SOME REMARKS ON THE CLIMATE/ TREE GROWTH RELATION IN NORTHERN EUROPE

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ABSTRACT

The growth pattern of Scots pine at its northern forest and tree limit is shortly described. The correlation between the different, annually varying visible growth processes (here including growth in thickness, in length and height and in flowering intensity) and the climate (i.e. temperature) series increases northwards, in general. Similarly, the variation coefficient of the annual growth series of pine increases towards the north. There seems to be a renewed interest in this variation coefficient or "climatic hazard coefficient" of growth series, i.a. as related to crops of cereals, which variation increases towards the northern margin of cultivation.

We still know little about the chemistry and physiology of the tree growth processes themselves, their 'beginning', optimum and slowing-down during the season. But, of course, we can use a tool, in this case visible growth data, without knowing the sophisticated biological machinery behind it. This is certainly the case with tree rings. Compared with an earlier overoptimistic dendrochronological approach (tele-connection over continents without adequate understanding of

the material itself) the use of tree rings as a tool for understanding of earlier climatic variations and for dating of archeological material etc. is nowadays mostly restricted to local problems and to areally small regions, where the co-variation of the annual growth and climatic series has been more carefully established. How small or large this area with simultanous annual co-variation of growth and climate indicators should be, depends on the topographic and climatic type of the area in question.

We should not use too subtile mathematics for an evaluation of growth processes, which we don't yet fully understand. Relevant information concerning the growth pattern 'filters' away if we smooth the growth series too much. The ecologically very important key-years ("Weiserjahre") maight be hidden and their meaning misunderstood. Just as a sudden storm on a low shore might be responsible for a socalled shore line visible for centuries ahead, these key-years might have an influence on growth processes of trees (and perhaps for the forest line itself) for several decades to come. There is a macroclimatic pattern marked by such more or less irregular key-years in the annual growth and climate series in northern Scandinavia and Finland. A kind of a climatic 'Liebig's minimum law' operates at the northern margin of tree distribution (as well as towards the steppes in the south), a "law" easy to formulate, but not to understand.

Tree growth research has again, particularly in the 1970's, gained more interest. This is partly a reflexion of the general upsurge in the 1950's of quantitative methods, for which, for instance, dendrochronology is well suited, perhaps too well. There has also recently been a marked increase in the use of tree rings in climatology, as dating tools in archeology and hydrology and for monitoring environmental changes, see i.a. Vinš (1966) and the recent volume "Dendrochronologie und postglaziale Klimaschwankungen" (Frenzel, 1977).

My work in this field has been restricted to studies of the growth of Scots pine at the northern forest and tree limit in Europe (Hustich,1948) and of black and white spruce in Labrador (Hustich, 1954), This research has mainly been concentrated on visible growth phenomena only, i.e. growth in thickness of the trunk, growth in length of shoots and needles and the annually varying quantity and quality of flowering.

Often we too easily, as certainly I myself has done, correlate tree rings with some climatic indicators, from a weather station far away. We did not - and still don't - fully understand the biology and ecology of the growth process itself or the complicity of the relation between climate and growth. When one follows a problem of this kind long enough, one sooner or later realises the truth of J.B.S. Haldane's wise statement that nature is always more complicated than we think it is. Of course, we can use a tool, in this case tree ring chronology, without understanding its internal "machinery". But nevertheless, we should be more modest and know that there is, on a deeper level, a clear difference between the biological process of growth and the mechanical recordings of tree ring indices and meteorological instruments. We could also be more sceptical towards too sophisticated (or perhaps too simple?) mathematics in connection with tree growth research. It might too much smoth the tremendous complexity of vital biological factors involved, compare i.a. Heikkinen (1980) and Hustich (1978).

The visible growth pattern of pine at the northern or altitudinal margin of its distribution closely reflects both the annual and the long-wave climatic variations. The correlation between climate and growth is markedly higher as nearer we get to the northern (and the altitudinal) tree-line.

In the "forest-tundra" in the north (Figs. 1 and 2) with its scattered trees and small patches of forests, the individual trees are fully exposed to climatic and environmental factors, the concurrence from other trees is more or less

Fig. 1: The distribution of Scots pine in the central part of northern Lapland. The dark shading marks more or less closed pine forests (incl, spruce), the light shading marks the belt of scattered pine stands north of the closed pine forests. Dots indicate small stands of pines or isolated old trees, open circles indicate young pines or pine seedlings and the crosses fossil remains of pine.

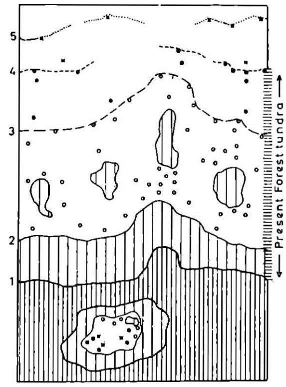

Fig. 2: The schematic succession of tree- and forest-lines: (1) the economical (rational, generative etc.) forest-line. (2) the physiognomical (empirical, vegetative etc.) forest- line, i.e. the timber-line proper. (3) the tree-line. (4) the tree-species line. (5) the historical tree-line, i.e. fossil remains. The forest-tundra belt extends from (1) to (4).
During a climatic fluctuation there is movements of the lines, retreat or advance.

eliminated. The structurally programmed growth of the trees at the northern forest- and tree-line is partly masked by the annual variation of the climate. There is, thus, a marked co-variation not only between climate and growth in thickness (i.e. tree rings) but also between climate and growth in length of shoots and needles (i.e. the annual growth of the assimilation area of the crown) and the annual varying quantity and quality of the flowering.

The good summers in the middle of the 1920's and in the late 1930's resulted in markedly good seed-years for pine. In the end of the 1940's pine seedlings were noted also above the tree line on the mountain slopes. The earlier rather pessimistic forest scientists in the begin of the century thought that seed-years occur only once or twice in a century, see i.a. Renvall (1912). In the northern forests we in the 1940's and 1950's witnessed the result of an unusual climatic improvement: some good seed-years and an increased growth in thickness of old pines, almost a kind of 'rejuvenation'.

The socalled "recent climatic improvement" in the late 1930's was much more clearly marked in northern Europe than in central and southern Europe. It was one of the dynamic climatic events in the north in this century, with great ecological impetus. Its marks are still visible in the advancement of pine on some mountain slopes in Lapland (Fig. 3) - as a scarce belt only, not as dense and promising as we thought it should be in the 1940's and 1950's.

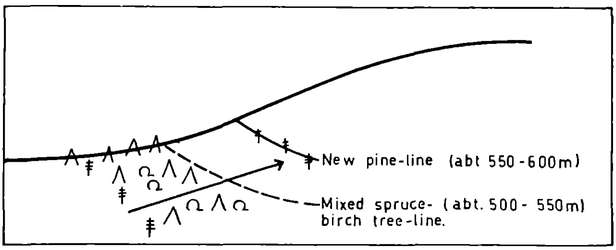

Fig. 3: A schematic idea of how the pine tree-line advanced on the slopes of the Pallastunturi mountain in western Lapland during the 1940's and 1950's.

The opinions of the forest scientists regarding forestry policy in the north changed, of course, with the fluctuation of the climate, from the pessimism in the 1910's into the exaggerated optimism of the late 1930's, compare i.a. Mikola (1978). The often discussed question: is the northern forest limit and the tree line advancing or retreating, has often been answered from rather 'static' premisses without understanding the dynamics of the climate/growth relation. There is nothing permanent about this relation.

The above stressed strong co-variation between climate and growth in the north is verified i.a. by the marked co-variation between radial growth series taken by different authors in different times. This fact is also an argument for the use of tree rings for chronological purpose (Fig. 4).

The eminent Finnish forest scientist August Renvall emphasized in the begin of the century the internal hierarchy or the "law and order", i.e. the organological structure of a pine tree (1914). In the forest-tundra the annual variation of the climate seems, however, in some way to overshadow the

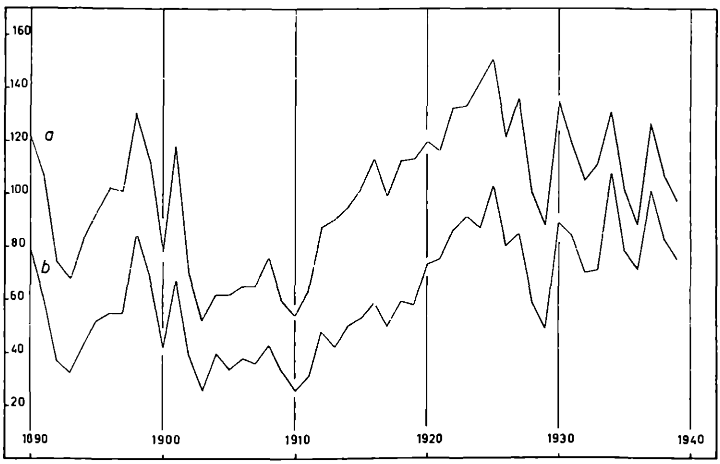

Fig. 4: A comparison of two radial growth series of pine in northern Finland: (a) is a standard series from the Utsjoki valley (Hustich and Elfving 1944), (b) is a sequence of radial growth of pine combined by Mikola (1950) from various parts of northern Finland. The correlation between the sequences (both about 150 trees), measured by different persons in different places, is good.

internal growth rhytmus of the pine tree to a higher degree than we earlier thought possible. The above mentioned "climatic improvement" with its dynamic effects on growth in general has, I believe, played a part in this change of opinion.

Thus, not only the radial growth, but other visible growth processes of the pine as well are closely linked to the annual temperature variations during the short growth season and to the climatic fluctuations in general. This was, for instance, as I mentioned above, illustrated by the marked effects on all kind of organic production (vegetation, crops, animal cycles) of the so called "recent climatic improvement" in the 1930's (for details, see a symposium arranged 1952 by the Geographical Society of Finland, and Erkamo 1955).

If there is such a strong climatically programmed growth pattern its effect should occur simultanously over wide areas. The hypothesis is below illustrated by three diagrams.

Fig. 5 shows that the annual variations in length of secondary shoots of pine are markedly similar in the forest-tundra regions of northern Finland and Norway. The annual variations in growth in length of secondary shoot of old pines in Kevo, Finland correlates very well with growth in length of terminal shoots of young pines in Archangelsk (Stalskaya 1978) regardless of the distance, about 600 km.

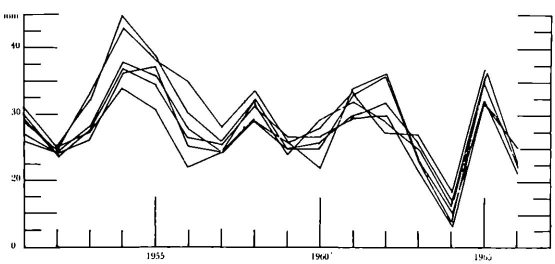

Fig. 5: The annual growth of secondary shoots of pine measured in different parts of northern Norway and Finland: Alta, Börselv, Enontekiö, Karasjok, Rovasuvanto and Utsjoki-Kevo. The co-variation between the sequences is good. (Note that maximum in length growth occurs one year after a favourable season.) 'Key-years' are 1952 and 1964 - 65.

If the relation climate/growth is as strong as visualized above it also means that the annual growth variations of pine should follow the same pattern regardless if the pines grow on a moist or on a dry habitat, on a stony fjord shore or on bogs inlands. This seems to be the case as i.a. demonstrated by Fig. 6.

A similar co-variation is, of course, also evident in the series of growth in thickness of pine, see i.a. Hustich (1948) and Mikola (1950).

This regional problem - over how large regions do annual tree ring sequences co-vary - has been intensively studied, see i.a. Fritts (1971). For dating purposes it is, of course, important that tree ring sequences co-vary over larger areas.

In northern Europe several authors (i.a. Mikola 1950) have tried to correlate tree ring series from different parts. Tree ring series from southern Norway with its heterogenous topography and transitional climatic situation (compare i.a. Slåstad 1957) do not correlate well with material from central Finland. Over large areas in continental northern Finland, Sweden und Norway, i.e. in regions where the temperature is the minimum factor, growth sequences of pine co-vary well.

Thoroughly, with inventive mathematics, this spatial problem of tree growth has been dealt with by Fritts (1972,

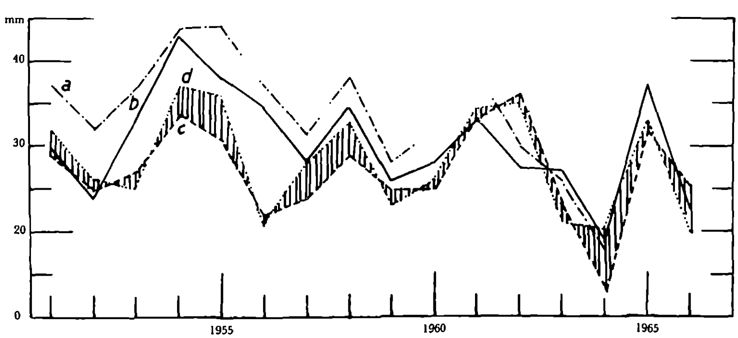

Fig. 6: Comparison between two pairs of growth sequences (length of secondary shoots of pine) on different habitats: (a) branches of 48 pines from stony and boggy terrains, Enontekiö. (b) 59 pines from lichen heaths and dry eskers, Enontekiö. (c) 18 pines grown on a high dry esker in Alta. (d) 20 pines from the moist and stony ocean shore near Alta.

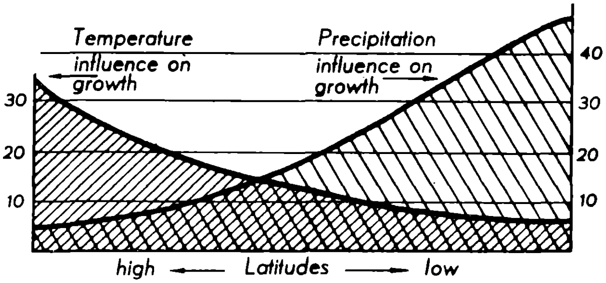

Fig. 7: The climate/growth relation changes with latitude. In the north the temperature is in general the minimum factor for growth of pine; the variation coefficient of the sequences, i.e. the "climatic hazard coefficient" increases northwards. But towards the low or 'dry' latitudes precipitation is in general the minimum factor; there the variation coefficient of the growth sequences can reach still higher values.

1976) and his co-workers in the western USA, recently also by European dendrochronologists (see Feliksik 1972, Bednarz 1975, Eckstein and Bauch 1977 a.o.).

The pine does not show the same strong correlation between growth and temperature in central Europe or in temperate parts of the Soviet Union as the pine at its northern limit. Tree growth porcesses in the north are, as was documented already several decades ago, to an astonishing degree programmed by the July temperature or the varying temperature sums for the growth season. Many other climatic constellations have, of course, been tried, see Hustich (1945), Sirén (1961), Jonsson (1969) a.o. The growth season in northern Europe is short and sudden changes in temperature, for instance, cannot easily be neutralized later on in the season.

Fig. 7 roughly illustrates how the climate/growth relation changes with latitude. In the north the annual growth variation (regardless which kind of organic production, growth in thickness of pine or crops of cereals etc) is strongly programmed by temperature, as marked by the increased size of the variation coefficient of the series. This "climatic hazard coefficient" [1] increases northwards. The growth pro-

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1) $\underline{v} = \% \frac{\sigma}{\underline{M}}$ where σ = standard deviation, $\underline{M}$ = means of the series and $\underline{v}$ = variation coefficient.

cesses in southern dry regions are, however, programmed (except near the altitudinal tree-lines) by the annual variations in precipitation; the variation coefficient for growth sequences in low latitudes increases strongly towards the "dry" limits for growth.

Fig. 7 explains in a simple way why there are such controversial opinions regarding the climate/growth relationship from the middle latitudes. My hypothesis of 1949 was later verified, see i.a. Fritts (1976).

The climatic hazard component for all kind of organic production measured, for instance, by the annual formation of dry-mass, increases northwards. (In earlier days the northern limit of cultivation of barley in northern Europe ran nearly as far north as the pine forest limit. Therefore, old crop series co-variate rather well with tree ring records of pine in the north.)

Instead of comparing long, complete tree ring and climatic series with each other using different kinds of mathematical smoothing or "manipulation", we often simply could use "key-years" ('Weiserjahre', 'index years' etc.), i.e. exceptional, more or less irregularly occuring years with very wide or very narrow rings.

For the crops exceptional minimum-years, of course, usually meant a catastrophe. The effect of such a minimum-year on tree growth in less pronounced. The continuing growth process of a tree more easily absorbs or neutralizes one or a few cold summers. The effects are spread over into the following years growth and beyond it, i.e. the "lag effect" or autoregression, compare Hustich and Elfving (1944), Eklund (1967), Jonsson (1969), Fritts (1976) a.o. It means that in the case of pine the tree ring for the year (n) is to a certain degree positively correlated with the radial growth during the previous year (n-1).

The autoregression coefficient of pine increases northwards(Eklund 1967) and upwards (LaMarche 1974). One explanation is perhaps the 'ecological pressure' (a rather loose expression, I'm afraid) of a species to survive, i.e. a certain growth capacity is carried over into the following year.

This is made possible by pine because the old pine needles in the north stay on up to 7 - 8 years still assimilating; pine needles in the south fall off in 3 - 4 years.

Why such an autoregression is not found, for instance, by Norway spruce is, according to Eklund's pertinent discussion (l.c.), difficult to understand. Spruce species show, however, an other important feature - spruce reflects more markedly than pine the restricting effects of seed years on radial growth. This feature is also characteristic for beech, oak a.o. species.

It seems that the width of the late-wood section (see i.a. Leikola 1969) of a pine tree ring correlates with the current years temperature, whereas the width of the early-wood formation correlates (and probably particularly more clearly for pine in the north) with the temperature of the previous year.

The width of the late-wood of the pine ring is probably influenced by the added assimilation capacity of the new needles (i.e. of the current year) which start to assimilate slightly later in the season.

We need physiologically more relevant studies on how the effect of climatically exceptional growth seasons, i.e. minimum and maximum years, are carried over into the total growth process of the tree.

Organologically speaking, female inflorescences are long shoots, male inflorescences short shoots. There is thus in the north usually a fair correlation between female flowering intensity and the length of annual shoots.

A favourable growth season (n) results in intense flowering during the season (n+1). If the year (n+2) is also favourable, we get a good seed year. In such years also cones on pine near the uppermost tree line have mature seeds. A long sequence of how seed years correlate with radial growth in northern Finland has been worked out by Sirén (1961).

Exceptional years occur at rather irregular intervals. Dendrochronologists have, however, tried to extract from tree ring series certain periods or regular cycles of various length, looking for a connection with, for instance, sunspots etc. This is, of course, a fascinating exercise. But the road into that direction is, however, still rather foggy.

In general, the deep valleys and sharp peaks (i.e. the "key-years") on diagrams of growth sequences occur, as illustrated above, simultaneously over wide areas. The tree ring series reflects the pulsation of the macroclimate itself. The radial growth series, thus, not only register annual climatic variations, but also long-wave climatic fluctuations, i.e. the general pattern of the atmospheric circulation. One of the first to realise this was, as far as I know, the American meteorologist Brier (1948), for later attempts see i.a. Fritts (1971).

The less pronounced dents on our tree ring graphs seem to represent mere local oscillations of the climate of perhaps different ecological happenings in the environment of the trees measured.

If this is the case, efforts to connect tree ring series over long distances (see above about the regional or spatial problem in a lesser scale) could perhaps simply be reduced to a careful analysis of how and when exceptional "key-years" occur. In 1956 I made such an attempt comparing the occurrence of year with very narrow tree rings in spruce species in northern Europe, Labrador and Alaska, see also Haugen (1967). The result of the "teleconnection" in 1956 was not very clear-cut. It displayed, however, one interesting feature, i.e. the shifting of exceptional growth seasons from one year to an other, reflecting the general atmospheric circulation.

There is still reason for a sound scepticism against too simple teleconnections of tree ring series. When doing such circumpolar exercises we must at least use only tree species of the same genus, which show - more or less - the same pattern of response to climatic variation.

Dendrochronologists like to use sensitive or should we say "communicative" trees (i.e. trees grown isolated on mountain slopes, in the forest-tundra etc.) to evaluate their tree ring indices. Features like "double rings" and "missing rings" have, I think, played an overaccentuated rôle in dendrochronology because of the fact that the first and during a long time the most active dendrochronological school is located in an area (Arizone) where such features seem to be common. It seems, however, that "missing" or "absent rings" are, as far as I know, almost entirely absent in material from northern regions, i.e. in areas where the temperature during the growth season plays a more significant role than precipitation.

Of interest in this connection are attempts to use also other tree species as the usual conifers or oak for dating purposes. This in itself stimulates necessary research into the growth physiology of the "new" species, compare for instance, Elling's work on elder (1966).

From an ecological and forestry point of view, it would be of great interest to find a proper correlation between the variation of the climate and the variation of the annual amount of dry-mass (or plain volume of wood). The annual increment in dry-mass or volume of a mature tree is, of course, difficult to estimate and still more difficult to measure. I have tried it, but with poor results. Compare Jonsson (1969).

Some rather academic questions:

Do the trees react exactly similarly towards climatic changes throughout their whole life-cycle?

Do tree rings of very old tree (and the "density coefficients" of these tree rings) reflect the same response to annual climatic variation and to environmental changes as the tree rings of the same tree did one or a few centuries ago?

Do trees of the same or presumably the same species react today to climatic impulses as fossile representants of the species did some thousand years ago?

How does the increased amount of carbonoxid in today's atmosphere effect tree growth in general?

How do the "climatic signals" come through in the tree rings when we increasingly have to deal with introduced tree species or with trees grown in forests where an increased amount of different chemicals is used or with a slowly changing chemical "pollution" of the atmosphere?

How does the climate/growth profile develope for a single tree species throughout its whole area, from the polar tree line to its southern extension?

Recent tree growth research seems to move in two directions:
(1) The physiology of the growth processes in allits details. When, how and why does the early-wood change into the late-wood of the current tree ring? How is the rather slow xylem-formation influenced by other growth processes of the tree? There is already good research in this physiological direction (see the recent work by Tranquillini 1979), but more is needed to understand properly i.a. the biochemistry (compare Kubila-Ahvenniemi 1966) behind the visible results of growth.
(2) The increasing use of tree rings as a chronological instrument for different purposes in other sciences, compare, for instance, the use of dendrochronology for monitoring changes in the quality (degree of pollution etc.) of the environment. It is, however, not easy to separate the influence of the annually and irregularly changing climatic factors from the "non-climatical" factors or what the statisticians call "noise". The line between "signals" and "noise" is certainly very diffuse, perhaps no such line should be drawn at all.

The two paths outlined above seldom cross each other. This symposium is, however, an exception, I mentioned above that we don't necessarily need to know the inner mechanism of an instrument or how an engine works (in this case the growth process itself) which we use. But no harme is done if we try to know it.

In studying the annual variation of different growth processes of pine or other tree species in the north, we at the same time register the breathing or pulsation of the whole vegetation cover. This annual "growth vibration" is in the north in its smallest details (note the Scots pine studies partly presented above) strongly programmed by climatic factors, particularly the temperature. When we study, for instance, the pine growth variations we also register the annually changing relationship between vegetation (i.e. organic production) and, for instance, the frequency of lemmings and other animals.

These simple studies of the annual variation of growth of pine in the north presented above also learn us an ecological truth, which we too often forget. When we analyse causal connections in northern ecology, we should not base our perhaps rather absolute statements on observations during one or two years only. To understand more clearly the true amplitude of the climate/growth relation we must use data for several years. The "climatic hazard coefficient" is high in the north. - The trouble with ecology in the north is that there never is a socalled "normal condition".

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