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VERTICAL UNIFORMITY IN THREE NEW ENGLAND CONIFERS

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Until the point has been tested for a geographical area, there is no certainty that the sequence of relative ring-widths found at one level in a tree trunk will be repeated in measurements at some other level above the roots. Glock[1] found such uniformity to be very good in the western yellow pine *(Pinus ponderosa* Laws.) of northern Arizona, at an elevation of 7200 feet and with an annual rainfall of only 18 inches. On the contrary, Shreve[2] found a young Monterey pine *(Pinus radiata* Don) near the shore at Carmel, California, to vary so much in secondary growth at different levels that he wrote "it is seldom that a ring is continuously greater or less than an adjacent ring when they are followed for several meters up the trunk." A second tree there gave greater uniformity but many examples of contradiction in wide and narrow rings at different levels in the trunk.

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[1] *Carnegie Inst. Wash. Pub.* 486 (1937).
[2] *Carnegie Inst. Wash. Pub.* 350 (1924).

Since timbers that appear in cases requiring crossdating as a means of dating old buildings, bridges, dams, etc. will come from various heights in tree trunks, the use of a species for such problems requires a demonstration of the degree of vertical uniformity. In the New England area the three species of conifers in general use for construction purposes are white pine *(Pinus strobus* L.), red spruce *(Picea rubens* Sarg.) and hemlock *(Tsuga canadensis* (L.) Carr.). Their suitability for cross-identification and their dependence on seasonal rainfall for growth in critical years has been demonstrated in a series of papers by Lyon.[3] Both pine and hemlock have been used successfully in a few archaeological problems of the area,[4] but the proof of their vertical uniformity has remained unpublished.

Since rings in New England trees, growing with a normal annual rainfall of 35 inches or more, are never absent on all radii of a transverse section, the necessary dissection of a tree for purposes of checking ring-widths at different heights requires only a series of transverse sections. Using the average of ring-width along three good radii for each section, as required for ring analysis in the area,[5] the pattern of growth rate at each height is given by the graphs and skeleton plots of the resulting average widths.

Figure 1 shows the graphs of ring-widths for 7 heights in the trunk of a white pine tree, 80 years old. It was sectioned at 2 feet from the ground and at intervals of 5 feet to a final section at 32 feet, well within the crown of the tree. The integrity of crossdating for all sections is obvious from 1900 on and reasonably good for all but the oldest portions of the four lower sections. The tree grew at the edge of a bog in Hanover, N. H., but the sensitivity of the rings is characteristic of northern New England where such trees crossdate well with upland trees.[6]

An analysis of agreement in minima between sections shows that the sequence of ring-widths at the 7-foot level is the best measure for the trunk as a whole. The years for relatively narrow rings there agree perfectly with the consensus of the years for the seven sections. The misses in agreement for the other six sections are: 4 for the 2-foot level, 2 for the 12-foot level, 3 for the 17-foot level and 5 each for the three upper sections in spite of the progressively fewer rings for possible agreement at the higher levels. In general, the vertical uniformity is good for the portion of the trunk without large branches except for the variations to be expected at low stump height, where the buttress effects cannot be entirely eliminated by choice of the three best radii for measurements.

A second pine tree from a nearby boulder slope was sectioned at 9 levels, 8 feet apart, starting about 2 feet from the ground where 132 rings were

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[3] *Ecology* 17: 457-478 (1936); 21: 425-437 (1940); 24: 329-344 (1943); 30: 549-552 (1949).
Tree-Ring Bull. 5: 27-30 (1939); 7: 24-26 (1941).

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[4] Lyon, *Science* 90: 419-420 (1939); Lyon and Goldthwait, *Geog. Rev.* 24: 605-614 (1934).
[5] Lyon, *Tree-Ring Bull.* 5: 27-30 (1939).
[6] Idem, *Ecology* 30: 549-552 (1949).

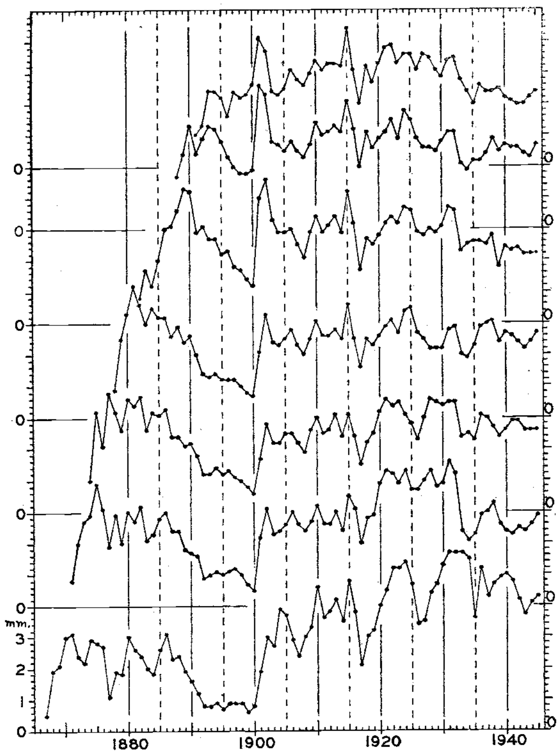

Fig. 1. Growth increments of a white pine, measured in 7 transverse sections cut 5 feet apart. Lowermost graph shows average ring-widths 2 feet from ground. Other graphs in vertical order, each with its base line marked zero.

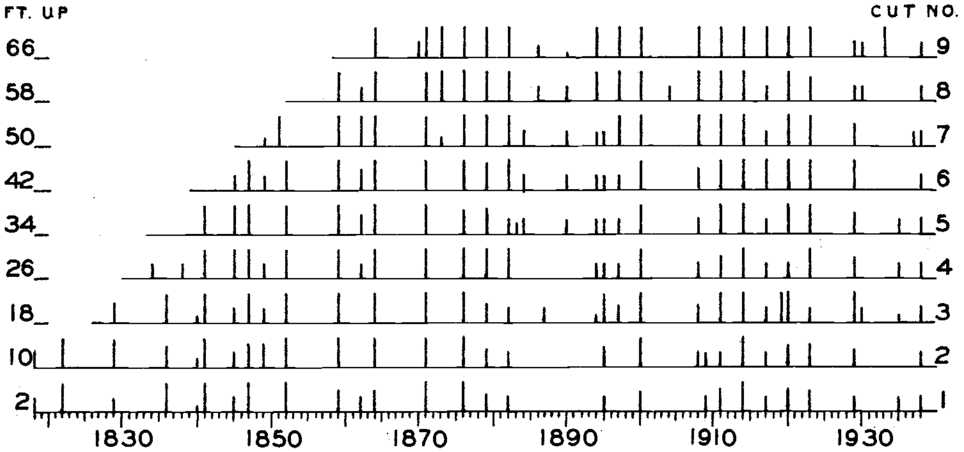

Fig. 2. Skeleton plots of narrow rings in 9 transverse sections of a white pine at Hanover, N. H.

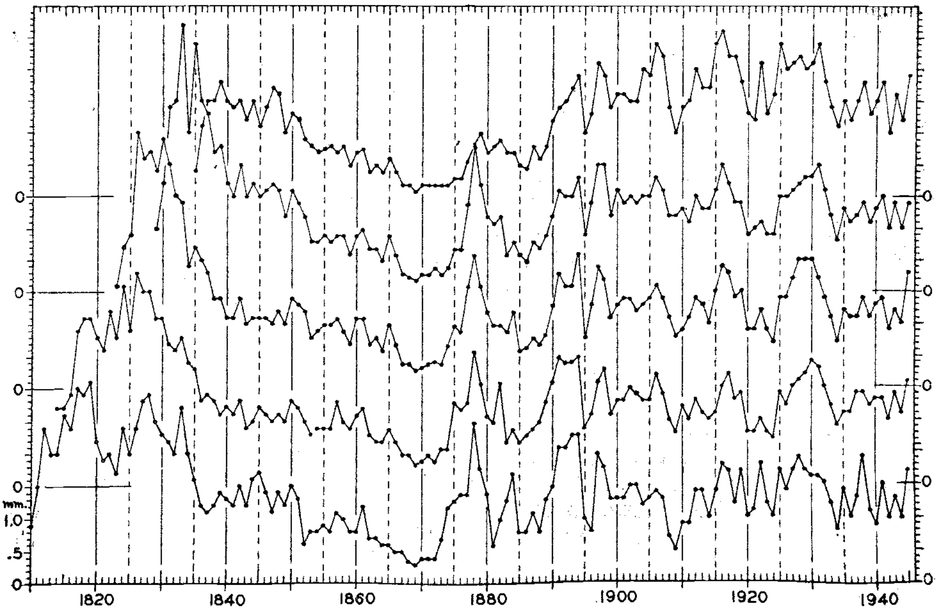

Fig. 3. Growth rates of a hemlock, measured in 5 transverse sections cut 8 feet apart. Lowermost graph shows average ring-widths 2 feet from ground. Other graphs in vertical order, each with its base line marked zero.

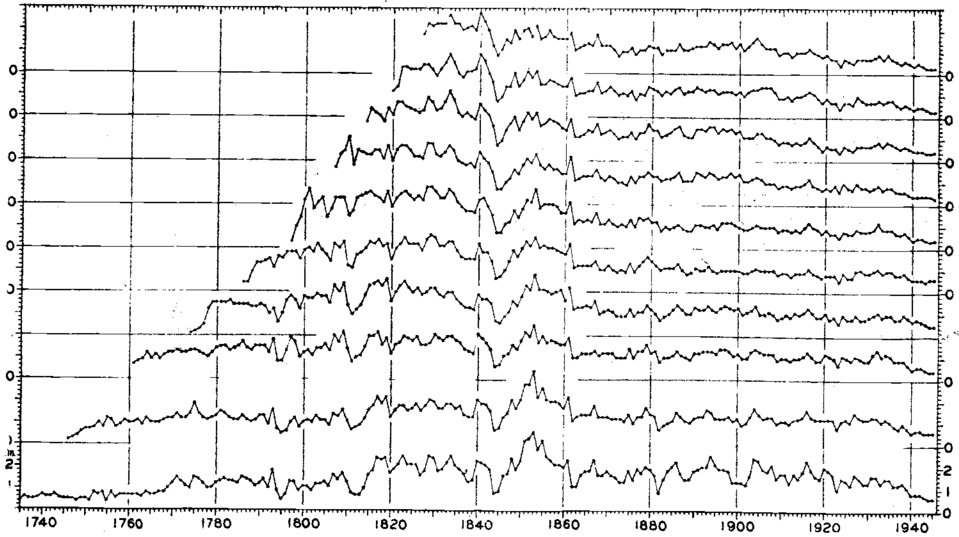

Fig. 4. Growth rates of a red spruce, measured in 10 transverse sections cut 8 feet apart. Lowermost graph shows average ring-widths 2 feet from ground. Other graphs in vertical order, each with its base line marked zero.

found. The trunk was practically free of branches up to 42 feet where the sixth section was taken, with the other three sections in the crown of the tree. The growth rates of this relatively old tree and the mean sensitivity of the ring record were essentially like those of the tree in low ground about 200 yards away.

The skeleton plots of minima in Figure 2 show that the vertical uniformity is good enough in this tree to permit crossdating between any of the 9 sections. However, new lows appear in the main axis at crown levels in comparison with lower levels; considerable allowance for them would need to be made in crossdating such sections of unknown age against a standard obtained in the usual way from the main trunks.

As for the level with the most reliable record of growth rates for the tree as a whole, there is little to choose between the sections at 2, 10, 18, and 34 feet, each with 3 or 4 disagreements with the consensus as to the years with narrow rings, though all four of these sections crossdate easily. Curiously, the record of growth rates at the 26-foot level shows no variation from the consensus for years of retarded growth. This evidence along with that from the younger pine tree seems to make it clear that all wood from the main trunks of this species has sufficient vertical uniformity to permit its use in archaeological problems. Likewise, main axis timbers between the levels of origin of large branches can be used if there are several decades of rings present, thus permitting some allowance for imperfect agreement of narrow rings in the skeleton plots.

Essentially the same conclusions are to be drawn from an analysis of vertical uniformity in a hemlock tree that grew on a hillside at 800 feet elevation at Plainfield, N. H. The exposure was southwest and the soil a shallow loam over a ledge. The growth increments were typical of the species in New England, including a period of suppression about 1870. They are shown by graphs in Figure 3 as obtained in the usual way for 5 levels, 8 feet apart, with the lowest section 2 feet from the ground where 143 rings were measured. As usual in the species in an open stand, the branches started less than 15 feet from the ground.

The obvious crossdating of the four lower sections over a period of more than a century reflects the good vertical uniformity well into the crown of the tree. Only at the height of 34 feet, where the axis of the tree was tapering fast into a size useless for timbers, did the crossdating become questionable and then chiefly for the innermost rings if they were to be used alone. This fifth section with 111 rings at 34 feet showed 8 failures to record the significant minima in growth rate for the tree as a whole; the second section (at 10 feet) had 2 such failures and the others had only 4 each. All these data emphasize the essential vertical uniformity of the hemlock and its value for problems of both climatology and archaeology.

That red spruce has about the same degree of uniformity in the New England area is shown in Figure 4. The 10 sections were cut from a typical forest tree in a mountain valley at 2400 feet elevation near Warren, N. H. The lowest section was taken about 2 feet from the ground and the other nine at intervals of 8 feet up the straight trunk to the point where the axis in the crown was practically useless for timber at 74 feet. The soil was a stony podzol and the site typical for normal timber supply from spruce.

By the striking agreement in these graphs of growth increments between 1800 and 1870, the vertical uniformity for mature spruce trees is shown to hold over an unusual range in the main axis. Because the average ring-width is rarely more than 3 mm, even during the period of rapid growth in diameter, spruce timbers and logs no more than 10 inches thick will often show a chronology of 80 years or more. In this respect spruce compares favorably with hemlock and for construction purposes is more widely used than hemlock.

The relative complacency of these spruce data during the last 80 years of the growth is due to the age of the tree then (236 rings at the 2-foot level) rather than to the normal growth responses of the species. Except as it, like hemlock, may be suppressed by taller trees during its early decades, the species is quite sensitive until the tree is over-age and the rings less than 2 mm wide in all sections above stump height. Even then the most pronounced minima (and maxima) appear at nearly all levels in the tall trunks, as in the years 1876, 1882, 1909, 1912, and 1923 of this tree's growth. The measurements must be made more precisely in spruce (and hemlock) wood with such small growth increments, but the worker is repaid by the reliable chronologies of more than a century in relatively small samples of wood, regardless of their height of origin in the tree.

In order to present quantitative data for the degree of uniformity in ring-width at different levels in the trunk, a series of correlation coefficients were computed for approximately the last century of growth in each of the three species of conifers. This study was confined to the younger portions of the wood of old trees, where sharp changes in growth trends were absent and the ring measurements therefore suitable for use as recorded. As shown in Figures 3 and 4, however, there is a gradual decline in ring-width after the period of maximum width. This made it necessary to compute the correlation coefficients for several short periods within the range of the analysis, since the same trends appeared in the white pine measurements of the old tree for which the skeleton plots are shown in Figure 2.

The coefficients were computed by the standard method for the 25-year periods of 1850-74, 1875-99, and 1900-24, and for one shorter period of 1925 to the end of the tree's life. The results are shown in the three tables. For each species the correlation was determined between the absolute ring-widths of the first (lowest) section and those of each of the higher sections except for those too young or too high into the crown of the tree.

The resulting coefficients are all positive and highly significant with 4 exceptions in spruce for which the means are all highly significant. These positive correlations confirm and emphasize the vertical uniformity already demonstrated for each species by other methods. They also provide a measure of the uniformity for old trees of each species and a method of comparing the three species.

The comparison shows that the white pine is consistently and quantitatively most uniform for ring-width at different levels and in different

Table I. Correlation coefficients (all positive) for ring-widths of a white pine tree, computed in pairs between the lowermost section (number 1) and each of the higher sections in the trunk. Data for this tree also used for the skeleton plot in Figure 2.

	Section Numbers						
	2	**3**	**4**	**5**	**6**	**7**	**means**
1850-1874	.877	.853	.812	.842	.762	.652	.800
1875-1899	.881	.881	.872	.757	.782	.592	.794
1900-1924	.923	.959	.958	.927	.931	.959	.943
1925-1938	.890	.851	.877	.832	.855	.821	.854
means	.893	.886	.880	.840	.833	.756	.848

Table II. Correlation coefficients (all positive) for ring-widths of a hemlock tree, computed as in Table I, from data shown by graphs in Figure 3.

	Section Numbers			
	2	**3**	**4**	**means**
1850-1874	.805	.935	.751	.832
1875-1899	.828	.900	.577	.768
1900-1924	.629	.742	.531	.634
1925-1945	.757	.818	.671	.749
means	.755	.850	.633	.746

Table III. Correlation coefficients (all positive) for ring-widths of a red spruce tree, computed as in Table I from data shown by graphs in Figure 4.

	Section Numbers								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**means**
1850-1874	.963	.935	.886	.889	.893	.871	.901	.890	.904
1875-1899	.766	.689	.713	.288	.407	.623	.747	.563	.600
1900-1924	.864	.759	.520	.631	.642	.361	.365	.518	.583
1925-1945	.947	.950	.881	.914	.927	.968	.879	.935	.925
means	.885	.833	.750	.681	.717	.706	.723	.727	.753

quarter-centuries. There is a smooth decline in the size of the mean correlation coefficient for pairs of measurements in different trunk sections as the upper section gets farther from the lowest section. Even the smallest value, however, is far above that required for "highly significant," although it involves the use of measurements in the seventh section, well within the axis of the tree's crown.

There is little to choose between the mean values of the coefficient for spruce and hemlock. With the exception of the 4 values for spruce that fall below .500, the correlation coefficients are unexpectedly high for both species, in view of the use of data in which some growth trends were disregarded when the computations were made. Perhaps the high values in column 9 of Table III indicate a somewhat more dependable uniformity in red spruce because there was a distance of 64 feet between the sections for which these correlation coefficients were computed, in contrast with a gap of only 15 feet involved in the coefficients shown for hemlock in column 4 of Table II.

All these positive correlations, however, add considerably to the other proofs for a high degree of vertical uniformity in the annual rings of white pine, red spruce, and hemlock as they grow in northern New England.

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