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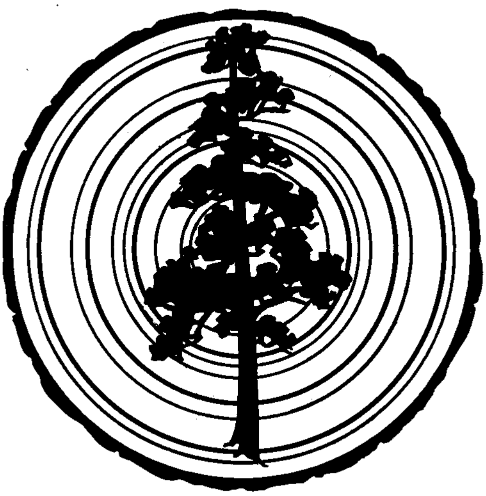

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GROWTH-RING RESEARCH IN NORWAY

OVE ARBO HØEG

The first paper on the correlation between growth rings and climatic factors in Norway was published in 1926 by Eide, on the basis of an investigation of 1243 stems of spruce (*Picea abies*) in eastern Norway. This was also the first study of growth-ring variation in spruce in Scandinavia.

Since the nineteen-thirties a number of other investigations have been published. They fall into three groups:

Some of them have been carried out by forest research workers directly or indirectly connected with the Norwegian Forest Research Institute at Vollebekk. These authors, particularly Ording and Ruden, have introduced the statistical methods usually applied in forest research and have paid great attention to the reliability of the material and to the various sources of error to be taken into consideration. Their critical attitude and careful methods have had a great influence on all other Norwegian work in this field. Their papers on the theory and methods of growth-ring research and dendrochronology contain a wealth of facts and views which only to a limited extent can be included in the following review.

Other work has been carried out at Oslo University. For their final examination (to obtain the title of *cand. real.*) the graduate students of botany have to present a thesis which is the result of 2-3 years' research work. Some of these investigations have given valuable results which either have been published or will be published (Aandstad, Eidem, Johnsen, Eiklid, Slåstad, Damsgård), and most of the botanists in question have continued their research work in this field after leaving the University.

Finally, since 1950 the Norwegian Research Council for Science and the Humanities has supported research in this field, by paying the salaries of part-time or whole-time research workers as well as contingencies, and by providing a measuring apparatus of the type constructed at the Swedish Forest Research Institute (described by Eklund 1949).

In a few cases material from Norway has been treated by non-Norwegians (Douglass 1919; De Geer 1938, 1939; Schove 1954). A review of some of the earlier work in Scandinavia was given by Schulman (1944).

The growth-ring research in Norway was started with the ultimate purposes of (1) solving problems of practical forestry, (2) dendrochronological dating of buildings, and (3) analysis of long growth-ring index series with a view to climatic cycles (if any) and the possibility of climatic prognosis.

However, a number of other problems have had to be taken up first, both because they were necessary to provide the basis for attacking the said main problems and because they are interesting in themselves. This basic work is partly concerned with the methods employed in growth-ring research and partly with the various factors influencing the radial growth, particularly the connection between growth and climatic factors.

Till now, practically all investigations published in Norway deal with conifers, of which only two species are of any importance in this country: Norway spruce (*Picea abies*) and Scotch pine (*Pinus silvestris*). There are some unpublished investigations by Ruden on birch (*Betula,* chiefly *B.verrucosa*). An investigation rather different from the others was carried out at the Norwegian College of Agriculture, Horticulture, and Silviculture (by Ljones and Nesdal 1954) on apple trees, showing the correlation between radial growth and fruit yield.

METHODS

Sampling. When possible, discs of stems are used for measuring growth rings, but they are not always available. To obtain them from living material one has to depend on felling. In buildings discs are, as a rule, not obtainable at all. Therefore we have to a large extent used cores taken by means of a Pressler's increment borer (length up to 25 cm).

In timber houses of the traditional Norwegian construction it is important to take the samples in places where the logs have not been cut by axe so that the outermost growth rings have been removed. As the timber has often been flattened on the vertical sides, this means that one has to bore obliquely from above or below, at angles approximately 45° to the vertical. In this position the handle of the sampler is usually obstructed by the log above or below. To avoid this difficulty we use a borer in which (on Slåstad's suggestion) the bit has been lengthened by means of an extra piece.

The cores are kept in rolls of corrugated cardboard. Samples from old buildings are fragile and have to be handled with great care to avoid breaking.

Measuring. In the earlier investigations most of the measuring was carried out by means of a lens furnished with a scale divided into 1/10 mm (as regards the measuring by means of proportional compass, see Ording 1941a: 133). Later a measuring apparatus of the type described by Eklund has been used, by which the work is done quickly and the risk of errors is greatly reduced.

Before measuring takes place the surface of the sample has to be planed by means of a sharp razor at right angle to the direction of the fibres. Particularly in old material from houses it is important to cut from the surface inwards, because otherwise the outermost annual rings may be torn out.

In stems of slow growth it may be difficult to see the annual rings. They become more clearly visible if (as suggested by Ruden) a white paint is applied to the smoothed, moistened surface and then wiped off with the finger, only very small amounts of it thus remaining in the pores.

In most cases the growth rings in the innermost two centimeters nearest to the pith have not been measured.

Measurements along two or more radii; radial and vertical uniformity. Although the idea of radial and vertical uniformity has been universally recognized as a general rule, some of the Norwegian workers have tested its validity on the basis of their own material (Ording 1941a:125, 314, and others). Among the results only the following ones may be mentioned here:

Eidem (1953:16, 140), in a disc of spruce from Tydal, measured the widths of the growth rings for the years 1818-1821 along 42 radii drawn at equal distances in all directions. Along some of the radii the ring for 1818 was broader than that for 1819, along other radii it was narrower. This shows that one should not attribute too much importance to individual variations in a small material. Eidem (1953:18, 140) also measured the ring-widths for 65 years (1867-1931) along 10 radii in a section of spruce from Selbu. Mean values were computed on the basis of 2, 3, 5, and 10 radii, and each of the mean series was corrected and standardized in the usual way. Correction and standardization were also carried out for each of the 10 radii individually. All index-series thus obtained were compared to the standard series for spruce from the same district for the same period, by calculating (1) the correlation coefficients and (2) the trend coefficients (percentage similarity) (Tab. 1). Trend coefficients as well as correlation coefficients show that measurements along a single radius are less reliable than means of measurements along two or more radii. As a rule, two or three radii will suffice, but much depends on the nature of the material.

Table 1. Correlation coefficients and trend coefficients (in per cent) between the standard index series for *Picea abies* in Selbu for 1867-1931 and corrected and standardized measurements along 10 different radii on a disc of the same species in the same district, as well as means computed from 2, 3, 5, and 10 of the radii. Adapted from Eidem (1953:19).

Number of radii	*Correlation coefficients*	*Trend coefficients, %*
10	0.62	81
5	0.66	82
3	0.51	81
2	0.68	80
1	0.47	72
1	0.59	77
1	0.50	76
1	0.67	83
1	0.54	73
1	0.48	75
1	0.73	76
1	0.74	78
1	0.19	76
1	0.31	73

It has been pointed out (Ording 1941a:129, 315) that it is better to measure a greater number of stems with one radius or a few radii in each, than to measure many radii in few stems. The former alternative has a better chance to reflect in a reliable way the influence of the climate upon the radial growth.

Most Norwegian botanists have preferred to measure along two radii in each stem, not only because the means of two measurements are far more reliable than measurements along only one radius, but also because the comparison of the two sets of measurements means a reciprocal check. By several authors the checking has been done by plotting the two sets of measurements above each other on graph paper. Any striking discrepancy in the trends of the curves then indicates that there may be something wrong; for instance, in one of the radii a false growth ring may have been mistaken for a real one, or (what is more frequent in Norwegian material) two very narrow growth rings have been counted as one.

In order to facilitate the computation of means of two sets of measurements Slåstad has used a simple nomogram. He writes three vertical columns of figures with equal distances between them. In all of them the same numbers, for instance 100, 101, and so on, are on the same level. If a certain growth ring has been found to be 85/100 mm wide in one radius and 105/100 in the other, a ruler is placed on 85 in the left-hand column and on 105 in the right-hand one. The ruler then crosses the middle column at 95, which is the mean.

Standardization; correction for the effect of age; computation of mean index-series. All Norwegian authors in the field of growth-ring analysis and dendrochronology have agreed that standardization and correction for the effect of age is necessary before the material is used for the study of the relation between climate and growth, or for crossdatings. However, the methods employed have been rather varied, and only lately has a certain uniformity been reached.

For the correction for the effect of age various methods have been recommended (see particularly Aandstad 1938a: 207; Ording 1941a: 137, 316; Ruden 1945: 196, 257; Eidem 1953: 26, 141). The method most commonly used, however, is the one first proposed by Douglass, viz., by plotting the measurements, or means, on graph paper, drawing a standardizing line following the general trend of the curve, and expressing the width of a growth ring as the departure from the standardizing line. When drawing the line it is possible at the same time to eliminate, wholly or partly, the effect of environmental changes like the felling of neighboring trees, but great care has to be taken so as not to lose the fluctuations due to climatic factors. The method contains a subjective element, but it works well, it is simple, and in the Norwegian forests, where the growth of the trees often shows the effects of environmental changes, it is no doubt better than any strictly mathematical method. A material so treated shows well the short-range variations, which are the most important ones for the purpose of analyzing the connection between growth and climatic factors and for dendrochronological purposes. However, the long-range variations are mostly lost and the material after the treatment cannot be used for the study of long climatic cycles.

For graphic representation of the material Ruden (1945: 215, 260) recommends the use of a logarithmic scale. This was first introduced into growth-ring work by Huber in 1943, but Ruden (l.c.) also gives the mathematical justification. It is based on the fact (which Ruden has proved on an extensive material; see Ruden 1945: 211) that the size of the variation is proportional to the mean width of the growth rings. If the width of one growth ring is a, that of another is a_n and the ratio between them $a_n/a = f$, then the difference, if represented in an ordinary linear scale, is:

$$a_n - a = af - a = a\ (f - 1)$$

Consequently the difference is proportional to a.
With the use of logarithms the difference is:

$$\log a_n - \log a = \log\ (af) - \log a = \log f$$

That is, the difference is independent of a and proportional only to f. Consequently, in a graphic representation of the logarithms instead of the actual measurements, the difference between any two neighboring growth rings depends on the proportion between the widths and not on their absolute values.

In later Norwegian growth-ring literature graph paper with logarithmic scale has been commonly used.

It has been common to standardize the indexes by expressing the width of each growth ring in per cent of the average width for each stem or each small group of a uniform material. Ruden (1945:223, 261) has shown that in spite of such standardization two overlapping series of different lengths or comprising different periods may not be fully comparable, due to the long-range variations. If, for instance, a series has been standardized on the assumption that (1) the mean index for the years 1881 - 1910 is = 100, or (2) that the mean index for 1901 - 1930 is = 100, the indexes for the period 1901 - 1910 may turn out to be different from each other in the two cases (see Ruden 1945:224, Table 6). He has therefore proposed that the period 1901 - 1930 should be used as a standard period and all index series be multiplied by a factor making the mean 1901 - 1930 = 100.

Some authors have investigated to what degree the value of an index-series increases with increasing number of trees on which it is based. Ording (1941a:151, 317) found that 5 or 6 trees may suffice to give a very reliable picture of the growth-ring variation due to climatic factors.

Eidem (1953:12) compared his standard series for spruce from Selbu with three different series from the same district. These three series consisted, respectively, of 10, 10, and 28 trees, and comprised the years 1867 - 1931. For each of them he calculated the correlation coefficient as well as the trend coefficient between the standard series and each single tree, and between the standard series and the mean of two trees, the mean of three trees, and so on. The coefficients, that is, the reliability, increased distinctly with increasing number of trees. Also he arrived at the conclusion that on the whole 6 to 8 trees suffice to give a reliable result, but that much depends on the nature of the material.

Eidem (1953) has introduced the use of exponents in his tables of index-series to indicate the number of trees on which the series is based from a certain year onwards. The exponent is printed only at the year in which the number changes.

When two or more index-series are combined in order to establish a standard series it is important to introduce certain corrections if the series are of different lengths or consist of different numbers of trees. Ruden (1945:223, 261) first pointed out that without such corrections serious errors may be introduced, and other authors have also discussed this point (Eidem 1953:28, 142; Slåstad).

An example from Eidem (1953, Tab. 3) may be mentioned. It is based on his studies on spruce in Selbu and comprised the years 1553 - 1560. The material consisted of three series, from localities which may be called A, B, and C, of different lengths and different sizes, that is, based on different numbers of trees (8, 1, and 1 respectively). The last column in

Table 2. Example of the combination of index-series of different sizes and different lengths. The exponents indicate the number of trees on which each series is based. Adapted from Eidem (1953:29).

Year	*Locality*			*Series means*		
	A	B	C	*Uncorrected*	*Corrected for size*	*Corrected for size and length*
1560	135^{8}	175^{1}	150^{1}	153	141	141
1559	105	200	200	168	124	124
1558	110	250		180	126	135
1557	95	200		148	107	116

the table reproduced here (Tab. 2) gives the combined series calculated with due corrections. The figures have been obtained thus:

$$\text{For the year 1560: } \frac{8 \times 135 + 175 + 150}{10} = \frac{1405}{10} = 141.$$

$$\text{For the year 1559: } \frac{8 \times 105 + 200 + 200}{10} = \frac{1240}{10} = 124.$$

For the year 1558 the index, if calculated in the same manner, would be 125. However, this would be wrong, because locality C here drops out. The correct index for 1558 should be of such proportion to the index for 1559 that it reflects the growth-ring variation in the two localities A and B, which are the only ones in which these two years can be compared. The necessary correction may be obtained thus:

$$\frac{8 \times 110 + 250}{8 \times 105 + 200} \times 124 = 135.$$

For the preceding years the indices have to be given the same corrections.

Comparison between two index series, or between an index-series and, for instance, a series of meteorological data, is in Norwegian literature always based on mathematical calculations. "Skeleton plots" and "constellation systems" have practically never been used. "Percentage similarity" (trend coefficient, cf. Huber's "Gegenläufigkeitsprozenten") has been used to a very slight extent (for instance, Aandstad 1934, Ruden 1945:247, Eidem 1943, 1953:12, 87). The value of some of these methods with a special view to Norwegian material has been discussed in detail by Ording (1941a: 279, 325; 1944:89) and Ruden (1945:227, 255). In crossdatings ocular comparison between curves is regarded as a useful help in many cases, but is always tested mathematically.

The reliability of the ocular crossdating was tested by Ording (1941a:333) in an experiment, in which 10 persons, all of whom beforehand possessed a considerable practice in the treatment and evaluation of graphs, each received a standard scale comprising 500 growth years and 3 curves of 50 years each. The 10 persons were asked, independently of each other, to try to crossdate the short curves on the standard scale. Ording's conclusions were that with a very high correlation between the standard scale and the cross-identification curve it is possible to carry through an ocular dating of considerable significance. Such high correlations, however, cannot be expected except between growth curves from identical or closely related tree-species within one and the same climatic region. Reliable crossdatings over longer distances, or from one species to another, were found to be difficult or impossible.

In order to obtain a numerical expression of the degree of correlation between two index-series, Ording (1941a) has introduced into Norwegian growth-ring work the use of correlation coefficients computed by means of the usual formula for product moments. For crossdatings he stressed the importance of using only a small portion of the series to be dated for a tentative, ocular comparison, and then checking the obtained result by using the rest of the series for calculation of the correlation coefficient.

Ruden (1945:230, 262), though agreeing with Ording, has improved his methods by introducing the calculation of the correlation between the 2nd order differences (l.c., p 262). This has proved to be extremely valuable. It gives a mathematical expression of the degree of similarity between two series with regard to the variations from year to year. No hard and fast rules can be laid down about what numerical values the coefficients should have if a dating is to be regarded as proved. Tentatively, Ruden (1945:265) suggests that the following values of the correlation coefficients for the numbers themselves and for the 2nd order differences may be regarded as significant:

For a number of index pairs equalling 25: one of the correlation coefficients should exceed 0.75 or both exceed 0.65.

For a number of index pairs equalling 50: one of the correlation coefficients should exceed 0.60 or both should exceed 0.55.

For a number of index pairs equalling 100: one of the correlation coefficients should exceed 0.40 or both should exceed 0.45.

These figures are given on the assumption that the parts of the series used in the computation of the coefficients are not identical with those on which the tentative dating was carried out.

The use of mathematical methods is a characteristic feature of Norwegian growth-ring research. It involves a very great amount of work in order to give statistically reliable results. For instance, Eidem's work in 1953 was based on about 182,000 measurements of nearly 62,500 different rings, and every measurement was followed by a number of arithmetical operations. However, in view of the nature of the Norwegian tree material it is felt that this is the only way to obtain reliable results.

FACTORS INFLUENCING THE WIDTH OF GROWTH RINGS IN NORWAY

Specific differences; flowering; seeding. Norway spruce and Scotch pine, the two species on which practically all growth-ring research in Norway has been based, in most cases respond in the same way to external factors. Under certain circumstances, however, the response has been found to be different. The question has been treated by several authors.

Ording (1941a:206, 319), for instance, compared the growth of spruce and pine in forests in the southeastern lowlands of Norway. He found that on the whole their radial growth varied identically, warm summers giving broad growth rings in both. In some summers, however, there was a marked discrepancy. A careful analysis showed that this probably was connected with the fact that spruce has a greater ability than pine to take advantage of a high temperature in the early part of the growth season, probably because the spruce already then has got new shoots capable of assimilation, while the new shoots in pine develop later. On the other hand the growth in pine is more influenced by a preceding warm summer, probably because in a warm summer the number of needles increases proportionally more in pine than in spruce; in pine about ⅓ of the total number of needles is renewed every year, while in spruce the needles remain on the tree for approximately 7 or 8 years, and consequently a year with long shoots and many needles (and long needles, as shown by Hesselman 1904, Kolmodin 1935) has a greater influence on the total assimilatory apparatus in pine than in spruce. Thus, if a warm summer is followed by a year of cold spring and medium summer, the pine may produce a broad growth ring, while that in spruce may be narrow. Therefore (and also for other reasons) the maxima and minima may sometimes fall in different years in spruce and pine in one and the same forest.

Flowering is another factor affecting the radial growth. It does so differently in the two species.

The fact that a year of intensive flowering, or seed production, may result in a narrow growth ring has been mentioned by various authors. In Norwegian literature, see particularly Eide (1926: 93), Ording (1941a: 273; 1944: 70), Mork (1942), Ruden (1945: 207, 260), and Ljones & Nesdal (1954, on apple trees).

As a striking example of the mutual effect of a climatic factor and seeding on the radial growth the following case may be mentioned. Slåstad studied pine in high elevations along the valley of Gudbrandsdal. From two localities his graphs showed, on the whole, a very good correlation with the temperature in June and July. In 1901 the summer was exceptionally warm and the growth rings wide. The next year was cold and the growth rings narrow, although not so narrow as one might have expected, probably owing to the previous favorable year. 1903 brought another fairly warm summer, but in spite of that the growth rings of that year were narrower than those of 1902. The explanation, as Slåstad points out, may be that as a result of the warm summer in 1901 the trees flowered in 1902, and the production of seeds in 1903 cost so much that there was not enough left for the growth of the trunk. The same happened in the years 1914 - 1915 - 1916.

Since the seeds of pine ripen in the year after the year of flowering, while in spruce they ripen in the same year, the effect of flowering and seed production on the radial growth will be different in the two species.

In the year 1954 the flowering and seed production in spruce in Norway were exceptionally intensive. The effect on the growth rings is now being studied in the Norwegian Forest Research Institute, but the results have not yet been published.

Soil humidity; nutrition; insects. Changes in edaphic factors like humidity and pH in the soil affect the radial growth of trees. In most cases, however, these factors are of no great importance in the material on which growth-ring analysis and dendrochronology are based in Norway.

As regards the effect of the nutrition on the radial growth a few very special cases may be worth mention.

In Norway some experiments have lately been carried out with nitrogen fertilizer in forests, giving distinct results on poor soils (Berg 1952, 1953). For instance, pine on sandy ground showed a very marked increase in growth besides much better reproduction. Full reports on the experiments have not yet been published.

The following case has also recently been studied in detail. In the narrow, deep valley Vestfjorddalen, at Rjukan, a big nitrate factory belonging to the Norsk Hydro-Elektrisk Kvelstof A/S started in 1911, and since then there has been a continuous and inevitable leakage of gases containing nitrogen in the form of NH_3 and HNO_3. In this valley the luxuriant growth of the trees, particularly the birches, is very striking. Recently foresters have made a careful survey of the growth of spruce, and a certain effect on the radial increase has been proved beyond doubt (Strand 1950).

The effect of an insect attack on oak was demonstrated by Ording (1931).

Light. Increasing density of a stand gives less light to the dominated trees and therefore a slow decrease in growth, while cutting or wind-felling of a big tree gives immediately much better conditions to the remaining neighboring trees.

In the Norwegian forests timber cutting is a far more important cause of improvement in the light conditions than wind-felling and other natural changes and often has a greater effect on the radial growth than annual fluctuations of temperature and precipitation. For centuries the cutting of trees has been going on in most parts of the country and there are few forests that can be regarded as untouched by human activity. Usually the effect is local, but it may also, in certain years, be regional, especially in years when the state of the market has made it profitable to cut timber all over the country. The reaction to cutting sometimes makes it difficult to utilize the material for the determination of periodical variations, and it may make crossdating unsafe. When studying the growth rings in Scandinavian forests for the purpose of judging the effect of climate on growth, one must be aware of this source of error, which is greater here than in many other parts of the world.

Fortunately it is often possible from the characteristic form of the growth curve to recognize the effect of cutting. If a tree is suddenly exposed to more light its growth often first shows a slight decrease, followed by an increase which usually is very great. It reaches its maximum in the second or third or even fourth year, with a very slow decrease afterwards.

When correcting the growth curve for the effect of age by the method mentioned above (by means of a standardizing line drawn by freehand) it is often possible to eliminate the effect of cutting.

Temperature. In Veldre, Hedmark, eastern Norway (about 110 km north of Oslo), Eide (1926) studied the radial growth of 1243 spruce trees and found that in the years 1906-1922, on which his investigation was based, the growth followed the summer temperature. This correlation was found in the whole material, whether the trees were old or young or growing under different edaphic conditions. There was an exception for the year 1915. This year was cold, but gave a fairly broad growth ring. Eide explained this as the aftereffect of the warm year 1914, which enabled the trees to store large quantities of food; however, the long shoots and the great number of needles developed in 1914 may also have had some influence on the growth in 1915.

Ording (1941a:208, 319) made a very careful study of the growth of spruce and pine in Eidsvoll (about 50 km north of Oslo) and found in both species an increased growth in warm summers. It seemed, however, that a warm summer had a somewhat greater effect on the following summer's growth in pine than in spruce, and that the spruce was better able to utilize a warm period in early spring.

Other workers (Aandstad 1934; Eidem 1943, 1953; Slåstad) have also found a correlation between summer temperature and growth. This correlation doubtless exists in by far the greater part of Norway.

Slåstad arrived at some interesting results in the upper part of the valley of Gudbrandsdalen. While the growth in the bottom of the valley was influenced by the rainfall (see below), he found a very high correlation between temperature and growth in pine on the sides of the valley, in altitudes up to 930 m, that is, up towards the timber-line. Summer is short in this elevation, and starts late. This explains why he found the best correlation between the growth and the temperature when the temperature factor was calculated from the temperature of the last half of June and the whole of July.

Precipitation. In Norway all earlier investigations showed a high degree of correlation between summer temperature and radial growth in pine as well as in spruce. They were, however, carried out in parts of the country where rainfall is fairly abundant and more or less evenly distributed throughout the year, and where the temperature is the minimum factor, as is the case in the greatest part of the country.

Recently conditions in drier districts have also been studied, and as might be expected the precipitation was found to have a great influence on the width of the growth rings. None of these investigations has been published so far, but they may be briefly reviewed here.

Ruden studied spruce (130 trees) on islands of calcareous rock in the innermost part of the Oslo Fjord as well as on acid, hard rocks in the vicinity (33 + 30 trees). He found a good correlation between the three localities and between them and the summer rainfall.

Slåstad studied pine and spruce in the upper part of the valley of Gudbrandsdalen, which is one of the driest parts of the country. In the highest districts, Lom, Vågå, and Lesja, the annual precipitation is only about 300 mm, and farming is dependent on irrigation. Slåstad found that while the forests near the upper tree limit showed a very distinct relation between growth and summer temperature (as just mentioned) and were very homogeneous, the trees, and forests, in the lower parts of the sides of the valley, and in the bottom of it, reacted differently and offered a heterogeneous picture. Some of them behaved like the mountain forests, evidently because they got moisture enough from melting water coming down from the mountains. Other groups of trees showed a distinct dependence on the rainfall. For instance, the summers were very warm in the years 1901, 1914, 1925, 1933, 1941, and 1945. In one place only one of these years, viz. 1945, gave a maximum of growth; that year was not only warm, but also wet. The other years mentioned gave narrow growth rings, no doubt because there was not rainfall enough. Slåstad was able to show that in some places the temperature was the minimum factor in some years and rainfall in others.

Also along the southeastern coast (along the Skager Rack) the climate is dry, especially in the early part of the summer. Here Damsgård studied the growth of pine and found that it varied from year to year according to the summer rainfall. He even found this positive correlation in pine growing in bogs, which may appear surprising. However, as Damsgård points out, trees growing in such localities generally have very shallow root systems so that they may be just as sensitive to drought as trees growing in well-drained soil.

MISSING RINGS; DOUBLE RINGS; LATE-WOOD PERCENTAGE; RESIN CANALS

Missing rings and rings that are so poorly developed that they consist of no more than three cell layers are evidently much less common than in trees in certain parts of the U.S.A. However, they do sometimes occur, probably as a result of extremely unfavorable growth conditions (see, for instance, Ruden 1945:208; Eidem 1953:20,140; Damsgård).

"False", or "double", growth rings, for which Dobbs has recently given reasons to use the noncommittal term "lines", have been mentioned rarely in Norwegian literature published so far. However, they do occur, at least in the southeastern part of the country.

Ruden carried out a series of investigations (also referred to above) in the neighborhood of Oslo. The results were communicated in a paper read to the Norwegian Academy of Science and Letters in December 1954, but only a brief abstract has been printed. He found lines of frequent occurrence in dry localities. There was a high correlation between numbers of lines in two different localities on two islands near Oslo (13 and 17 trees). The position of the lines in the various growth rings (far out or in the middle or far in) seemed to be more or less the same for each particular year in the various stems. This fact, in Ruden's opinion, gives us a hope that we may be able to find in Norway something similar to what Dobbs has found in Britain (in larch), namely, that the position of the line corresponds to a dry period during the growth season.

Along the south coast, where the early part of the summer usually is dry, Damsgård also met with double rings, more or less well developed. Slåstad, however, did not come across them at all in the continental parts of the country, in Gudbrandsdalen.

Eidem (1953:21) has reported that indications of lines may be found in spruce as well as in pine in Trøndelag, but only as an extremely rare case. The line, if found at all, was always developed in only a part of the growth ring.

In the series of investigations just mentioned Ruden has also studied the variations of the following two growth-ring characters in spruce:

(1) Resin ducts. Ruden counted the number of resin ducts found per millimeter tangential length of the various growth rings and found that the variations in their number from year to year showed a high degree of correlation between the various localities (calcareous islands and forests on hard rock in the vicinity). He also found a good correlation between the number of resin ducts and the summer temperature.

(2) Late-wood percentage. There is a high positive correlation with the rainfall in July (while Ruden found that the absolute width of the growth ring in the same locality depends on the whole summer rainfall).

Ruden has pointed out that these three characters (absolute width, number of resin ducts, and late-wood percentage) follow three different climatic features, viz., respectively, summer rainfall, summer temperature, and July rainfall. They are therefore more or less independent of each other and it is possible that two of them may be used for checking a crossdating based on the third, and that they may throw a more varied light on climatic conditions in the past than the growth-ring width alone can do.

STANDARD INDEX-SERIES

One of the aims of the Norwegian growth-ring research has been to establish standard index-series which can be used, on one side, for dendrochronological datings, and on the other side, for analyses of the variation of climatic factors. Some of the series published so far are:

Northern Norway. Steigen and Sørfold (c. 67° 35′). *Pinus silvestris.* The oldest growth ring measured is from 1396; from 1465 onwards the series is based on 6 or more trees (Ording 1941a: 301, 305-6; cf. also Aandstad 1938b).

Trøndelag. *Picea abies.* The oldest ring measured is from 1424; from 1520 onwards the series is based on 6 trees or more. In *Pinus silvestris,* the corresponding years are 1461 and 1509. In addition there is a floating chronology of approximately 370 years, which there is good hope of dating finally, thus bringing the series back to the 10th century (Eidem 1953: 68,74).

Southeastern Norway. Various series have been published by Ording (1941a) and others. The longest series is from Flesberg near Kongsberg, for *Pinus silvestris.* The oldest ring measured is from 1383. From 1394 onwards the series is based on two beams, and from 1520 onwards on a large material (Eidem, unpublished). Among floating chronologies a very interesting one is based on 100 logs (6,662 measurements, 3,331 growth rings) of *Pinus silvestris* from a 10th century mound, Raknehaugen; all the trees were rather young and, with a few exceptions, felled in the same year, so that the series is short, about 50 years, but the crossdating fully reliable (Ording 1941b).

For the practical work it is important to know to what extent beams from one part of the country can be crossdated by means of a standard series from another district. In view of the very great climatic variation within the country—from west to east, from the interior to the coast—all Norwegian investigators have found it necessary to adopt a cautious attitude toward the idea of teleconnections even within Scandinavia, not to speak of transcontinental ones (for a critical analysis of the dating of a small Norwegian material by comparison with the growth curve of *Sequoia gigantea,* see Ording 1941a: 293, 338). However, recent experiences have given at least some ideas of the validity and limitations of the various standard series and the correlation between those of the various parts of the country.

Thus, in the Trondheim area Eidem (1953: 61, 143) found that one standard series is valid for the whole area with exception of the districts nearest to the sea. Farther north, in the cases that have been tested, the growth curves follow that of the Trøndelag area rather closely, although the covariation is not complete (Ording 1941a: 202, 342).

The eastern part of south Norway is evidently fairly homogeneous and there is also a high degree of correlation with the Trondheim area (Eidem 1955). However, the dry upper parts of the valley of Gudbrandsdalen have an entirely different variation, and the south coast also follows a separate pattern.

In the western part of the country, south of Trøndelag, practically no growth-ring research has been carried out.

DENDROCHRONOLOGICAL DATING OF BUILDINGS

The basic work carried out so far has shown us in what parts of the country the dendrochronological method of dating old building material is reliable and where it is not. In those parts of the country where the rainfall and temperature may irregularly alternate as the decisive factor from year to year and from locality to locality there is only slight hope of being able to use the method with success. In most other parts of the country, however, it works well.

The extension of the growth-ring series backwards in time has been possible only by supplementing the material from living trees with beams from old buildings in the same district. In that way a number of houses have been dated, but most of them are only locally of interest.

However, the foundations have been laid for taking up also more important chronological problems. Thus, Eidem has been able to date various buildings in the Trondheim area and near Kongsberg. In spite of the scarcity of available material from the 15th and 14th centuries there is good hope that it will be possible to extend the work so far back as to include the very characteristic wooden churches called *"stavkirker"* of medieval age.

CYCLES

As in many other countries the earlier workers in growth-ring research in Norway mostly analyzed their material for periodic cycles. To a certain extent this has also been done in recent publications (for instance, Aandstad 1934: 141; Ording 1941a: 227, 321; Ruden 1945: 231; Eidem 1953: 85, 136). Cycles of 3, 5, and 11 years are among those found.

Lately, however, this line of research has not been followed up, chiefly because other problems have seemed more immediately important, but also because cycle analysis would necessitate a mathematical treatment of the material different from the one that is used.

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TREE-RING RESEARCH IN FINLAND

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Studies on variation in the width of tree-rings and on its causes were initiated in Finland by Laitakari (16) in his "Studies on the effect of weather conditions on the height and diameter growth of Scotch pine." His material comprised 322 pine trees from southern Finland and the width of all annual rings was measured. The age of the trees was about 100 years. In order to find out the relationship between height growth and climatic factors the annual shoots of 360 young pines were measured, as far back as possible. Laitakari discovered, as Hesselman (4, 5) did previously in Sweden, that height and diameter growth are different in their relation to climatic factors. The annual height growth depends distinctly on the temperature of the late summer of the preceding year. The width of the annual ring, on the other hand, is dependent, according to Laitakari, on the spring temperature of the current year. Between precipitation and tree growth no correlation could be found.

Laitakari studied also, following the example of Douglass in America, whether any periodicity could be found in the variation of tree growth. According to him, an 11-year cycle exists and the maxima and, minima of diameter growth coincide with the maxima and minima of the sunspot cycles.

Boman's (1) paper, "Studies on the variations of the radial growth of pine", published in Finnish, treated mainly of cycles of different length in the growth of Scotch pine. His material, 230 trees, originated from all parts of Finland and the oldest trees were over 300 years. Boman reported several cycles and he tried to determine their length and amplitude. According to Boman, the lengths of the cycles are 7, 11, 21, 35, and 70 years, and probably there exists even a cycle of 105 years. The causes of these cycles were not discussed.

After the above-mentioned preliminary investigations the Finnish tree-ring research has proceeded along two main lines. Foresters have been interested in the relation of tree growth to different climatic factors, and in the practical significance of growth variations (Mikola). Plant geographers, on the other hand, have studied the recent fluctuation of climate and its effect on vegetation, e.g. on the diameter growth of trees (Hustich). Besides watching diameter growth, the variations of height growth, needle length, flowering, and reproduction have been studied, as well as their relationship to climatic factors. Dendrochronological dating has not been practiced in Finland.

The studies of Laitakari and Boman have shown considerable variation occurring in the growth of pine. Furthermore, it was apparent that, in order to determine the magnitude and practical significance of growth variation, an extensive research material would be required. Because practical growth estimates are always based on a measurement of the total radial growth of several (5 or 10) years, the results depend greatly on eventual favorable or unfavorable periods preceding the year of measuring. Thus, for instance, the effect of thinning cannot be studied by comparing only the width of annual rings before and after thinning, unless the growth fluctuation in unthinned stands is known at the time. The first nation-wide forest survey was performed in Finland in 1922-1923. The preceding years seemed to be exceptionally favorable for the growth of pine and thus the reported annual increment of pine was probably too high. The second national forest survey was carried out in 1936-1938. In order to eliminate the effect of climatic fluctuation when comparing the results of the first and second survey, a large material was collected in the second survey. This material comprised annual ring analyses of 1757 pines and 884 spruces from all parts of Finland. The samples were taken with the increment borer at breast height.

Because of war-time difficulties, this vast material was given to the Swedish Forest Research Institute, where Eklund (2) performed its final treatment and published a paper called "An experiment to estimate numerically the effect of climate on the radial growth of pine and spruce in the two Finnish national forest surveys" (in Swedish). The same material or parts of it has been used as a starting point in several later tree-ring investigations. Eklund studied only the 50-year period of 1887-1936 and calculated for each year a so-called annual ring index, separately for pine and spruce and for South and North Finland.

According to Eklund (2) and Ilvessalo (15), during the 10 years' period preceding the first national forest survey the diameter growth of pine was on a considerably higher level than before the second survey. Regarding spruce the available material is much smaller; the result, however, shows that the growth of spruce was during the second survey lower in North Finland but higher in South Finland than during the first survey (Table 1). Because fluctuation in the general level of growth is so large, a new material was also collected in the third national forest survey in 1951-53, in order to correct the measured growth to normal climate. The results have not yet been published.

Table 1. The average diameter growth of Scotch pine and Norway spruce during the 10-year periods preceding the first (1922-1923) and second (1936-1938) national forest surveys (normal level = 100).

	Pine		*Spruce*	
	1st survey	*2nd survey*	*1st survey*	*2nd survey*
South Finland	109.0	94.9	97.2	98.6
North Finland	106.8	97.2	106.2	98.6

Mikola (17), when studying growth variations, used partly the same basic material as Ilvessalo and Eklund. To supplement it, in 1942-43, 755 trees were sampled, part of them in Soviet Carelia, and an additional 3200 sample trees in 1945-46. Thus his material exceeded 6500 trees, of which 2000 were spruce and 4500 pine; and more than 700,000 individual rings were measured accurately to 0.01 mm. Based on this large material, annual ring indices were calculated for pine and spruce and also for different parts of Finland. Most series go back to 1800 or 1750; some of them are even longer. Later on, Nyyssönen (20) gathered new material and built up an index-series that agrees with the indices by Mikola conspicuously well.

Mikola (17) has also tested in his material the occurrence of cycles reported by Ording (21) in Norway. Most distinct seemed to be the 23-year cycle, but cycles of 11, 17, and 35 years, too, could be traced in the growth of pine. In the growth of spruce the cycles were more obscure, and the cycle of 11 years could not be found at all.

In recent Finnish research little attention is paid to the eventual cycles in growth fluctuation. On the other hand, the effect of climatic changes on tree growth as well as on other phenomena in fauna and vegetation, especially along the northern timber-line, has been the subject of several investigations.

During the first decades of this century the prevailing opinion was that the northern timber-line was receding, due to unfavorable climatic development. This idea was based on the lack of young seedlings in the timber-line region as well as on the occurrence of subfossil pine remnants above the present timber-line. Later on, however, meteorologists showed that the annual mean temperature has been generally increasing in northern Scandinavia. In the 1920's and 1930's plenty of pine seedlings appeared along the Scandinavian timber-line. The studies of Hustich (6, 7, 8, 9, 10, 14) and Mikola (18, 19) showed that the diameter growth of pine increased considerably from 1910 until the 1930's. Hustich used the material of the national forest survey from northernmost Finland, and, to supplement it, he gathered annual ring series of several hundred pines along the timber-line.

According to these northern studies, the diameter growth of trees depends closely on the temperature of the growing season. A clear correlation exists between the diameter growth of pine and the July temperature. Towards the south, the correlation weakens. Mikola (17) confirmed the previous observation made by Ording (21) in Norway, that the diameter growth of pine depends mainly on the temperature of the late season (July) while that of spruce is more dependent on the temperature of early summer (June). Therefore the correlation between index-series of pine and spruce is rather weak. Mikola studied also the effect of climatic conditions on the formation of different components of the annual ring, early and late wood. Thus, variations in the width of early wood are much smaller than in the width of late wood. The late wood is the broader, both absolutely and relatively, the earlier the growth commences in the spring and the higher the temperature is of middle and late summer.

The studies of Hustich and Mikola confirmed the previous results of Hesselman (4) and Laitakari (16) that the height growth of pine depends mainly on the temperature of the preceding summer. Hustich (11) stresses especially the difference that in this respect occurs between humid and arid climates. In an arid climate both height and diameter growth depend on weather conditions of the same year; in a humid and cold climate on conditions of different years.

In Finland no correlation has been found between precipitation and diameter growth of trees. Since in central Europe, however, the growth of trees is evidently proportional to precipitation, the moisture may exert some influence in Finland, too, but its significance is hard to ascertain because the rainfall and the temperature of the growing season are usually more or less inversely proportional. Indeed, when examining tree-ring analyses, it is noticeable that very dry summers have been unfavorable to tree growth on the driest sites, just as very rainy summers on wet peatlands (17). In general, however, growth variations are rather uniform, independently of the site.

In the tree-ring studies of the timber-line region the large variation in the width of the annual rings is of special interest. As Hustich (11) stresses in particular, variation is largest where the growth is determined mainly by one varying factor, as by temperature on the northern timber-line or by moisture in the transitional zones between forest and steppe. When going from the north to the south, the variation gets smaller. To express the extent of variations Hustich (11) uses the variation coefficient that he calls "climatic hazard coefficient", and Mikola (17) has calculated mean sensitivities according to Douglass. The figures below show the average extent of variations in Finland.

	Climatic hazard coefficient (Hustich)	*Mean sensitivity (Mikola)*
Pine		
Northern timber-line	31 %	0.22
North Finland	23 %	0.15
South Finland	18 %	0.12
Spruce		
North Finland	20 %	0.18
South Finland	12 %	0.15

Hustich (9, 11) compared also the variations of agricultural crops in Finland and noticed a parallel development, as when moving in Finland from the north to the south or in America from a maritime to an arid climate.

Climatic variations in pine growth on the polar timber-line are often accentuated by extensive frost injuries, as is demonstrated by Mikola (18). A prolonged growth depression, such as occurred in northern Scandinavia in 1903-1911, may be due to one single year of heavy frosts. Corresponding depression in spruce growth does not exist, and therefore the growth improvement of spruce in 1911-1930 is not so steep as that of pine. Mikola's tree-ring analyses include also growth depressions, both in pine and in spruce, that probably result from damage caused by insects or fungi.

Finland is climatically a rather uniform area without high mountains, and accordingly a close correlation exists between tree-ring index-series from different parts of the country (Table 2). The only exception is the northern timber-line region (between 68° and 70° latitude) where variations are considerably larger than elsewhere. On the other hand, correlation between index-series from different parts of the Scandinavian timber-line, as those by Hus[illegible] (8) and Erlandsson (3), is conspicuously high.

Table 2. Correlation coefficients between north Finnish (67°-68° lat.) and more southern annual ring indices in 1887-1936 (Mikola).

	Pine	*Spruce*
67-68°/66-67°	0.93 ± 0.02	0.89 ± 0.03
67-68°/65-66°	0.76 ± 0.06	0.83 ± 0.04
67-68°/64-65°	0.69 ± 0.07	0.76 ± 0.06
67-68°/63-64°	0.58 ± 0.05	0.68 ± 0.07
67-68°/62-63°	0.43 ± 0.11	0.54 ± 0.10
67-68°/60-61.5°	0.36 ± 0.12	0.38 ± 0.12

Going from west to east in northern Europe the change of climate takes place much faster, and tree-ring index-series from the same latitude, e.g. from Finland and Norway, have almost no common features (Table 3).

Table 3. Correlation coefficients between annual ring index-series (1887-1936) of Soviet Carelia and Finland and Norway, after Mikola (17).

	Pine	*Spruce*
Soviet Carelia/East Finland	0.77 ± 0.06	0.86 ± 0.04
- " - /West Finland	0.53 ± 0.10	0.70 ± 0.07
- " - /East Norway	0.22 ± 0.14	–0.23 ± 0.13

Hustich compared Finnish tree-ring analyses to American ones (11) and also gathered new material from eastern Canada (12, 13). The comparison reveals that quite an opposite trend prevailed in 1910-1930 in climatic development in Europe and in America. While a marked growth improvement is characteristic to the Scandinavian timber-line region, a distinct decrease occurred in eastern Canada at the same time.

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(Selections from the Author's Summary)

COLLECTION OF THE MATERIAL FOR THE INVESTIGATION

Under the leadership and planning of the Forestry Research Institute's present director, professor Manfred Näslund, a production investigation on a broad basis was put in hand by the Institute's Department of Forestry in the year 1941. The main purpose of this investigation was to provide practical forestry workers with more definite direction for determining the magnitude of the production as regards its volume and value under the effects of different forms and degrees of thinning. As a first stage in this very comprehensive and exhaustive investigation a total of 981 temporary sample plots in undisturbed stands (intact stands insofar as thinning is concerned) were laid out in different parts of Sweden during the years 1941-1948.

The investigation was also arranged in such a way, however, as to allow the observation material collected to be employed for a series of special studies, including an investigation of the variation in the widths of the annual rings in pine and spruce due to climatic conditions. By boring a number of representative sample trees selected from each sample plot laid out, at breast height with the Pressler increment borer, a very large number of increment cores was collected from the sample plots in unthinned stands.

MEASUREMENT OF THE ANNUAL RING MATERIAL

During the field work each separate increment core was placed in a cardboard tube provided for the purpose, on which the necessary registration data for the subsequent identification of the increment core were noted. The increment cores were then dispatched to the Forestry Research Institute where they were stored in a special archives section while awaiting measurement. Immediately before starting the latter the cores were soaked for about one hour, this time being necessary to compensate for the changes in length caused by shrinkage after the increment core had been removed from the living tree. (Eklund 1951). The measurements were then carried out in special recording machines (Eklund 1949) . . . from the year of boring back to 1900.

The mean annual ring-widths for different calendar years were then plotted as points surrounded by circles on a diagram printed in the form of special chart paper. . . The graphic picture of the annual ring development thus obtained has permitted the close checking and sifting of the annual ring material, in which sample plots were excluded which, according to the annual ring diagram, exhibited signs of an abnormal or disturbed annual ring development.

The elimination of the age-decrease for annual ring series either representing separate sample plots or groups of sample plots can be effected by regressive analytical means in accordance with a method originally proposed by Näslund (1942). Briefly, this consists in reproducing the declining tendency of the age-decrease by a function . . . the constants for which are obtained by numerical adjustment of the annual ring series according to the method of least squares, after which the observed mean annual ring widths for each of the calendar years included in the investigation are placed in relation with that calculated according to the function, whereupon a so-called annual ring index is obtained. This is independent of the absolute size of the annual ring-widths and constitutes an approximate expression for the calendar year's property as a good or bad growing year with respect to the increase in diameter. An index value of 100 represents a normal year, whereas an index figure of 120, for example, indicates that the annual ring width is 20% greater than the normal.

When an annual ring series is adjusted numerically in accordance with a certain type of function which will thus reproduce the age-decrease of the annual ring-width schematically, and the annual ring variations are then converted to an annual ring index, any influence of a long-period climatic fluctuation is eliminated. The advance made during the past few decades in climatology, meteorology, glacierology, and other branches of scientific research have unanimously proved that the general climatic situation has undergone demonstrable changes over large parts of the earth's surface since the beginning of the present century. As a working hypothesis, therefore, it is necessary to reckon with the probability that the climatic fluctuations in our latitudes have left their record on the annual rings of our forest trees.

MAIN OUTLINE OF THE MATHEMATICAL-STATISTICAL TREATMENT

The treatment of the comprehensive observation material has been primarily directed to the derivation of functions which reproduce the collective effect which the observation year's-, date-, and age groups exercise on the width of the annual rings. The term "observation year's group" refers to the groups resulting after dividing the annual ring material into groups of five years beginning from the year 1900. . . The date group, on the other hand, refers to the point of time at which the trees examined, in accordance with the age determination undertaken at the same time as the annual ring measurement, were found to have reached breast height. . .

The regression coefficient which represents an expression for the variation in the annual ring-widths due to climatic conditions for the five-year observation year groups has been converted graphically to an annual ring index for each separate calendar year over the period 1900-1945. This annual ring index may be considered to reflect the variations in the annual ring-widths due to climatic conditions for pine and spruce in northern Sweden fairly satisfactorily.

ANNUAL RING INDEX-SERIES

Pine. . . . The pine annual ring index follows a relatively pronounced undulating course. Specially characteristic in this respect are the series of high index values which occurred at the beginning of the 1920's and indicate that the climate exercised a very noticeable favorable effect on the annual ring formation of pines. The pine index-series thus shows that this takes place under a marked influence of the secondary climatic effects from the immediately preceding period of vegetation, and probably foremost amongst them, the changes in the size of the assimilating foliage which is a consequence of the climatic conditions existing at the time. . . A constellation of climatic conditions leads at times to an ample blooming and cone yield in which connection appreciable quantities of assimilated material are probably absorbed at the cost of the annual ring formation. Similarly, it is probable that the annual ring formation is impaired by pronounced attacks of insects that consume the foliage of the crown or destroy it in other ways. The effects are probably the same where a malignant attack of foliage-destructive fungi occurs.

The annual ring index-series for pine in the north of Sweden has been compared with annual ring index-series for the north, south, and whole of Finland. Correlation calculations made in conjunction with graphic comparisons have thereby shown that, under the weather conditions prevailing during the period of comparison 1900-1936 and different calendar years, a relatively similar influence on the annual ring formation of pine has been noted in a number of cases in northern Sweden and in the different parts of Finland.

Spruce . . . The undulatory nature of the annual ring index-series so characteristic for pine is not found in the index-series for spruce. The latter exhibits appreciable similarities and considerable correlation with a previous index-series for spruce in northern Sweden drawn up by Näslund (1942). Comparisons with the Finnish index-series give a higher correlation between the annual ring variations of pine than those of spruce, so that within a wide geographical area the growth climate in different calendar years is probably recorded in a more uniform manner in the annual rings of pi[illegible]an those of spruce.

THE ANNUAL RING INDEX OF PINE COMPARED WITH THAT OF SPRUCE

The relatively pronounced differences encountered in a comparison of the annual ring index-series of pine and spruce may be attributed to some extent to the fact that the annual ring formation of pine takes place under the strong influence of the radial growth during the preceding calendar year, whereas that of spruce is very slightly affected. . .

If the influence of auto-correlation on the annual ring formation of pine is eliminated, the annual ring index-series will undergo a very remarkable change. . . The very conspicuous undulation that marks the primary annual ring index-series is appreciably damped. A comparison with the "adjusted" annual ring index-series for spruce, which is practically identical with the primary series, leads to the astonishing result that the two adjusted index-series agree with each other in a very striking manner, particularly within certain sections of the time scale. . .

Since the annual ring formation in pine takes place to a considerable extent under the influence of secondary climatic effects from the immediately preceding vegetation periods, whereas spruce is not influenced at all, it is an obvious step to regard this as a manifestation of the differences which exist according to the foregoing, with respect to the rate of change of the assimilating masses of foliage in pine and spruce. In view of the fact that in northern Sweden the pine normally has 3-5 generations of needles living simultaneously, against 8-9 for spruce, and the growth of new foliage takes place under the influence of the weather during the vegetation period when needle buds are developed, the effect of weather favorable to growth over a few successive years leads to a far more rapid increase in the assimilating foliage of pine than in that of spruce.

CONE YIELD AND ANNUAL RING FORMATION

. . . Whereas the annual ring variations of spruce are chiefly affected by the weather conditions during the actual vegetation period but also undergo a perceptible influence due to the cone yield during this period, the annual ring variations in pine are primarily due to the weather conditions both during the actual vegetation period concerned and the immediately preceding periods. On the other hand, in this species of tree the cone yield does not as a rule appear to react on the annual ring variations to any great extent. The insufficient reliability of the observation material respecting the magnitude of the cone harvest for different years calls for certain caution in drawing conclusions in the foregoing connection, however.

THE ANNUAL RING INDEX-SERIES FOR DIFFERENT GEOGRAPHICAL AREAS

Provinces . . . The harsher the climatic conditions under which the annual ring formation takes place, the more strongly accentuated will be the character of the more prominent extreme years recorded, either as good or bad growing years. The annual ring index correlation likewise tends to increase the more northerly the position of the province in question is.

Climatic areas. From a comparison of the annual ring index-series for the areas in northern Sweden distinguished by Ångstrom as local continental and local maritime, it would appear that the climate has affected the annual ring variations in all areas in a relatively uniform manner. Nevertheless, certain differences between the various series indicate that these are specially marked to some extent. The conditions are the same for the annual index-series for the most northerly local climatic and local maritime areas on the one hand, and the other climatic areas on the other, which must be interpreted as a result of the somewhat strongly marked climatic conditions prevailing in the two first-mentioned areas.

Latitude groups. The climate must be considered to have exercised a slightly varying quantitative effect on the annual ring formation in different latitude groups. A very remarkable feature is found in the fact that the auto-correlation in the annual ring index-series for pine tends to increase with the higher degrees of latitude. The farther north one goes, the more markedly the annual ring formation of pine appear to be dependent upon the weather conditions during the period in which the immediately preceding annual ring is formed.

Similarly to pine, the annual ring index-series for spruce changes somewhat in character the farther north the series represented by the latitude group is located. For spruce also the auto-correlation tends to increase somewhat at higher latitudes. In this instance, however, the tendency is not so pronounced or statistically reliable as in the case of pine. . .

Altitudes. On dividing the annual ring material according to the four following altitudes: <200, 200—299, 300—399 and >400 m above sea level it is found that the annual ring variations run relatively synchronously, although a certain variable quantitative effect makes its appearance in the annual ring formation. No tendency towards an increase in auto-correlation with changes in the altitude above sea level is noticeable either in the case of pine or spruce.

Site classes. Taking the age and average height of the stand as a starting point, the annual ring material has been divided into five site classes. The annual ring index-series have then been worked out for each of these site classes. Comparisons between the annual ring-index series for these classes have shown that the variation in the annual ring-width due to climatic conditions takes place relatively independently of the stand's site class, both for pine and spruce. It should be emphasized here that this statement refers exclusively to the variations in the annual ring-widths due to climatic conditions and not to the absolute annual ring-width which is, of course, dependent to a great extent upon the site class.

Degrees of density. . . . "a stand is considered to be dense when the crowns of the separate trees interlace with one another or touch one another so that the ground is in shadow at all points". Comparisons between the annual ring index-series for the different degrees of density have shown that the density does not exercise any actual influence on the variation of the annual ring-width due to climatic conditions on pine or spruce.

Degrees of moisture. . . . The apparently slight influence of the water factor on the annual ring-width variation due to climatic conditions supports the view advanced earlier that in northern Sweden it is primarily the temperature conditions during the vegetation period, and probably during the most intensive phase of the latter, that cause the annual variations in the annual ring-widths of spruce. On the other hand, in the case of pine it is necessary to reckon with the fact that the temperature conditions not only exercise an influence during the actual vegetation period but that they are also dependent to a certain extent upon secondary climatic effects which in their turn are associated with the weather conditions during the immediately preceding vegetation period.

THE PRESENT-DAY CLIMATIC FLUCTUATION AND THE ANNUAL RINGS OF FOREST TREES

When studying the relatively comprehensive annual ring material included in the present investigation a special endeavor was made to determine and reproduce numerically any possible long-period influence of the climate on the annual ring index-series of pine and spruce. It was not possible, however, to obtain any reliable and definite criteria relating to the recording of such influence on the annual rings of the tree species in question. The temperature conditions remained substantially unchanged for an appreciable time during the actual vegetation period. The progressive changes in the climatic situation are primarily due to a rise in the winter temperature but are not the result of a general rise of temperature over the individual years, being caused by the fact that the extremely cold winters have occurred less frequently. In all probability the mathematical-statistical methods at present available are not sufficiently developed to enable us to isolate successfully any long-period climatic effect from the complex of site and stand infiuences recorded in the annual rings of conifers.

THE PRACTICAL APPLICATION OF CLIMATIC CORRECTIONS AT THE PRESENT STAGE AND WITH A VIEW TO THE FUTURE

. . . In our latitudes the radial growth of both pine and spruce is characterized by such a marked variation due to climatic conditions that it must be taken into account in forestry calculations which have for their purpose the accurate determination of the thickness increment of individual trees, stands, or entire forests. In this connection it is extremely important that the increment noted should be critically examined against the background of the climate's influence on growth over the period covered by the calculation. . .

. . . In obtaining data for climatic corrections of the increment in the future there is reason to place certain hopes on a comparison between the increment assessment prepared annually by our National Forest Survey for different regions of the country. It is possible that in order to obtain reliable annual ring indexes both for research work and for practical forestry we may find it necessary to prepare and carry on a continuous investigation of the annual ring development in specially selected undisturbed stands which are known as "indicator stands". Another possible method of procedure would be to derive so-called climatic functions, in accordance with which the magnitude of the climatic corrections could be calculated on the basis of the "official" weather observations. . .

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(Selections from the Author's Summary)

HISTORICAL REVIEW

. . . As investigations have shown that the increment variations in trees of Norway, Sweden, and Finland are mainly due to the temperature conditions, while in central Europe (apart from mountainous regions) they can chiefly be ascribed to variations in precipitation, it is difficult to draw conclusions as to conditions in Denmark based on investigations made in neighboring countries.

Some Danish investigations showing the annual variations in ring-width or volume increment in single stands are available. Of more comprehensive papers, based on investigations of a great number of trees from different stands, there are but few, however (Reventlow, posthumously 1879 and 1934; Løvengreen, 1935 and 1951; and Holmsgaard, 1945a and 1945b).

Little is indicated about the dependence of the increment on meteorological conditions. Prior to 1800, Reventlow (1879) made extensive ring measurements of 61 oaks and 181 beeches, and he calculated the mean ring-width for each year in the period from 1763 to 1792 for 4 groups of trees, "in order to find out whether climatic conditions or other chance conditions furthered or checked the growth in any year as compared with that in any other year". However, Reventlow indicates nothing as to which climatic conditions might be assumed to have caused the ring variations found. Lütken (1891) found that the increment of silver fir in 5-year periods showed some agreement with the relative precipitation of the period (mean precipitation for the whole year divided by the mean temperature for March-November). Løvengreen (1935) found that the annual volume increment in Norway spruce in the Friisenborg forest district was dependent on the rainfall in the months of April, May, June, and July. Holmsgaard (1945) showed that the ring-width of Norway spruce in a heath plantation on poor sand was greatly dependent on the rainfall in the months of May, June, and July, and that the ring-width of Scotch pine on good quality soil had the greatest correlation with the temperature in February-April, whereas no dependency on the precipitation could be established.

THE DATA INVESTIGATED

Greatest importance has been attached to investigations of beech (*Fagus silvatica* L.) and Norway spruce (*Picea Abies* (L.) Karst.), which are the most important species in Danish forestry. The investigations have, however, also comprised data of oak (and other species) . . .

The object of this work is merely silvicultural, and all data have been collected from typical, well-tended forest districts. . . Virgin forest is not found in Denmark, and all stands investigated have been subject to thinnings, which, according to common practice in Denmark, are made every 2 to 4 years in young stands and every 5 to 8 years in old stands. Consequently, the individual thinnings are not heavy. . .

The tree-ring measurements, of which about 78.000 were taken, were made on increment cores taken at breast-height from trees with a diameter which was about the same as the mean diameter of the stands. Generally, only one core was taken from each tree.

THE METHODS APPLIED AND AN ESTIMATE OF THEIR ACCURACY

. . . The same correlation between the most important climatic factors and the ring variations would have been obtained if these variations were determined on the basis of data from 6 to 8 stands as if they were determined on the basis of data from two or three times as many stands.

Should it be desired to get a fairly good expression for the climatically conditioned ring variations of individual stands, this would appear to be obtainable under Danish conditions by measurement of increment cores from 6 to 8 trees. It is true that some stands will have particularly untypical ring variations, but it does not pay for that reason to increase the number of increment cores in investigations like the one here made. It is a better plan to include a greater number of stands in the investigation. . .

Measurements of the ring-widths were taken with a microscope fitted with eyepiece micrometer — in the majority of cases with a magnification of 24 times, the unit of measurement being 1/18 mm. Measuring was done on soaked increment cores. In cores of beech and alder the pores were filled with white opaque.

The dating of the annual rings was checked by crossdating, and the dating gave rise to difficulties only in beech data from the poorest site (Buderupholm). . .

The series of mean figures for the ring-widths from the individual stands were adjusted for age effect by means of age curves plotted on the basis of the mean ring-widths from the 6 to 8 stands in each group of data. The age curves were drawn by graphic smoothing. . .

The mean ring-widths for each stand were expressed in percentages of the age curve values and finally multiplied by a constant which made the average of the whole series equal to 100. . . Due to the long-lasting effects of thinnings, etc., it is impossible to attach any importance to the values for individual stands as an indication of the quality of the growing seasons. . .

RING VARIATIONS AT DIFFERENT HEIGHTS ABOVE GROUND

. . . The ring variations were investigated in 7 to 8 trees in one Norway spruce stand and two beech stands. Each tree was examined at six different heights, and the variations proved to be fairly uniform at all heights. Also the relative magnitude of variations is the same.

The correlation between the tree-ring indices for the locality and the percentual mean ring-widths at all heights of measurement shows that the tree-ring indices are extraordinarily good expressions for the relative volume increment of the Norway spruce and usable expressions for that of the beech stands. The top sections and branch cross-sections of beech show less good agreement with the other parts of the tree, where, however, the larger part of the volume increment is found. . .

RING VARIATIONS DUE TO THINNINGS, SEED-BEARING

. . . The ring-width of beech in trees which are 100 years old or more is reduced greatly by the bearing of seeds. From an age of about 130 years the ring-width in good seed years (which generally occur at 6 to 7 years' intervals) is, on an average, only half the size of the rings in the years which are not affected by seed-bearing.

Furthermore, there is a considerable increment reduction for at least two years following a good seed year, presumably because the trees then restore the food reserve drawn upon for the formation of seeds. . .

Less information is available about the seed years of Norway spruce, but as far as it is possible to conclude on the basis of material from three localities for which detailed information exists, the ring-width is reduced by 25-30% in 60-year-old and still older stands. Also in Norway spruce there may be a question of an effect over several years. . .

RING VARIATIONS IN STANDS OF DIFFERENT PROVENANCES

As more than one-half of the Danish forest area is covered with foreign tree species, it is of interest to investigate whether stands of different provenances have different ring variations. Data from provenance experiments with Norway spruce and Scotch pine were investigated. Neither of these species is native to Denmark.

For both species, the ring variations are very uniform, the larger maxima and minima being common to all provenances. . .

RING VARIATIONS IN DIFFERENT LOCALITIES AND THEIR DEPENDENCY ON THE STAND AGE

. . . There does not seem to be any great difference in the relative magnitude of the increment variations in the various beech data, whereas the ring variations of Norway spruce are increasing with decreasing site quality — with the notable exception, however, that stands of rather good quality, but growing on stiff clayey soil at Vallø, have just as great increment variations as stands growing on lean sand.

RING VARIATIONS IN BEECH IN A STAND BORDER AFFECTED BY THE WIND AND IN ISOLATED BEECHES

. . . It will be seen that the wind conditions (especially in the latter part of May, when the beech has newly opened leaves) can account for the differences in the increment course, a particularly small increment in the forest border coinciding with high wind forces from the west, and a great increment with low wind forces.

The tree-ring variations in six practically isolated 300-year-old beeches were examined. These trees had, largely, the same increment variations as trees in closed stands, but there were also deviations (which could not be explained by seed bearing). In the author's opinion, there can, therefore, hardly be any doubt that systematic errors will be introduced by assuming that isolated trees have the same increment variations as trees in closed stands.

ON THE APPLICATION OF TREE-RING INDICES IN THE CORRECTION OF INCREMENT INVESTIGATIONS

. . . To most of the examined tree-species the May-July rainfall is of decisive importance for the magnitude of the increment, while the summer temperature could only be demonstrated to have any effect for oak and silver fir. The influence of the autumn temperature the year before on the increment of the oak is explained by its effect on the shoot ripening.

The temperature in winter and early spring seems to be of great importance to the increment of alder, Scotch pine and Douglas fir, of less importance to the increment of ash. Presumably, the unfavorable effect of low winter temperatures is due to the fact that the water absorption is impeded by the cold soil in spring, which may cause partly a weakening of the trees due to water deficiency, partly a shortening of the length of the growth period.

Also the climatic conditions of previous years play a part. Thus it was found for all Norway spruce data that the rainfall of the preceding year should be incorporated in the equations with regression coefficients of magnitudes corresponding to ¼ to ½ the magnitudes of the coefficients to the same expressions in the growth year. . .

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ERRATA, VOLS. 1-20 (See also 12:32, 1946)

Vol.:Page	For	Read
1:22.3	Jug House	Mug House
2: 5.5 (E.W.H. paper)		"Tree Rings: The Archaeologist's Timepiece"
2:33.5 (col.5, ln 14)	M 23	MV 23
2:33.5 (col.5, ln 15)	Earth Lodge (A)	Pit House (C)
5:12.7	" " "	" " "
12:21.9	" " "	" " "
2:33.7	H 179	M 179
5:13.2	Kiatuthlanna	Nutria Canyon
5:16.6	Steese Highway	Richardson Highway
6:28 (no.17)	1935	1925
6:31 (no.137)	Geografiska Annaler . . .	Stockholms Högskolas Geochronol. Inst., Data 23, 1936.
6:33 (no.218)	Reader's Guide	Reader's Digest
9: 6.9	Ahteut	Ekseavik
12:20.8	Jug House	Mug House
14:11.5 (F-1935, col.7)	997	1097
14:19.8 (KS-13)	NA2630	Keet Siel
15:10 (A.D. 710)	108	141
15:20.7	P: 10:50	W: 10:50
15:20.8	P: 10:51	W: 10:51
15:32.1 (A.D. 177)	83	173
15:32.1 (A.D. 178)	162	100
16:21.4 (no.11/212,col.8)	1256	1256 vv
18:21 (Table 1)		1730 ring is *not* absent; add one year to dates 1700-1729.
18:33.7	all specimens are charcoal	all specimens are charcoal except GP-2997
18:34 (Table 2)	col.heads 9,8, . . .	-9, -8, . . .
20:33 (ln 4)	Cooper River	Copper River

TREE-RING STUDIES OF THE FORESTRY-BOTANY INSTITUTES OF THARANDT AND MUNICH[1]

BRUNO HUBER AND WITA VON JAZEWITSCH

METHODS

Under the direction of the senior author about 250,000 annual ring widths have been measured and evaluated since 1938 at the Forestry-Botany Institutes of Tharandt and Munich. The so-called Leitz "cross-adjustable mount" (Kreuzverschiebungsstativ) was used for these measurements, by which the microscope itself is moved and not the object (tree section or increment boring). When the width of the rings is measured by one person (approx. 30 scale divisions = 1 mm), it is convenient for a second person to write down the measurements as they are read, or a magnetophon may be used for the same purpose. At the present time, however, we are preparing an automatic instrument for the measurement of ring-width after the Swedish model (Eklund 1950).

Since the climate of Germany is less variable than that of the southwestern United States where much of the American research has been carried out, the ring-widths vary less: the mean variation (=durchschnittliche Schwankung) is on the average not higher than 20%. The most sensitive species are *Larix europaea* and *Fagus silvatica* with mean variations up to 40%, but even these two species do not show as much variation as *Pseudotsuga* according to Schulman[2] (*Tree-Ring Bull.* 13:10, 1947 and 18:12, 1952).

On account of these slight changes we can only in exceptional cases cross-date our curves with the help of the skeleton plot (Glock 1937). Ordinarily we have to compare the whole extent of the curves. We do this over glass plates which are lighted from underneath[3]. As an objective comparison we use the percentage of agreement or that of disagreement (Gegenläufigkeitsprozent). We count how often a curve sinks when the comparison curve rises, or the other way around. Very similar curves, for example curves from sections of two separate spruces from the same habitat, often show 20 to 30 per cent disagreement. This is caused by the fact that the dissimilarity is found in rather flat areas in the curves while strong variations often agree with each other[4]. More recently we have developed an apparatus counting automatically the number of disagreements and facilitating the synchronization of curves of unknown age.

As our central European material does not make possible such clear cross-dating as that of the American Southwest[5], in the beginning we did not venture to synchronize old samples but worked at first with synchronization of recent material. Later we used the bridge method (Glock p. 29). We derived chronologies as follows: (chronologies obtained by the bridge method are marked by asterisks):

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[1]Kindly translated by Johnson Parker.

[2]These variations can only serve as a measure of sensitivity if different species of the same area and same date are compared. We have proof that a tree species on a similar habitat in the post-glacial warm period shows much greater variations in ring-width than today. In this case the greater intensity of the variations indicates that a different climate existed at that time.

[3]The ring-widths are placed on the ordinate in logarithmic scale since we are thus independent of absolute growth intensity and can spare standardizing. Years are given on the abscissa, proceeding from left to right.

[4]One can make an evaluation in this case by counting the disagreements for different strength of variations according to classes: variations of 25, 50, and 100 per cent — called fractionated disagreement statistics (fraktionierte Gegenläufigkeitsstatistik).

[5]The only exceptions are our Bronze Age material, especially from "Wasserburg Buchau", and some *Larix* chronologies. All others Schulman would call "obscure chronologies" (*Bull. Amer. Meteorological Soc.* 23, 1942, p. 205).

Softwoods		**Hardwoods**	
Taxus baccata	1784-1939	*Quercus petraea**	1224-1950
Abies alba	1701-1950	*Fagus silvatica*	1661-1948
Picea abies	1642-1943		
*Larix decidua**	1340-1947		
Pinus cembra	1573-1947		
Pinus silvestris	1691-1939		

It was possible to date some 50 oak beams from the medieval town of Ziegenhain near Kassel and larch beams from cottages in alpine pastures.

THE PROBLEM OF "TELECONNECTION"

In this connection we are especially interested in the question of how far over great geographical distances similar curves appear. The percentage of disagreement is a good measure of this decrease of similarity with distance (see the following table):

Table 1. Percentage of disagreement by comparing samples of different species and sites (according to Müller-Stoll).

	The same site	*Different sites of central Europe*
A. Samples of the same species:		
Abies compared with *Abies*	23.9	35.4
Fagus compared with *Fagus*	30.1	37.9
Picea compared with *Picea*	32.1	40.1
B. Samples of different species:		
Abies compared with *Fagus*	35.9	42.3
Abies compared with *Picea*	40.8	44.8
Fagus compared with *Picea*	44.4	45.1

By comparing German with Scandinavian spruce and pine there was found a percentage of disagreement of 46.2 and 47.0. Since 50 per cent agreement shows a purely chance distribution, it appears that crossdating between central Europe and Scandinavia and even more between Europe and America is impossible. The hypothesis of Ebba H. De Geer that the variations in width of tree-rings and varves depend on cosmic factors and therefore agree over the whole earth does not stand up under critical examination. *Each country must set up its own chronologies.*

RELATIVE CHRONOLOGIES OF PREHISTORIC SAMPLES

In the case of the prehistoric woods which cannot be absolutely dated[6], we set up a relative chronology; thus the pine posts of the Bronze Age fort at Buchau can be synchronized with each other without any doubt on the basis of striking signatures, and it can be shown that the outer palisade was built over a period of four years. The inner palisade is from another time, but again built within a rather short interval. Ording reports a similar situation with the fort at Raknehaugen in Norway. More recently similar investigations have been made in neolithic pilework from Switzerland.

DENDROCLIMATOLOGY

The correlations of ring-width to temperature and precipitation is not so clear in central Europe as in Scandinavia and North America. Usually the temperature influence is greater in the mountains; in lower areas, the precipitation influence is greater. Especially unclear are the relations in the case of oak, which is such an important building material. As long as it comes from the valleys (*Quercus robur* mostly, but species diagnosis is uncertain using only wood anatomy for identification), the tree-ring width follows the temperature better, whereas when it comes from steep slopes, like the famous Spessart oak (*Quercus petraea*), ring-width follows the precipitation (Wellenhofer). With beech the minima of ring-widths are traced back to heavy seed years.

[6]Dating by radiocarbon has been started.

An important conclusion is possible from the 600-year-old larch chronology of our co-worker Brehme: in Berchtesgaden the speed of growth of larches before 1600 A.D. was twice as great as after 1700, a proof of considerable worsening of the climate, already known from other sources such as glacier research.

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EARLY HISTORY OF CROSSDATING

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The early history of crossdating has recently been summarized by the author.[1] The salient features of this review, in so far as they apply to crossdating and the historical events leading up to the concept, are here briefly stated, since many readers of the *Tree-Ring Bulletin* may not have easy access to the publication in which it appeared. For the sake of brevity, documentation is omitted in the present paper; such dates as are included are for the purpose of helping the reader to keep his perspective in historic time.

In its historic development, the fundamental idea of crossdating arose from the subject of internal markers, and it may be considered to be a part of this broader field. An internal marker is any anatomical feature whereby an individual growth ring in a tree can be identified and often dated; included are ring thickness, partial rings, and the presence of abnormal or unusual cells in the ring. Most of the markers have been placed into the wood as a result of insect defoliation, drought, lightning, fire, frost, or hail, each of which factor is capable of producing a characteristic growth ring.

Once it had been shown that a distinctive ring was commonly produced in a given year, the tables could be reversed and a similar ring found in a similar position in another tree could logically be used to date such local occurrences as fire, frost, drought, hail, lightning, and insect defoliation. Such natural internal markers have been extensively used in dating individual rings, especially in Europe and America.

As long ago as 1882, Hough expressed the belief that it should be possible to date accurately certain insect injuries a century or more back from characteristic rings to be found in the discs of tree trunks stored in the museums of forestry and other schools. The dating of hail, frost, and insect injury was actually done by R. Hartig (1892), Rubner (1910), I. W. Bailey (1924, 1925), and many others. Such are the applications of tree-ring studies to climate — or rather, to the weather.

An outstanding early study involving naturally placed internal markers is a paper reprinted several times by Enos Mills (1904, 1908, 1909).

At an earlier time, when it was still thought that the earth is only 6000 years old, it was suggested by Agardh (1829, 1830) that tree rings might tell us the age of coal measures, of limestone strata, and other geological formations. And Candolle (1827, 1831, 1833) suggested applying age counts from tree rings to the age of talus slopes, to changes in dunes and river beds, to the origin of volcanic and madreporic (coral) islands, and even to the "last revolutions of the globe" (cataclysms).

Proposed applications of tree-ring dating to archaeology are also not new. As early as 1811, Waterhouse said: "Who knows, but we may hence form a probable conjecture of the age of those surprising antiquities (Indian mounds), discovered in this new world on the banks of the Ohio and Muskingum?" And in 1884, Baldwin reported that Professor Jeffries Wyman had thought that he could date Indian mounds in Florida by counting the rings of trees growing upon them; Baldwin seems to have prevented this work from being attempted by calling Wyman's attention to possible grave errors because of the many multiple rings present in the native trees of Florida.

The use of tree rings in dating "monuments" was frequently referred to in the European literature, but it is not clear what type of monuments was

[1]Studhalter, R. A. 1955. Tree growth: some historical chapters. *Botanical Review* 21:1-72.

being considered. Possibly they included initials and dates which successful hunters carved on trees as mementos.

Perhaps of greater human interest than natural markers are various internal markers which are intentionally placed into a tree by man. His purpose in so doing may have been quite hazy, or he may have been trying to solve some problem of diameter growth, or he may have been dating some individual growth layer, or again, he may simply have wanted to carve his initials into the bark of a tree. The method has been called internal tagging when it is done for the purpose of dating growth lawyers. Here, too, we find an extensive literature, going back to the Greeks, namely to Theophrastus, the student and successor of Aristotle. Although this early scientist of more than two millenia ago did not know that the growth rings of trees are supposed to be annual, he nevertheless knew in what region the new wood of trees is added to the old, and he saw the relation of a time concept to the diameter growth of trees. His own statement is as follows:

> ". . . and if one forces a stone or some similar object into a tree, it becomes hidden, since the new growth surrounds it, as was the case with the wild olive tree which stood in the market place at Megara."

The French botanist and forester Duhamel du Monceau (1751), in an effort to discover where and how new wood is formed, placed small strips of tin foil at definite depths in the cut bark and wood, treated the wound with an antiseptic, tied the parts together, and examined again at the end of the growing season. In other experiments, he (1758) forced fine wires through the bark and wood at approximately known depths for later examination. In these ways he was able to delimit the radial growth of a single season, thereby dating a growth ring accurately.

Artificial defoliation has been used as a tool in dating, as has also artificial freezing.

Although not originally intended as internal markers, the axe blazes of surveyors have very often served this purpose. As long ago as 1787, Burgsdorf used an axe mark made in 1767 on an oak tree at a boundary line as proof that only one ring is formed in a year; in 1785 the blaze had been grown over by 18 rings. A large number of boundary disputes have been settled in court by dating a surveyor's blaze from the number of growth rings which have grown over the wound in a known number of years. In general, courts in this country and elsewhere have recognized the accuracy of this method; only one instance has come to our attention in which a court ruled that one ring does not always represent the diameter growth of a single year, and that therefore a blaze cannot always be accurately dated.

The significance of the woody overgrowth covering dates, initials, and other markings cut through the bark is discussed by many writers, such as Goeppert (1868), who begins his citations with Bartolinus (1654).

The work of Enos Mills, referred to above, also contains a number of instances of internal markers deliberately placed by man, although the original purpose of the marker was not one of dating a given ring. Mills' painstaking study is still one of the best examples of interpreting the events which had befallen a single large tree during its long life.

While the applications cited above do not usually involve true crossdating, they at least represent a close approach to its methods.

It is a relatively short step from the dating of individual growth rings to the method which we now know as crossdating, for this method makes use of the same internal markers discussed above. Crossdating involves the use of identifiable characteristics of rings in two or more trees, with a view of assigning dates to the individual rings. The first direct approach to this method appears in three countries of Europe in the eighteenth century. The Frenchmen Duhamel and Buffon (1737) counted back to the wood ring of 1708-1709, in which they found a severe frost injury, called false sapwood by them. There is more than abundant historical proof that the winter of 1708-09 was a very severe one in Europe. The false sapwood was believed to be the result of severely cold weather, it being a common belief at that time that wood continues to be formed in a tree throughout the winter. Such a backward count assumed, no doubt correctly for most trees in central and northern Europe, that a single prominent growth ring is laid down in one year. Just a few years later, Linnaeus (1745, 1751) in Sweden also counted back to the winter of 1708-09, for which he found a thin ring. Still later, Burgsdorf (1783) in Germany again counted back to the same winter, the ring for which contained a severe freezing injury. Candolle (1839-1840) in France also succeeded in counting back to the same severe winter on a juniper tree. None of the first three men, at least, seems to have known of the work of the others. If these data are combined into one, we have here, in a sense, the beginning of crossdating, for the growth ring of 1708-09 was identified in several trees — trees of different ages, of different species, and growing in different localities and habitats. I believe that we would be justified in stating that crossdating had its birth in the year 1737.

If, however, one is not willing to accept that date, he will be forced to accept the year 1783 as the first date of crossdating and the German botanist and forester Burgsdorf as the father of crossdating. For on that date, Burgsdorf tells us that (1) frost damages the bark and may also injure the wood; (2) sometimes one finds dead and decayed areas enclosed within the normal healthy wood, which has grown over them; and (3) according to ring counts, this condition occurred in the winter of 1708-09 *in beech and in most other trees.* The italics are mine. In thus comparing several trees of different species he fulfilled all of the criteria of crossdating. It is of considerable interest that, in all of this early work, the factor responsible for the recognition of the telltale rings was not drought, but frost. With temperature in mind, Linnaeus called tree rings the chronicles of winters. In the course of time, this terminology gave way to others which are based on the factor of drought rather than temperature. Twining (1833) spoke of tree rings as meteorological tables and records of the seasons, and Pokorny (1865-66) referred to them as meteorological yearbooks, which go back hundreds and even thousands of years. Baldwin (1884) considered them true records of the weather and L. H. Bailey (1885) used the term meteorological records of the years.

Two of the five methods suggested by Candolle (1833) for estimating or determining the age of trees involve simplified crossdating. He recorded ring thicknesses in groups of ten for as many trees as possible of a given species, taking into account the fact that growth rates differ in young and in older trees. Having thus established the average annual diameter increment for each species in different periods of growth, one would be able, he says, to determine the age of a given standing tree of that species with reasonable accuracy from its diameter. Or else, by making a cut in the side of a trunk one could measure the ring thicknesses for a given period of time and arrive at an estimate of the total growth and age from the diameter of the trunk. This method, he says, was used long ago by Adanson in estimating the age of a large monkey bread tree (*Adansonia digitata*) on Magdalena Island. These methods of Candolle came to my attention too late to be included in the paper printed in *Botanical Review*.

The suggestions of Candolle were apparently quite fruitful for, forty years later, Elias Lewis (1873) stated that it had long been customary to make estimates of the age of standing trees from the number of rings on another tree of the same species in which rings could be counted.

Next we come to a completely forgotten letter to the *American Journal of Science* by Twining (1833), who once more discovered the very essence of crossdating. Working in New Haven, Connecticut, he stated in part:

> "In the year 1827, a large lot of hemlock timber was cut from the north eastern slope of East Rock, near New Haven, for the purpose of forming a foundation for the wharf which bounds the basin of the Farmington Canal on the East. While inspecting and measuring that timber, at the time of its delivery, I took particular notice of the successive layers, each of which constitutes a year's growth of the tree; and which, in that kind of wood, are very distinct. These layers were of various breadth, indicating a growth five or six times as full in some years as in others, preceding or following. Thus, every tree had preserved a record of the seasons, for the whole period of its growth, whether thirty years or two hundred,—and what is worthy of observation, *every tree told the same story*. Thus, if you began at the outer layer of the two trees, one young and the other old, and counted back twenty years, if the young tree indicated, by a full layer, a growing season for that kind of timber, the other tree indicated the same."

That Twining fully appreciated the significance of his discovery is indicated by his own italics, as given above.

In addition to his clear statement of crossdating, Twining spoke of having, in these logs, two or three hundred potential meteorological tables, each of which is a natural, unerring, graphical record of past seasons. While he does not mention rainfall and drought specifically, these factors are implied as being responsible for the unusually thick and thin growth rings. And his prophetic insight into the future is shown by his last paragraph, which reads as follows:

> "If you should think fit to make such a suggestion (the collecting, labelling, and preserving of discs of tree trunks in all parts of the country), it might lead, in fact, to the preservation of sections from aged trees in different parts of the country, and a comparison of their lines of growth with the history of the weather as far back as our knowledge extends. If the observations just related, with respect to a particular lot of timber, should be found to hold true of trees, in general, drawings of these sections, on a reduced scale, would soon find their way to the pages of scientific journals. It would be interesting, then, to make comparisons of one with another, — to compare the sections of one kind of tree with that of another kind from the same locality, — or to compare sections of the same kind of tree from different parts of the country. Such a comparison would elicit a mass of facts, both with respect to the progress of the seasons, and their relation to the growth of timber, and might prove, hereafter, the means of carrying back our knowledge of the seasons, through a period coeval with the age of the oldest forest trees, and in regions of the country where scientific observation has never yet penetrated, nor a civilized population dwelt."

Here, indeed, do we have not only the truest type of crossdating, but a clear statement of some problems not undertaken until a century later.

Pokorny (1865-66, 1867, 1869) discussed accurately both the background and some of the problems of crossdating. In eastern Europe, he studied a large number of Christmas trees (firs) and found a characteristic thick ring for 1861, regardless of the greatly varying ages of the trees and of their presumably variable former habitats. Again, in a study of discs of pine trees collected by Professor Simony, Pokorny found the ring for 1808 extraordinarily thin, whereas those of 1806, 1807, 1809, and 1810 were quite thick. He placed considerable emphasis on relative thicknesses as opposed to actual thicknesses.

In Germany, Ratzeburg (1866) compared the ring of a certain year, which was the result of caterpillar injury, in a number of different trees, in this manner assigning definite dates to these rings and hence to the injuries.

A modification of crossdating, in which however its exact principles were used, was reported by Robert Hartig (1897). In some trees which had been killed by smoke and fumes, he found it impossible to make actual ring counts at the base of the trunk because of the frequent omission of rings at that level. First he studied the ring patterns in the upper part of the bole, where he assumed all rings to be present for the age represented there, recording the especially thick and thin rings and the number of more nearly average rings between them. Then, by locating the distinctive rings in the lower bole at DBH and interpolating for the missing rings, he was able to determine rather accurately the age of the tree. This method, as stated by Andrew and Gill (1939), is almost exactly the method in use by the dendrochronologists; it differs only in that the work was limited to different parts of a single tree.

The article of the Dutch astronomer Kapteyn (1914), reporting on work done in 1880 and 1881 in Holland and Germany, has been previously reviewed in the *Tree-Ring Bulletin.*

It is quite probable that there have been many other cases of crossdating previous to 1900 which have not been sufficiently described in the literature to indicate with certainty that the methods of crossdating were used, and not merely those of dating. If, for example, an old insect injury or a frost injury is dated from tree rings, it proves to be a matter of simple dating if only a single tree is used, but it becomes a clear-cut instance of crossdating if the same injury is dated from more than one tree. And it is equally probable that in some of the court cases involving boundary disputes blazes from more than one tree were used as evidence. This might prove to be a fruitful field of historic investigation for one who has a legal turn of mind.

To summarize: It is clear that a lot of work had been done by botanists, foresters, and astronomers on crossdating between 1737 and 1900, and that the methods of this dating tool were often used consciously. It is the present writer's belief that scarcely any of these men knew anything about the work of any of the others; that each one had arrived at the concept independently. With the single exception of Candolle's books, each of the writings mentioned in this paper seems to have been forgotten shortly after publication. A few, such as Kuechler, Pokorny, R. Hartig, and Kapteyn, had been resurrected by others within the past few years; others, such as Burgsdorf, Twining, Vonhausen, and Ratzeburg, appear to have been rediscovered only now and reviewed for the first time in the issue of the *Botanical Review* mentioned above.

Preceding 1900, not one of the papers in which crossdating was used, except those of Candolle, made much impression on the scientific world and apparently none on popular thought. It remained for Dr. A. E. Douglass to rediscover the method in the American Southwest after 1900, to use it persistently and extensively, and to apply it widely to astronomy and archaeology.

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