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Forest resources in Finland and findings on the impacts of air pollution on forests

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Abstract

A large body of information was collected in Finland in 1985-1990 on forest resources and air pollution. Many pollution effects were detected but at the same time it was observed that tree growth has not been affected as a nation wide average. Forest resources have sharply inceased since mid 1970's because removals have been less than forest growth. The authors believe that acidification and other investigated mechanisms of pollution effects do not cause major impacts on wood supply and markets in Finland in the next 10 to 20 years. However, there may evolve problems in restricted sensitive areas. In the time horizon of 50-100 years it is possible that changes in the nutritional status of Finnish forests will cause adverse effects on trees over wider land areas.

1. Introduction

The first national forest inventory in Finland was organized by *Yrjö Ilvessalo* in 1922-24. This survey was completed shortly before the corresponding surveys in Norway and Sweden and its results appeared as the first national forest inventory results in the world. Comparable inventories have been carried out seven more times under the leadership of Ilvessalo and *Kullervo Kuusela*. The first three inventories relied on a line inventory method in which the lines were situated 26 km apart from each other. Kuusela developed a cluster sampling method which was applied for the first time in 1963. Since the 1970's the method has been developed towards the use of permanent sample plots combined with satellite imagery.

The standing stock of the main tree species - pine, spruce and birch - has in this way been recorded and monitored for over a time period of more than 60 years. The mean error of the results has been in the order of plus minus one per cent referring to the total standing stock in Finland. Tree growth has been measured in all inventories by taking increment cores and height increment measurements from sample trees. Tree growth estimates have thus been based on a statistically representative sample which covers all the forests. Growth measurements provide slightly less accurate data than those on standing stock, nevertheless revealing eventual long term trends.

Crown defoliation observations were introduced into the national forest inventory in 1985 and have been taken since that year on an annual basis according to UN/ECE recommendations. A large, multidiciplinary research programme (the HAPRO-programme) was carried out in 1985-1990 to investigate and assess air pollution situation in Finland as well as its impacts on ecosystems, in particular forests and lakes.

Soil acidification implies a long term risk on forest productivity (c.f. de Vries and Breeuwsma 1987). The mechanisms are related to changes in the amounts of both nutrients and toxics in soil solution. Trees growing in severe climatic conditions are especially vulnerable to such changes (Huttunen 1990). Acidification would first threaten trees growing on poor soils (c.f. Raitio 1990).

Nitrogen fertilization serves as a comparison for estimating the impacts of nitrogen deposition on forest resources. Application of nitrogen fertilizers increases the growth of stemwood in Finnish conditions by 1-2 cubic meters per hectare and year (Mälkönen et al. 1990). It has been calculated that forest fertilization has increased the growth of Finnish forests by 1-2 mill. m3 per year in the 1970's and 1980's. Nitrogen is applied in doses of about 150 kg per hectare and the growth response has been observed to continue for about ten years. Annual fertilization area was about 100 000 hectares, and the total amount of nitrogen applied in fertilization in Finland ranged from 6 000 to 8 000 tons per year.

The rate of nitrogen deposition from the atmosphere is low on a hectare basis (2 to 6 kg/ha/yr). However, the total amount of deposition in Finland in the 1980's was about 50 000 tons per year in the form of nitrate-N and about 40 000 tons per year in the form of ammonia-N (Eliassen et al. 1988). It can be estimated that half of the deposition is from natural sources and half is man-made. Two thirds of the Finnish landscape is forests and it can be estimated that most of the nitrogen is deposited into forests. It can thus be concluded that deposition is by far the largest source of man-made nitrogen entering Finnish forests.

Deposition nitrogen cannot have the same effect as fertilization nitrogen. Fertilizers are applied only to highly responsive forests. The growth response of needle uptake can be different from that of root upteke. Airborne nitrogen is toxic in extreme conditions (Ferm et al. 1990). Nitrogen depositing in winter conditions can leach into surface water without contact to trees. Nevertleless, deposition can have a substantial fertilization effect on forest resources given the amounts of nitrate and ammonia it carries.

The carbon dioxide concentration in the atmosphere has risen from about 315 parts per million in the 1950's to over 350 ppm in 1990. Such a change can stimulate photosynthesis and forest growth.

National forest inventory has formed the basis of Finnish forestry policy over the past decades. The main policy principle has been to follow and further develop the concept of sustainable forestry. The threat due to air pollution has added a new dimension both to research and to policy formulation. Air pollution implies uncertainty in empirical, long term trends and relationships. Deposition can have different kinds of effects. It can tend to decrease as well as to increase forest growth. Different sites can react in quite a different way. A large body of new information is now available in Finland to assess the situation.

In this paper we review results from Finnish investigations on forest resources and on the impacts of air pollutants on forests. The specific aim of this paper is to describe the long term trends of forest resources and the impact of air pollutants on these trends. This is in a way a new version of a similar paper by Nöjd (1990). The trends in forest resources are directly relevant to timber market.

2. Methods

21 Forest resources and total growth

The methods of forest inventories have been described in detail in a number of publications (c.f. Kuusela and Salminen 1969, Kuusela and Salminen 1991). The survey in Finland rotates from one region to another so that measurements for certain parts of the country can be as much as five years old. An update was constructed computationally by correcting the latest field measurements by cutting statistics, growth models and increment variation measurements. Standing stock and tree growth were thus updated to corrrespond the situation in the end of the growing season of 1989 (Tomppo and Siitonen 1991).

22. Interannual variation in diameter increment

Acidification and high levels of tropospheric ozone can retard forest growth. On the other hand the increasing CO2 concentration in the atmosphere and the deposition of nitrogen compounds can have a fertilizing effect. In order to study these effects, tree ring analyses were carried out. Trees subject to silvicultural activities improving growth were omitted.

Increment cores were taken from about 2 000 trees in 1989. These trees were selected systematically from the sample plots of the national forest inventory, located all over Finland (for details of the method, see Henttonen 1990).

23. Air pollution research

A whole set of different methodologies was applied in air pollution research including emission surveys, air chemistry measurements, deposition measurements, pollution transformation and transport modelling, vegetation surveys, water quality surveys, controlled laboratory and field experiments etc. The methods applied in Finland have been described in a recent publication of the HAPRO programme (Kauppi et al. 1990).

3. Findings

31. Forest resources and total growth

Finland's forest resources were rather stable from the early 1920's until the 1970's (Fig. 1). During the last 20 years the total growing stock increased from 1 540 mill. m3 to 1 880 mill. m3 that is, by slightly over 20 per cent. The reason to this is that annual growth exceeded the removal of stemwood. In 1985-89 the difference between growth and removals was anually about 25 mill. m3.

The total growth of stemwood in Finnish forests in the years 1985-1989 was 79 mill. m3/year on the average. This is about 25 mill. m3/year above the level recorded twenty years earlier. The relative increase of forest growth was over 40 per cent and thus considerably higher than the corresponding increase in standing stock. The annual removals in 1985-90 accounted for 55.2 mill.m3/year of timber comprising of 21.0 mill.m3/yr of Scots pine, 22.2 mill.m3/yr of Norway spruce and 12.0 mill.m3/yr of decidious trees.

Regeneration of low-producing stands, ditching of peatlands, intensive silviculture of young plantations, bigger volumes in older stands and fertilizations are the main reasons to such a high production increase. The latest future projection on forest growth in 1984 (Forest 2000 Report) clearly underestimated today's wood production.

32. Interannual variation in diameter increment

No general long term trends were detected in the diameter growth of Scots pine. The growth varied substantially from year to year (Fig. 2). The growth patterns differed between regions and sites. For example, in 1987-89 the diameter increment of pine trees growing on peatland sites in northen Finland was 10 to 20 per cent below the average. Those peatland soils were exceptionally cold and frosty following a very cold winter period in 1986-87.

The diameter growth of Norway spruce was relatively high throughout the 1980's with some exceptional years. The high seed production decreased the growth of Norway spruce by 20-30 per cent in the years 1973 and 1989. There was an increasing growth trend of 12 per cent in 20 years between 1967 and 1987 (Henttonen 1990). The trend correlated to weather variables, notably temperature and precipitation. A similar correlation could have existed between tree growth and nitrogen deposition or between tree growth and CO_2 concentration. Such calculations, however, were not yet performed.

33. Air pollution research

There was a general tendency within Finland that concentrations and the levels of deposition of different air pollution compounds were the highest in the southernmost part of the country with another loading maximum in north eastern part of the country (Joffre et al. 1990, Anttila 1990, Järvinen and Vänni 1990, Tuovinen et al. 1990). Similar spatial gradients were measured on trace element concentrations of forest vegetation and lake water chemistry (Ruhling et al. 1987, Kubin 1990, Forsius et al. 1990). Pollution loading in ecosystems was linked with atmospheric emissions from energy production and industries (Johansson et al. 1990).

A large fraction of nitrogen deposition in Finnish forests was absorbed by tree needles (Hyvärinen 1990). Nitrogen is a nutrient to trees but it can have had toxic effects on some sensitive lichen species. This could explain the large scale substitution of pollution sensitive epiphytic species by other, insensitive species (Kuusinen et al. 1990). In

Finland there were no consistent relationships between the regional patterns of air pollution and crown defoliation (Jukola-Sulonen et al. 1990). Crown defoliation incidents rotated from one area to another depending on weather and on epidemic outbrakes of pests and pathogenes.

4. Discussion and conclusions

Up until the end of the 1980's there has been no general decline of forest growth in Finland. On the contrary forest resources have increased more than was projected in the early 1980's. Only some 70 per cent of the annual growth was utilized through removals. Air pollution has not caused large scale market effects in the Finnish forest sector.

There are no research results suggesting that the exports of Finnish forest products are affected by pollution induced market effects in other countries. In fact it has been demonstrated that the international market system is fairly insensitive to small scale perturbations in timber removals (Seppälä et al. 1990).

However, many early warning signals were detected indicating that air pollutants affect Finnish forest ecosystems. Pollution sensitive lichens have declined. Air pollution damage to trees has been detected in small geographic scale at many locations. Surface waters have acidified due to sulphur deposition, and sensitive aquatic organisms have declined. Mass balance calculations indicate that man-made deposition of sulphur and nitrogen compounds have affected element cycles to a substantial extent.

In the light of all the observations it is clear that trees are not among the most sensitive organisms to air pollution. However, man-made emissions have changed the chemistry of the atmosphere (air concentrations and deposition of various chemical compounds) over the past decades and continue to do so. The changes have not decreased the growth of Finnish forests as the country-wide average. Direct evidence of a general fertilization effect of air pollutants on forests is also lacking.

Given the buffering characteristics of typical Finnish soils, acidification is unlikely to cause a general decline of tree growth within the next 10 to 20 years. Within a time frame of 50 to 100 years (a typical rotation period of tree stands in Finland) there may evolve a general nutrition problem of forest soils. Soil acidification is one risk factor. Moreover, the favourable changes in the structure of forest stands seems to be coming to an end. Current research focuses on "early warning regions" that is, in areas of high pollution load and sensitive soils and stands. One possible future scenario in these regions is an increase in pest and pathogen problems.

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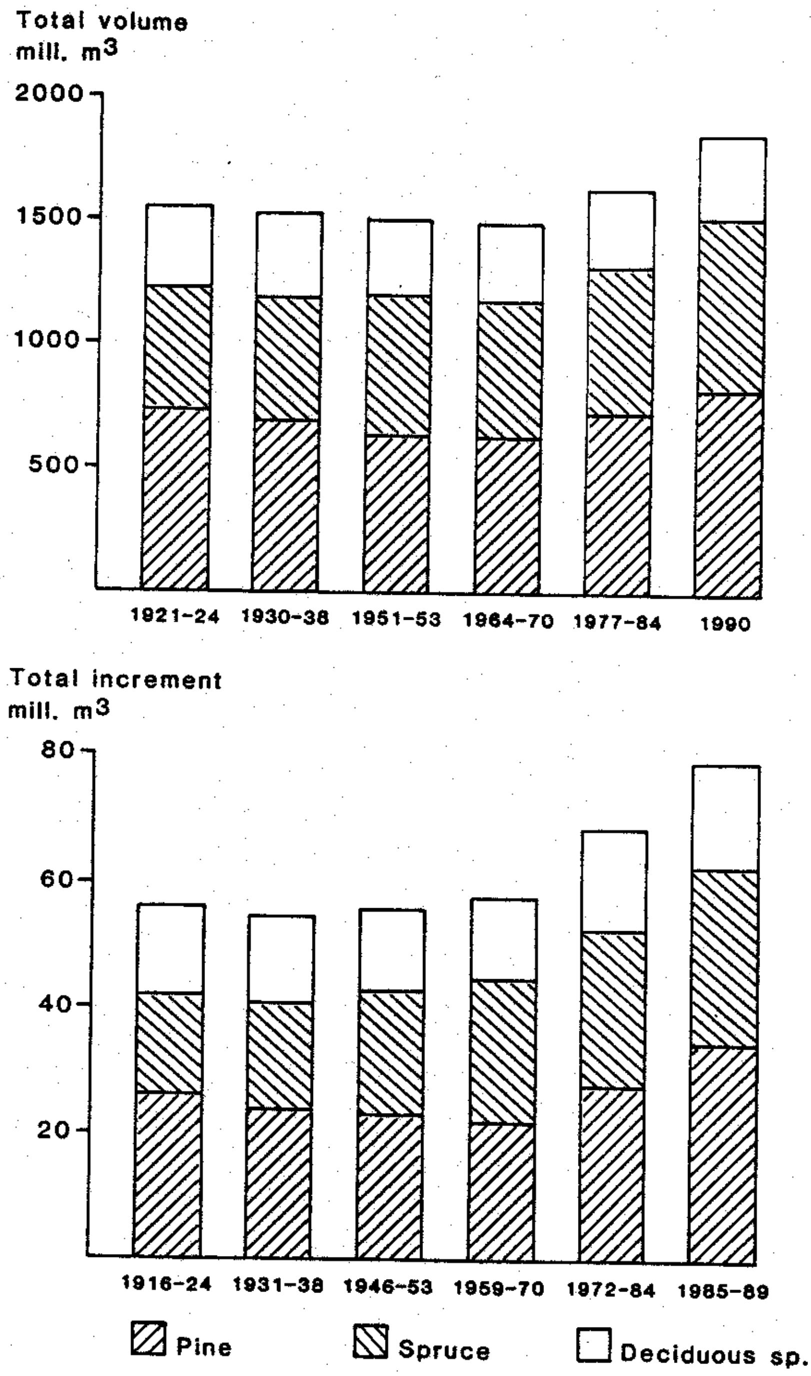

Fig. 1. Total volume and annual increment of the growing stock by main tree species in 1921-1990 on forest and other wooded land in Finland (Tomppo and Siitonen 1991).

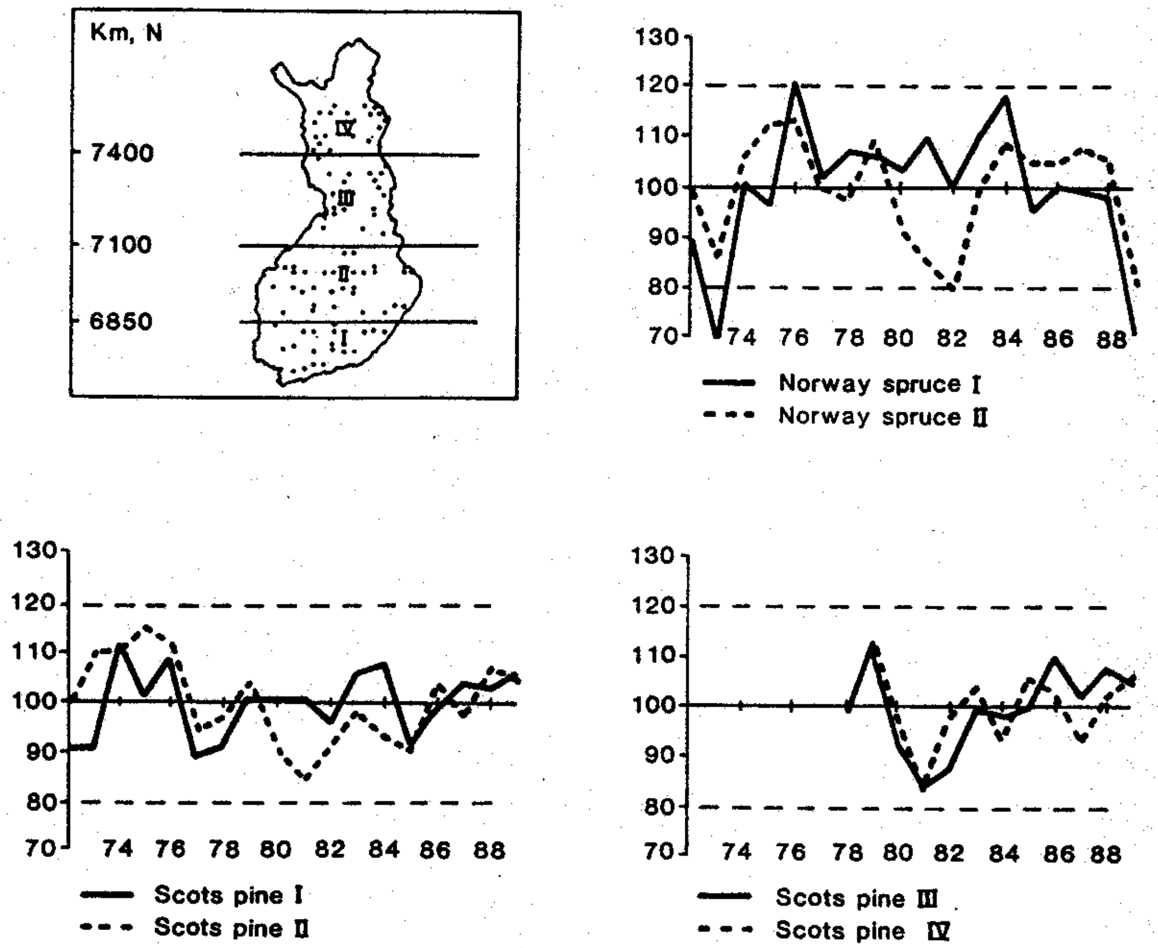

Fig. 2. Variation of tree diameter growth in Finland 1972-89.