the results of this analysis support previous estimates of tree-ring possibilities in New England.

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