A NEW LOOK AT DENDROCHRONOLOGY IN NORDIC COUNTRIES

JOHN M. FLETCHER

Research Laboratory for Archaeology and the History of Art, Oxford University
6 Keble Road, Oxford 0X1 3QJ, UK.

In the conclusion to their paper on dendrochronology at the Second Nordic Conference Eckstein and Wrobel (1981) wrote »Dendrochronology is far from being a routine procedure». They recommended that further development of the progress made in the previous decade required the »network of chronologies to become denser». Yet, as elsewhere in Europe, it had already been found that single chronologies often applied to very large areas.

I maintain that a *denser* network of chronologies is a misplaced target. Instead, for both oak and pine in Northern Europe, the requirement is for relatively few chronologies of high quality based on a wide knowledge of the ecological factors which affect the growth of the species concerned.

Eckstein and Wrobel drew attention in their paper to the various chronologies and their own notable achievements in the dating of artefacts in northern Europe. However, the period since 1968 has seen (i) the replacement of scientific research by emphasis on statistical methods for manipulating ring-width measurements of oak within the simplistic concept, popular with Baillie, that its growth is based only on 'the climate and local noise' (ii) the regretable view that much of the scientific research in central Europe during 1940—68 by Huber and his co-workers (G, 11, 15, 65) can be ignored. In fact, it included the analysis of growth patterns and gave dendrochronology a sound scientific basis. In his Greenwich lecture in 1977, Prof. Liese (G, 1) remarked that Huber, being the father of tree physiology, had concentrated on the interrelationship between the structure and function of trees and the influence of environmental factors, especially in his homeland, the Alps. In brief, Huber's main contributions to European dendrochronology were:

(a) That the balanced climate of Germany made pioneering methods developed in the semi-arid climate of Arizona inapplicable to oak, so the skeleton plot was replaced by charts of successive ring-widths plotted on a semilogarithmic scale.
(b) That »signatures», unusual sequences of annual rings occurring in the same years in a majority of samples, were important.
(c) That the same growth pattern applied to a very extensive area in central Europe.
(d) That climatic changes in recent centuries sometimes had a drastic influence on growth, e.g. on alpine larch after 1600 AD.
(e) That there was much to learn from wood structure research and from the biology of wood formation, e.g. about the growth pattern of oaks and of alder: they enabled the two main European species of oak *(Quercus petraea* and *Q. robur)* to be differentiated from their timber; and the impact of ecological conditions on the growth of oak, beech and larch to be compared.

Huber's methods have been extended by Becker at Stuttgart (G, 101) and by Schweingruber and Bräker in Switzerland (G, 89). Surprisingly, however, application of his research on oak has been disregarded in Baillie's work at Belfast (1982) where emphasis has been on statistics and methods used for conifers in Arizona, apart from the dating of Irish fossil oak for calibrating the carbon 14 scale.

In North Germany the research of considerable interest to Scandinavia is that reported in the dissertation (1972) and (G, 45) of Delorme of Göttingen on oak from the Weserbergland (to the north of Huber's own main source of samples, Hesse). Delorme, like Becker, not merely made use of Huber's research for his own oak results but has made informative advances (G, 101). At Hamburg, by contrast, the emphasis by Eckstein (G, 117) has been the formation of chronologies along the North Sea coast together with statistics; however it has added little to scientific knowledge and notice has not been taken of the importance of insect attack (*vide infra*).

In the following three sections aspects of research at Oxford and elsewhere in Europe are explained and their implications to Nordic countries discussed:

- Chronologies for oak and pine and the extent of the areas to which they apply;
- Climatic swings and their implications;
- Basic research on matters such as wood structure, insect attack, and their importance.

Chronologies for oak and pine

Oak

Research at Oxford has been based on the knowledge gained about oak in central Europe by Huber and others. The categories of the samples and their numbers are summarised in Table 1. The artefacts involved in the research differed from those elsewhere, with the exception of Hamburg, because of the inclusion of about 300 anglo-flemish paintings on panel (G, 303). The origin of their boards (mainly pedunculate) is not precisely known, but it is likely they came from woodlands in local hinterlands to the North Sea over an arc about 500 km long from E.Anglia to the Rhine estuary. Because of the need to make ring-width measurements *in situ* on panels or radial boards, some 60,000 ring-widths have been measured on cleaned edges with the aid of an eyepiece, providing an opportunity to examine the wood structure in relation to the species of oak, and to notice a rare abnormality (G, 339) that concerns the early vessels of oak and can occur as a result of unusual conditions.

In Britain as in the Scandinavian peninsula, hilly terrain on the west together with S.W. and W. air streams from the Atlantic create two types of zones (oceanic and continental) for the growth of trees. On the west are areas of high precipitation with cool

Table 1. Categories of oak artefacts examined.[1]

Category	Period of construction or first use A.D.	No. of artefacts	% dated
Paintings on panel	1450—1619	284	85
Bindings of manuscripts	715—1350	5	100
Furniture and entrance doors	1110—1525	23	95
Standing buildings	1130—1555	20	90
Excavated structures	600—1200	9	96

[1] Details are given in Fletcher and Tapper (1984).

Table 2. Oak chronologies formed at Oxford.

No.	Name	Years covered	Main species	Mean width, mm	Growth pattern
1	REF 7/5	845—1331	Ped/Sess	1.8	H
2	MC 14	902—1261	Ped	1.6	H
3	REF 3	1399—1687	Ped	2.4	H
4	REF 1	1099—1619	Ped	1.2	A
5	REF 2	1239—1606	Ped	1.9	A
6	MC 16	1314—1636	Sess	1.6	H

humid conditions, favoured by sessile oak producing a ring-width growth pattern (H) in which moisture shortage is rarely a limiting factor. In parts of the English midlands and in lowland eastern Britain (both areas of rain shadows) rainfall is relatively low and there is exposure in the spring to cold, dry N.E. winds from across the North Sea; the oaks are predominantly pedunculate and for slow growth the pattern is different (A).

For the period *c.* 850—1687 A.D. well replicated chronologies (Table 2) have been formed to which the following points apply:

(a) None include recent growth. We were aware in 1970 that cross-dating from the continent would be feasible. The Huber-Giertz chronology (G, 27) had already been used (Charles, 1971) to date building timber (since found to be sessile oak) on the borders of England and Wales at a distance of *c.* 800 km from its origin in Hesse; similar conditions of climate and terrain pertain to both areas. On the other hand a chronology for the Winchester area, by Barefoot *et al.* (G, 161), which started with living trees was limited to 1635—1972; attempts to extend it earlier than 1635 failed.

(b) Each is for sites with particular ecological conditions along the lines suggested for N.W. Europe for conifers by Schweingruber, Bräker and Schär (1979), namely:
   1. cool humid, often hilly sites in an oceanic (atlantic) climate;
   2. temperate, mild sites which combine a greater degree of warmth with moderate rainfall;
   3. dry, usually lowland and often continental sites with annual precipitation < 700 mm.

   Thus each chronology is based on an ecological zone rather than a region; no zone is necessarily geographically continuous — e.g. the same one exists on both sides of the North Sea; each may cover hundreds of kilometers.

(c) Each is of high quality, i.e. only well-matched sequences were meaned together and often up to 20 % of a sequence, e.g. for growth near the pith or narrow rings at the end of a long sequence, was excluded.

(d) Chronologies No. 4 and No. 5 (both based on sequences from boards of panel paintings and chests or cupboards) include ones from boards used in artefacts from York to London, as well as many used in Flanders and a few used in France. The need for treating such boards as having separate »regional» patterns did not arise.

At an early stage, inspection of the growth curves of pedunculate oak in the medieval period showed that those of narrow mean width (*c.* 1.2 mm) were not a good match with wider ones (*c.* 1.8 mm) of faster growth. At present this new discovery applies only to oak. We have sufficient samples to form separate chronologies for slow and moderate rates of growth (Nos. 4 and 5 in Table 2). They are of value in dating a high proportion of single sequences. Dating of the chronologies of pattern H has been based on agreement with those of Huber-Giertz or Hollstein (1980). The two chronologies of pattern A were floating to the extent of ± 1 year for some time; they have now been dated by the agreement of chronology No. 5 with contemporary years in chronology No. 3, formed by growth at a similar rate for oak from western England.

Geographical extent of Chronologies: Comparisons have been made between our chronologies (Table 2) and continental ones. Agreement is good over long distances (see below) when the chronologies are derived from oaks from areas with the same ecological conditions and the same type of growth pattern.

Growth pattern	Agreement of		t	Approx. distance apart in km
	Our chronology	versus		
Same, H	No. 3 (Ref 3)	Huber-Giertz	6	700—800
» , H	No. 6 (MC 16 1314—1636)	»	6	600—700
» , A	Nos. 4 & 5	Netherlands (Bauch, Chronology II)	11	200—350
Different	No. 4 (pattern A)	Huber-Giertz	0.0	500—600

For the hilly Weserbergland around Göttingen Delorme (1972) compared his 1004—1970 A.D. pattern H chronology for oak with adjacent ones in Hesse, Germany; and with many in Northern Germany, Denmark and Sweden, thereby covering distances up to 1000 km. Agreements, over hundreds of years, expressed in terms of *gleichlaufigkeit* (GL) were:

Chronology		Distance from Göttingen, km	GL %
Author	Region		
Huber-Giertz	Hessen	200	65
Eckstein	Hamburg	400	59
»	Schleswig	600	—
Holmsgaard	Denmark	800	56.5
Bartholin	Scania	600	—

Similarly Bartholin (1975) compared his chronologies for recent oak from three sites (S1, S2 and S3) in S. Sweden (Scania) with some of those for Germany and Denmark (but not with that of Bråthen (1982) for west Sweden); results from 1840—1949 were as follows:

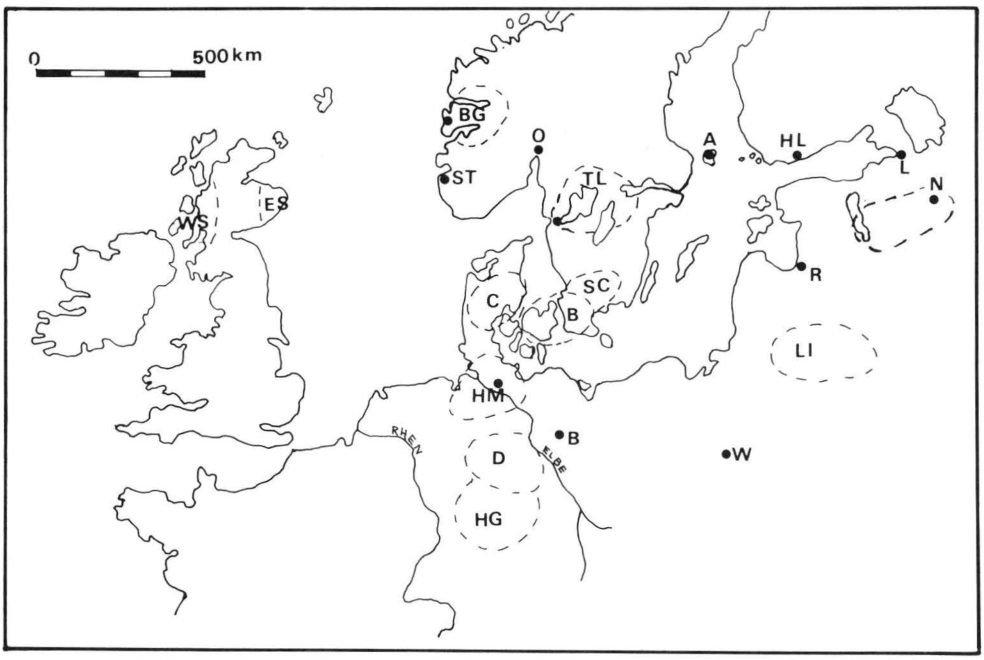
Region	Distance, km	GL %
Denmark	900	57—73
Schleswig	1300	66

These agreements suggest the possibility of there being some agreement between the Lithuanian oak chronology of Bitvinkas and Kairiukstis (G, 173 and 177) with Bartholin's more easterly site, S3, because its climate is more continental than those of sites S1 and S2. The mean distance (see Map) from S3 is about 600 km.

Fig. 1. Northern Europe with key to places mentioned and areas covered by certain important chronologies.

Places	
A	Åland Islands
B	Berlin
HM	Hamburg
HL	Helsinki
L	Leningrad
N	Novgorod
O	Oslo
R	Riga
Sc	Scania
St	Stavanger
Tl	Trollhättan
W	Warsaw

Approximate Areas of High Quality Reference Chronologies		
OAK		
	B	Bartholin: Denmark and Sweden
	Tl	Bråthen: Trollhätten, W.Sweden
	D	Delorme: Gottingen, Weserbergland
	HM	Eckstein: Hamburg
	HG	Huber-Giertz: Hesse
	Li	Bitvinkas: Kaunas, Lithuania
PINE		
	BG	Bergen
	N	Kolchin: Moscow
	ES	Eastern Scotland
	WS	Western Scotland



Pinus Sylvestris

This occurs in southern as well as northern Europe. A recent study of its growth in southern France has been carried out by Tessier (1981).

This pine was prolific in the Tertiary Period and in neolithic times in the southern Baltic (Grabowska, 1983). The *ripa succini* (amber coast), as the stretch from Lübeck almost to Riga was termed by Magnus (1539), was the source of vast finds of amber which gave the city of Danzig international fame. Elsewhere in Northern Europe, prehistoric examples of *pinus sylvestris* have been found in Jutland, northern Scotland and Ireland. More recently pine has been used at Bergen north of the oak belt in Norway (Thun, 1984) and in parts of central Sweden north and east of the oaks measured by Bråthen (1981, 1982). In Finland it was used at Kastelholm (Åland Islands) and samples back to 436 A.D. have been found in Lapland (Bartholin, this volume).

I suggest, as indicated above for oak and as applies to pine in the Alps (Schweingruber *et al.,* G, 115) a similar chronology will apply over a large area. Thus the growth of the Bergen pines may match (see Map) that of eastern Scotland (Schweingruber, 1979) while the growth of those in Finland may match the Novgorod chronology (see Map) formed by Kolchin (1962), stated as being formed from trees from a wide area around that city.

Influence of secular climatic swings

Five or six cold periods since early Neolithic times have been identified in Scandinavia, see Figs. 1 and 2 in the paper by Gräslund (1980); they affected not only human activity but the flora that prevailed in various parts of N. Europe. Thus the migration of Norway spruce *(picea)* from the east has been related to its partial replacement of indigenous *pinus sylvestris.* The last of those cold periods, often termed in western Europe, the »Little Ice Age», is placed by Lamb (1966), as starting at the end of the mild Atlantic conditions which gave rise to the optimum of the High Middle Ages (*c.* 950 to 1200 A.D.). The change to more boreal conditions continued with further small swings up to about 1850. Since then conditions, particularly in the first half of this century, have again become comparable to those before 1200 A.D., i.e. favourable for the growth of trees because of the prevalence of mild westerly air streams.

In Britain we have identified (Fletcher and Tapper, 1984) the cold period between *c.* 1200 and 1850 A.D. with a change in the growth pattern of oak (apparently pedunculate) that grew in woodlands, e.g. in hinterlands in Essex, Kent and Sussex around the southern basin of the North Sea in England and Flanders.

The results are based on observations and measurements of about 420 thin oak boards of radial section from works of art produced in south-east England or Flanders commissioned by royal or noble benefactors. Many of the boards have steady and relatively slow growth and form the panels of 15th and 16th century paintings with an average of *c.* 180 annual rings. Several thicker boards from large medieval chests in cathedrals, abbeys and Oxford colleges were also examined and found to have the same pattern.

The ring-width patterns on the slow-grown oaks could be divided into two groups:

(i) Those of boards with growth rings from *before c.* 1200 are of pattern H, that of the central Europe chronology of Huber-Giertz (G, 27) for sessile oak growing in hilly terrain.

(ii) Those from trees with slow growth *after c.* 1250; they were used to form a separate chronology with a different pattern we call A.

Thus for oak, a change in pattern specific to hundreds of slow-grown pedunculate oaks applies to 'dry' sites. By contrast, in western England relatively fast-grown building timber, of both sessile and pedunculate oak, continued to produce pattern H from 1250 up to the present.

Research on panel paintings was originated by Bauch (G, 133) at Hamburg where he, Eckstein *et al.* have built a chronology of pattern A from many Netherlandish oaks which covers almost the same years, *c.* 1100—1640 A.D., as ours, and match it very well. The Hamburg team were unable to find specimens of pattern A that grew in the Netherlands or in adjacent coastal areas after *c.* 1700.

The problems posed by these findings prompted us to investigate factors which influenced the growth of oak in northwest Europe. One was Becker's model of dendro-ecological zones (G, 101).

The key to solving the problem was the finding that the ring-width pattern of pedunculate oak for a tree or locality is considerably affected by the mean annual *growth rate.* We formed separate chronologies for those of slow, moderate and fast growth as results became available. Comparison with pattern H showed no agreement for slow growth rate; little for those of moderate growth rate; but *good* agreement for those of fast growth (mean ring-widths > 2.5 mm per year). The last, an unsuspected result, suggested that on sites with adequate moisture where pedunculate oak grew fast, pattern H was produced. That interpretation fits the provenance of the species and growth patterns from west to east across NW Europe. To the east, pedunculate oak occurs on lowland sites tending to be dry (often because of rain shadows).

With this model, the presence of pattern A from *c.* 1250 onwards in artifacts made in eastern England and Flanders may be due in fact to the climatic swing which made the sites drier. For two centuries before that time, eastern England and much of NW Europe had been influenced by the prevalence of warm westerlies which brought good growing conditions.

Basic research (wood structure, insect attack and their importance)

Wood Structure

Identification, as recommended by Huber (Huber *et al.,* 1941), of the oak species, *Quercus robur* or *Q. petraea,* was feasible for a substantial proportion of the samples examined (G, 329) the origin of many being in areas known to favour growth of one or the other. As a result, some of our chronologies are linked with a single species, others apply to both (Fletcher, 1984).

Thus we find that the unusual growth pattern A, which applies to chronologies 4 and 5, is limited both in duration and location and appears to be essentially relevant to pedunculate oak. It is this pattern for which we have identified specific years with abnormal vessels in the earlywood (see below).

Abnormally Early Vessels in Oak: This feature (G, 339) has been observed on some 40 % of medieval samples of pedunculate oak that we have dated, and to a lesser degree on samples from Norman, Saxon and Roman times. It is rare and confined to specific years, notably in the second quarter of the 15th century, and has proved reliable as a chronological indicator. The early vessels formed in such years are half, or less than half, the normal average diameter. In some cases annual rings are narrow for four or five years after the ring with abnormal early vessels; in others the widths of the subsequent rings are unaffected. Some examples we have observed are similar to those illustrated by Bolycevcev (1970) for pedunculate oak in his paper on »included sapwood». From his comprehensive study of trees from 50 to 250 years old growing in the Moscow region, he found that included sapwood occurred about once in every 50 years in trees that had experienced two successive dry summers followed by a very cold winter with prolonged frosts. It was accompanied, as illustrated in his paper, by abnormal early vessels, and thereby links the years in which we find the phenomenon with very severe winters. This we had already surmised (Fletcher, 1975) because the two examples most frequently found in our research occur in the period 1430 to 1450 when cold winters and hot summers were known to have occurred in Germany and N.W. Europe (Flohn, 1967).

Attack of oak by cockchafers

The work of Christensen at Copenhagen has shown the important influence on oak growth of cyclical attack by cockchafters (see Appendix). This has not attracted the attention it deserves and is relevant to observations on oak growth in Denmark, Schleswig, Germany and Central Europe. Christensen (see Appendix to this paper) finds that such attack on oak coincided with the onset *c.* 1100 A.D. of agriculture in Denmark, and reached a peak about 1300 and again in the 19th century. High values of the degree of fluctuation (called S. or M.F.) in the ring-width pattern suggest the existence of such insect attack. We find that 10—20 % of the many samples of pedunculate oak from around the North Sea basin have values of S. greater than 20 %, thereby suggesting attack in that area also. As Christensen mentions, disregard of this feature of medieval and of 19th century oak can render climate reconstruction in Europe, as attempted by Eckstein and Bartholin, a profitless exercise as the correlation with monthly meteorological data is rendered feeble.

It may well be that the difficulty of finding suitable samples for chronology formation from c. 1150—1350 A.D. that has been noted by various research workers, e.g. Eckstein for Schleswig-Holstein; Bartholin (1975) for S.W. Scania, and has been attributed, without evidence, by Baillie in Ireland to economic factors, is in fact the result of widespread cockchafers. The presence in samples measured by Bråthen from Lödöse in western Sweden indicates the presence of attack because they are said to show »intensive and oscillating growth». This effect may be one reason why sections of the oak chronologies of Hollstein and Delorme and, to a lesser extent, of Huber Giertz, all show periods with marked oscillating growth.

Conclusion

In the Nordic areas around the Baltic, as around the North Sea, there appear to be aspects of dendrochronology for interesting research likely to produce results which should be of ecological interest, in particular related to secular variations of the climate. Such research needs to take full advantage of past and present research in Europe on dendrochronology and to avoid fruitless effort such as trying to derive meaningful results from applying Fritts' response function approach to European oak without taking into account the effect of insects.

Acknowledgements

This paper has not attempted to include past research, here noted, in Scandinavian dendrochronology, e.g. in Norway by O.A. Hoeg (1956); in Denmark by E. Holmsgaard (1955); in Northern Europe by I. Hustich (1956); and in Finland by P. Mikola (1956). I am grateful for offprints sent to me from research workers in Northern Europe, including some from U.S.S.R. The research reported here was initiated about 1970 by a small grant from the National Portrait Gallery, London, followed by a six year grant from the Leverhulme Trust Fund. It has not been supported by any Science or Environmental Research Association. Finally, I must thank Margaret Tapper for her considerable help in finalising this paper at a time when I was incapacitated.

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Added at Proof (June 1985): Various matters, the species (*Q.robur*) of oak, the start and end of the Hanse trade with exports of Polish/Prussian oak to Lubeck, Flanders and England, indicate that many of the samples with pattern A in our chronologies 4 and 5 were imported from the Baltic. The dating of pattern A is now fixed at a position of +4 years.

Appendix

Tree-rings and insects. The influence of cockchafers on the development of annual rings in oak trees

Kjeld Christensen, National Museum of Denmark.

Several studies have shown that defoliation causes a substantial reduction of the increment of trees. In Copenhagen we have studied the influence of cockchafers *(Melolontha sp.)* and find the growth rings of oak *(Quercus sp.)* are affected at certain times over large areas of Northern and Central Europe, making the use of oak from these areas problematical for dendroclimatology.

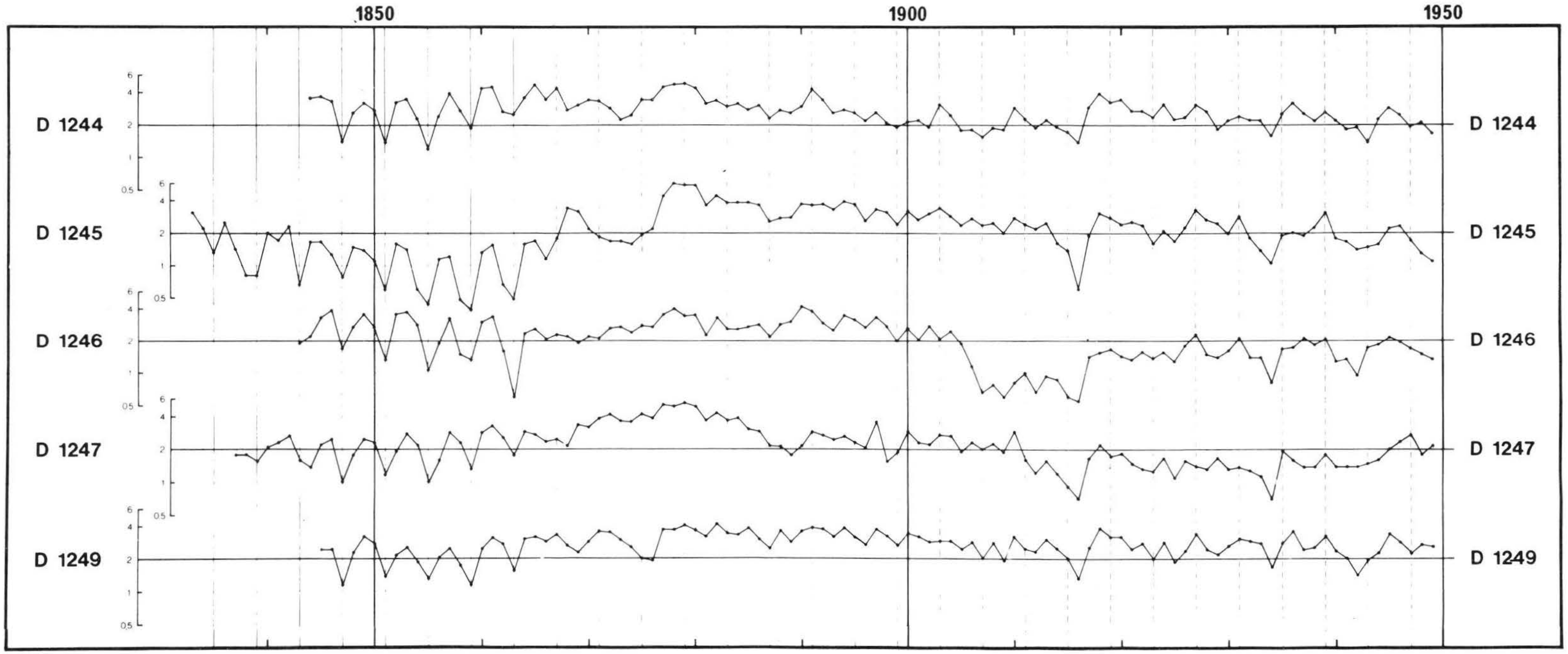
In most parts of Europe two species of cockchafers occur: *Melolontha melolontha* L. and *M. hippocastani* Fabr. In Denmark and North Germany *M. melolontha* has a life-cycle of four years while in most parts of Central Europe it only needs three years to fulfil a cycle. *M. hippocastani* has a life-cycle of four years in the southern part of Jutland as well as in most other parts of Europe, but in North Jutland, Norway, Sweden and Poland it needs five years to complete a generation. To-day only very restricted numbers of cockchafers occur in most European countries, but during the 19th century they were abundant, and both the grubs and the beetles were collected and killed in huge quantities because of the damage they caused to agriculture and forestry. They appear to have become widespread in Denmark with the expansion of agriculture after *c.* 1000 A.D. of, and to have reached a peak *c.* 1300.

Cockchafers with four-year generations live as grubs underground for three years eating all kinds of roots. In the fourth year the fully developed beetles eat the leaves of the trees; they prefer the young leaves of oak trees to those of other species. The beetles emerge from the soil in May, just at or shortly before the time of leafing, in such numbers that they can defoliate the biggest trees in a few days. So only a narrow growth ring is formed.

In areas where the cockchafers have a life-cycle of four years we can in theory expect four different strains of beetles, one strain flying each year. However normally one strain dominates a particular area, so that the beetles only occur in great numbers every fourth year in that area. The same strain of cockchafers is often dominant over a long time and in a wide area; thus the strain flying one year before leap-year dominated in both Denmark, South Sweden and Schleswig-Holstein during the second half of the 19th century. However shifts from one ruling strain to another do occur and local areas may have their own populations with flying-years different from the regionally dominating strain.

Fig. 2 depicts tree-ring curves for five oaks from Vallø in the eastern part of Sealand (*c.* 40 km SW of Copenhagen), published by Holmsgaard (1955). In the decades around the middle of the 19th century the curves show a regular four-year periodicity with nar-

Fig. 2. Tree-ring curves for five oaks from Vallø. Note the narrow rings formed in the years 1835—39—43—47—51—55—59—63 due to defoliation of the trees by cockchafers of the strain flying one year before leap-year. — The thin vertical lines are drawn through these narrow rings to make the periodicity stand out more clearly; where the periodicity ends, the same four-year rhythm is indicated with broken vertical lines.


1850
1900
1950
D 1244
D 1245
D 1246
D 1247
D 1249
6
4
2
1
0.5

row rings in the years 1835 to 1863. These years are known as great cockchafer-years in most parts of Denmark, including Eastern Sealand. Other parts of Denmark also had cockchafer-years later in the 19th century, but the records state that the last great flying-year in the Vallø area was 1863. A similar effect for the same 4-year period is present in the curves published by Bauch, Liese and Eckstein (1967) for six oaks from two forests near Schleswig (minima for 1843—1871 and again from 1879—1907); earlier the rhythm occurred at 4 year intervals but the sequence was one year earlier. The oaks from Gram in S. Jutland published by Bartholin (1973) show the 4-year rhythm from 1746 to 1794 and again from 1826 to 1914.

Elsewhere Nördlinger (1874, 1882) demonstrated a three-year periodicity due to cockchafer-attacks on samples from oaks and other trees from several localities in South Germany. Tree-ring curves with a five-year periodicity are known from archaeological finds, e.g. on undated 10th century curves from five oak trees from the viking-fortress Fyrkat near the town of Hobro in Jutland.

The anatomical structure of the growth rings formed after cockchafer-defoliation have been examined in detail on samples from Gram. When defoliation occurs early wood in the growth ring develops normally, while the width of the late wood is reduced. The transition from early wood to late wood is very abrupt, due to an unusually sudden change in the size of the vessels in the wood. In some of the growth-rings formed in cockchafer-years a spurious growth-ring boundary — similar to a real boundary — may even develop just after the early wood zone. This boundary consists of one or more rows of radially flattened parenchymatic cells, presumably cells that are not fully developed because of the weakening of the tree after defoliation. Experiments have shown that such a boundary can be developed after artificial defoliation of trees.

Defoliation of oak trees by cockchafers is not a rare phenomenon, but a normal feature in the life of the trees in certain periods and certain areas. The samples examined here have not been collected especially to prove the occurrence of this regular growth-rhythm, but have all been used previously by other authors for dendrochronological and dendroclimatological studies, and have thus been regarded as representative for the growth pattern of oak trees in the respective areas; the samples from Schleswig collected later by Eckstein and Schmidt (1974) and by Schmidt (1977) for dendroclimatological studies show essentially the same features.

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