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GROWTH-RING RESEARCH IN NORWAY

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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 cross-datings 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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