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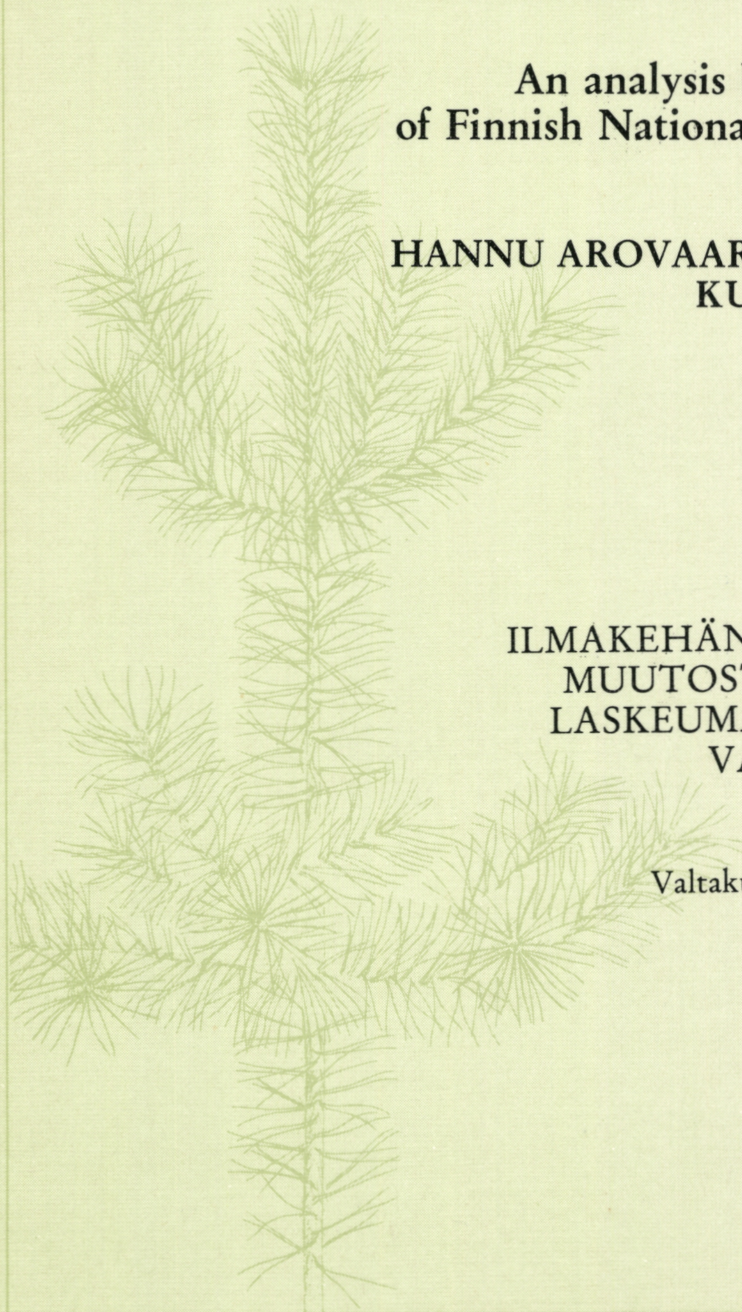
# POSSIBLE EFFECT OF CHANGES IN ATMOSPHERIC COMPOSITION AND ACID RAIN ON TREE CROWTH

## An analysis based on the results of Finnish National Forest Inventories

HANNU AROVAARA, PERTTI HARI &
KULLERVO KUUSELA



SELOSTE

## ILMAKEHÄN OMINAISUUKSIEN MUUTOSTEN JA HAPPAMAN LASKEUMAN MAHDOLLINEN VAIKUTUS PUUSTON KASVUUN

Valtakunnan metsien inventointien tuloksiin perustuva analyysi

HELSINKI 1984

# COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE



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*Cover (front & back):* Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

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AROVAARA, H., HARI, P. & KUUSELA, K. 1984. Possible effect of changes in atmospheric composition and acid rain on tree growth. An analysis based on the results of Finnish National Forest Inventories. Seloste: Ilmakehän ominaisuuksien muutosten ja happaman laskeuman mahdollinen vaikutus puuston kasvuun. Valtakunnan metsien inventointien tuloksiin perustuva analyysi. Commun. Inst. For Fenn. 122: 1—16.

In the study samples from the results of three Finnish National Forest Inventories were analysed. The aim of the study was to analyse, whether it is possible to detect the effects on forest growth of the changes in the atmospheric composition, i.e. increase in carbon dioxide concentration and acidity of wet and dry deposition.

The material from different inventories was sampled by the following procedure. The most important stand characteristics causing stand increment variation were selected. Stands which belong to certain classes of these characteristics were selected for the analyses. After this procedure the distributions of the material in relation to different stand characteristics were quite similar. The increments compared were volume increment percentage without bark for a five-year period and volume increment without bark for a five-year period.

A function predicting five year volume increment percentage without bark was determined using the material sampled from the results of 7th inventory. This function was applied to predicting five year volume increment percentage without bark in the material sampled from the results of 3rd and 6th inventory. In addition the volume weighted increment percentage and volume increment without bark for a five-year period was estimated in each age-class in each inventory.

In both comparisons increment in the material sampled from the results of 7th inventory is systematically on a higher level than in the other two inventories.

The method used is on the other hand very sensitive to systematic differencies in the determination of stand characteristics especially stand age. If stands in 6th and 7th inventory were determined systematically 5 years too old compared to 3rd inventory, the difference between 3rd and 7th inventory diminishes statistically non-significant.

The increase in growth cannot be explained unambiguously using the dependence of tree growth on climatic conditions as expressed in growth-indices. Thus the study gives some support to the hypothesis that changes in the composition of the atmosphere and/or the nitrogen compounds in acid deposition have increased forest growth in southern Finland.

Tutkimuksessa analysoitiin valtakunnan metsien kolmen inventoinnin (3., 6. ja 7.) tuloksista saatua näytettä. Vertaamalla eri inventoinneista laskettuja kasvulukuja keskenään etsittiin merkkejä ilmakehän koostumusten muutosten, ts. ilman hiilidioksidipitoisuuden lisääntymisen tai happaman laskeuman aiheuttamista metsän kasvun muutoksista.

Eri inventoinneista valittiin otokset seuraavasti. Maastossa pääosin silmämääräisesti arvioiduista metsikkötunnuksista valittiin sellaiset, jotka ovat merkityksellisimpiä metsikön tilavuuskasvun vaihtelun kannalta. Sen jälkeen vertailuun poimittiin vain näiden metsikkötunnusten tiettyihin luokkiin kuuluvat metsiköt. Tällöin oli myös mahdollista eliminoida metsänhoidon ja metsänparannuksen vaikutuksia tuloksiin. Vertailtavat aineistot eivät olennaisesti poikenneet toisistaan.

7. inventoinnin aineiston pohjalta laadittiin metsikön viiden vuoden kuoretonta tilavuuskasvuprosenttia ennustava yhtälö, jossa selittävinä muuttujina ovat metsikön ikä ja puuston kuoreton tilavuus. Tällä yhtälöllä ennustettiin 3. ja 6. inventoinnin tuloksista valittujen metsiköiden tilavuuskasvuprosentteja ja verrattiin niitä vastaaviin koepuiden perusteella estimoituihin tilavuuskasvuprosentteihin. Tämän lisäksi estimoitiin kunkin inventoinnin kussakin ikäluokassa puuston tilavuudella painotettu viiden vuoden kuoreton tilavuuskasvuprosentti ja viiden vuoden kuoreton tilavuuskasvu. Molempia kasvulukuja vertailtiin sen jälkeen eri inventoinneista valittujen otosten välillä.

Molempien vertailujen tulokset osoittavat 7. inventoinnin kasvulukujen olevan selvästi korkeammalla tasolla kuin aikaisempien inventointien kasvulukujen. Menetelmä on kuitenkin herkkä varsinkin puuston iässä oleville systemaattisille poikkeamille. Myöskään kovin pienien kasvumuutosten toteaminen ei tällä menetelmällä ole mahdollista suuren satunnaisvaihtelun vuoksi. Mikäli 6. ja 7. inventoinnin metsiköt on arvioitu systemaattisesti 5 vuotta liian vanhoiksi verrattuna 3. inventointiin, 3. ja 7. inventoinnin ero pienenee tilastollisesti merkityksettömäksi.

Kasvun muutosta ei pystytty selittämään ilmastollisilla muutoksilla ainakaan yksiselitteisesti. Tutkimus antaakin tukea hypoteeseille, että ilmakehän koostumuksen muutokset ja/tai happaman laskeuman typpiyhdisteet olisivat lisänneet metsän kasvua Etelä-Suomessa.

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# CONTENTS

# PREFACE

The study at hand is an attempt based on Finnish National Forest Inventories to analyse whether it is possible to find any change in the level of forest increment, that can not be explained by changes in silviculture, in the structure of the forests or changes in climatic conditions. If significant change in increment is found, it will give evidence for the hypothesis that changes in atmospheric composition, e.g. increase in $CO_2$ concentration of the atmosphere and changes in nutrient availability in forest soils mainly due to increase in nitrogen deposition have increased forest increment.

Of the authors Arovaara has carried out the calculations. The manuscript is constructed by Arovaara and Hari together. All of the authors have taken part to formulation of the working hypotheses, and Kuusela especially to critical evaluation of increment measurements in the inventories.

The authors want to thank especially MML Hans-Gustav Gustavsen for delivering material from the third inventory readily suitable for computer calculation. Mr Matti Kujala gave substantial help in the beginning of calculation procedure. Also we want to thank Mrs Anja Leskinen for preparing the tables and figures.

The manuscript has been read by Professor Risto Seppälä and M. Sc. Risto Ojansuu whose suggestion has been taken into consideration. The authors want to thank all those persons who have contributed to this work.

*Authors*

# 1. INTRODUCTION

One result of industrialization is that some environmental factors, which affect the functioning of the biosphere, are changing. There has been a steady increase in the $CO_2$ concentration of the atmosphere (Fig. 1). The pre-industrial carbon dioxide concentration has been estimated to be about 290 ppm (WMO/ICSU/UNEP 1981). The present concentration is about 340 ppm and is increasing by 1 ppm/year (Fig. 1).

Carbon dioxide is the source of carbon in the photosynthetic production of carbohydrates. A low $CO_2$ concentration in the air limits photosynthesis in conditions where there is an adequate water supply and sufficient light. An increase in water use efficiency is also likely to take place since the inflow of $CO_2$ is accelerated in suboptimal water conditions due to the increased partial pressure difference between intercellular and ambient air (see e.g. Osmond, et al. 1980). There is a lack of knowledge about the long term effects of increased atmospheric carbon dioxide concentration on growth. Results from short term experiments show that photosynthesis accelerates in very high ambient $CO_2$ — concentrations (Fig. 2).

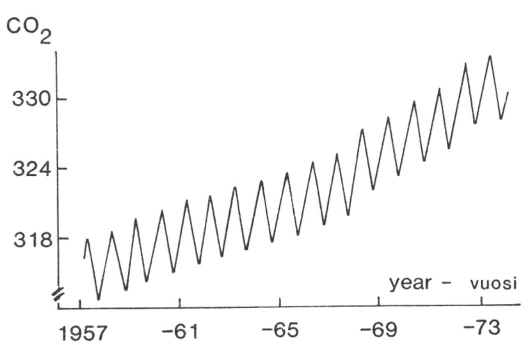


Fig. 1. $CO_2$ concentration at the Mauna Loa observatory. (Reproduced by Broecker, et al. (1979) from the measurements by Keeling and his coworkers).
*Kuva 1. $CO_2$-pitoisuus Mauna Loan observatorion mittauksissa. (Keelingin ym. mittausten perusteella laatinut Broecker ym. (1979)).*

Another trend-like change is growing conditions caused by the industrialization-induced combustion of fossil fuels is the increasing acidity of rain water and the increasing acidity of dry deposition too. The main effect of acid deposition is through changes in the soil processes. The main process affected is cation exhange. This is likely to cause changes in the cation uptake of plants. The analyses of pine needles collected from two stands during a period extending from 1950 to 1980 indicates that the nutrient content of needles is changing in southern Finland (Raunemaa et al. 1982).

About 1/3 of the acid deposition is composed of nitrogen compounds in a form readily available for plant uptake. The most common factor limiting plant growth in our forest soils is nitrogen deficiency. In southern Finland the total nitrogen load is 6—8 kg/ha x a. The natural load is probably

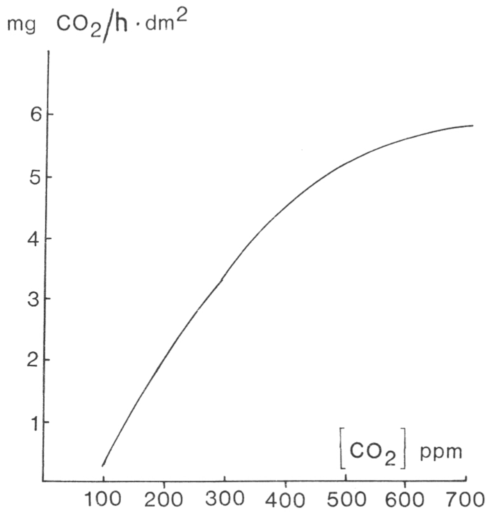


Fig. 2. Dependence of photosynthesis on atmospheric $CO_2$ concentration. Measurements carried out at Hyytiälä, middle of Finland. Light intensity 630 $\mu E/m^2$ x s, temperature 17,5°C.
*Kuva 2. Fotosynteesin riippuvuus ilmakehän $CO_2$-pitoisuudesta. Mittaukset tehty Hyytiälässä, Keski-Suomessa. Valon intensiteetti 630 $\mu E/m^2$ x s, lämpötila 17,5°C.*

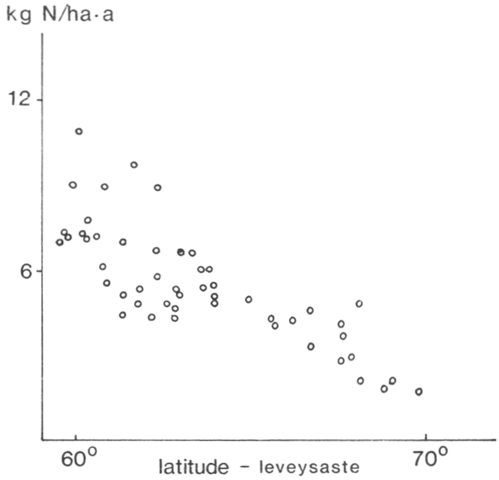


Fig. 3. Nitrogen deposition (total N) in Finland as a function of latitude. Reproduced from measurements by Järvinen and Haapala (1980).

*Kuva 3. Typen laskeuma (kok-N) Suomessa eri leveyspiireillä. Laadittu Järvisen ja Haapalan (1980) mittausten perusteella.*

about 1—2 kg/ha x a, which is the load in northern Finland (Fig. 3).

One very important factor causing variation in tree growth from one year to another is the changes in the climatic conditions. One or two unfavourable years for tree growth will result in a lower increment than average after the unfavourable period. This is due to the autoregressive features in tree increment, which are strong, especially in extreme growing conditions (c.f. Fritts 1976). Summer temperatures are the dominating factor causing variation in growth. A warm early summer is especially favourable. According to studies carried out on annual rings, rainfall is of minor importance during most of the summers in Finland (Mikola 1950). It has, however, been observed that in middle and northern Sweden irrigation improves stem growth by about 20 % and 10 % respectively (Axelsson 1981). It is obvious that normal variation in precipitation does not affect annual amount of photosynthates produced in young trees (Linder and Troeng 1980). However, large trees may be much more susceptible to drought (Axelsson 1983).

There has been an increase since the early fifties in silvicultural measures and forest amelioration-peatland drainage and forest fertilization (Kuusela 1982). This has resulted in a clear change in the structure of the forests. More than 5 million hectares of peatland has been drained, and forest fertilization has also been extensive.

This has led to an increase in the total volume and total volume increment (Kuusela 1977). The estimated total volume increment has increased from 55,23 million $m^3$/a at the time of the third national forest inventory (1951—1953) to 57,43 million $m^3$/a at the time of the sixth inventory (1971—1976). However, the age structure and tree stocking are very much determining the amount of increment. In the beginning of 1950's the age structure and tree stocking were favourable for large increment. Since then the age structure has become more unfavourable and there should have been a decrease in increment. The unfavourable age structure is caused by an increase in the area of young plantations which would not become productive before 1980's (Kuusela 1972).

Since the 6th national forest inventory was carried out there has been a very pronounced increase in forest increment. Preliminary results (Kuusela 1982) indicate that the total increment would be about 65 million $m^3$/a compared to the increment in the early 1970's of 57,43 mill. $m^3$/a. The improved level of silvicultural measures, forest fertilization, increase in forested area due to peatland drainage and afforestation of agricultural land are partly responsible for the increase in the increment. But have the changing enviromental factors also contributed to the increase as is indicated by the study of old protected stands (cf Hari et al. 1984, in print). A sharp increase in radial growth was also evident from the beginning of the 1970's in that study. The aim of this work is to obtain an estimate of the effect of increasing atmospheric $CO_2$ concentration and acid deposition on forest growth from the material provided by national forest inventories.

# 2. MATERIAL AND METHOD

## 21. Material

The material is a subsample from three National Forest Inventories namely the third (carried out in 1951—1953), sixth (carried out in 1971—1976) and seventh (carried out in 1977—). The methods of inventories are described in detail by Ilvessalo (1952), and by Kuusela and Salminen (1969). The latter reference refers to the fifth inventory. There are only minor differences in the sixth and seventh inventory compared to the fifth.

In the third inventory a circle sample plot (r=17,85 m) was measured at intervals of one kilometer along lines passing from SW to NE. These lines were located at a distance of 13 kilometers from each other in southern Finland.

In the later inventories, relascope sample plots were measured in inventory tracts located 8 kilometers from each other in southern Finland. In each tract 4 increment sample plots were measured. The study area consisted of forestry board districts in middle and eastern Finland (Fig. 4). These forestry board districts were selected because this part of Finland comprises geographically a rather uniform area. However, the area from which the material was sampled in the third inventory was enlarged in order to get a satisfactory number of sample plots in third inventory. The number of sample plots used in the comparison and certain characteristics of the compared material are presented in Table (1) and Fig. (5).

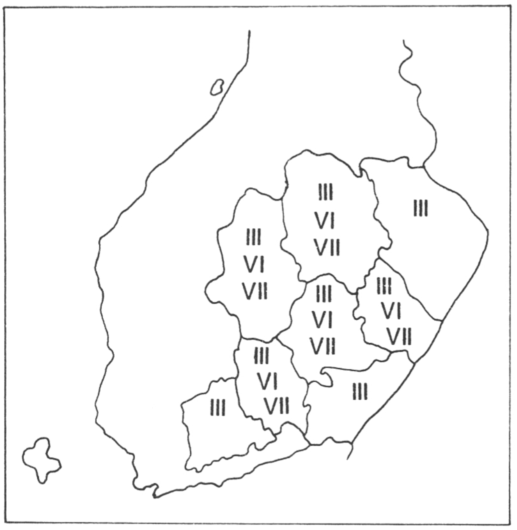


Fig. 4. Those forest board districts from which the material was collected. Numbers refer to different inventories.

*Kuva 4. Piirimetsälautakunnat, joiden alueilta aineisto kerättiin. Numerot viittaavat eri inventointeihin.*

## 22. Method

A subsample was sampled in order to eliminate the effect of changing silvicultural practises. It was assumed that this would be achieved by sampling plots which were located in stands with similar stand structure. Selection of the material was based on stand characteristics, most of which are determined subjectively in the field.

Table 1. Some characteristics of the material used in the study.
*Taulukko 1. Eräitä tietoja tutkimusaineistosta.*

a=sub-dry mineral soil sites,
b=sub-dry stony mineral soil sites.
*a=kuivahkot kankaat,*
*b=kuivahkot, kiviset kankaat.*

| Inventory<br>*Inventointi* | Number of plots<br>*Koealojen lukumäärä* | Site type distribution<br>*Kasvupaikkajakauma*<br>a | <br><br>b | Mean volume without bark<br>*Keskim. kuutiomäärä kuoretta*<br>m³/ha | Mean age<br>*Keskikä* | Mean vol. incr.-% (5a) without bark<br>*Keskim. 5 v. kuutiokasvu-% kuoretta* | Mean vol. incr. (5a) without bark<br>*Keskim. 5 v. kuutiokasvu kuoretta*<br>m³/ha | $s^2$ of the mean vol. incr. (5a) without bark<br>*5 v. kuutiokasvun $s^2$ kuoretta* |
|---|---|---|---|---|---|---|---|---|
| 3. | 109 | 89 | 20 | 113,6 | 74,9 | 16,5 | 18,76 | 87,88 |
| 6. | 143 | 98 | 45 | 116,3 | 71,7 | 16,5 | 19,19 | 86,32 |
| 7. | 202 | 138 | 64 | 122,3 | 72,5 | 17,8 | 21,77 | 84,51 |
| Diff. between 7. and 3. | | | | 8,7 | 2,4 | 1,3 | 3,01*** | |
| ” ” 7. and 6. | | | | 6,0 | 0,8 | 1,3 | 2,58* | |
| ” ” 6. and 3. | | | | 2,7 | 3,2 | 0,0 | 0,47 | |
| *Erot eri inventointien välillä.* | | | | | | | | |

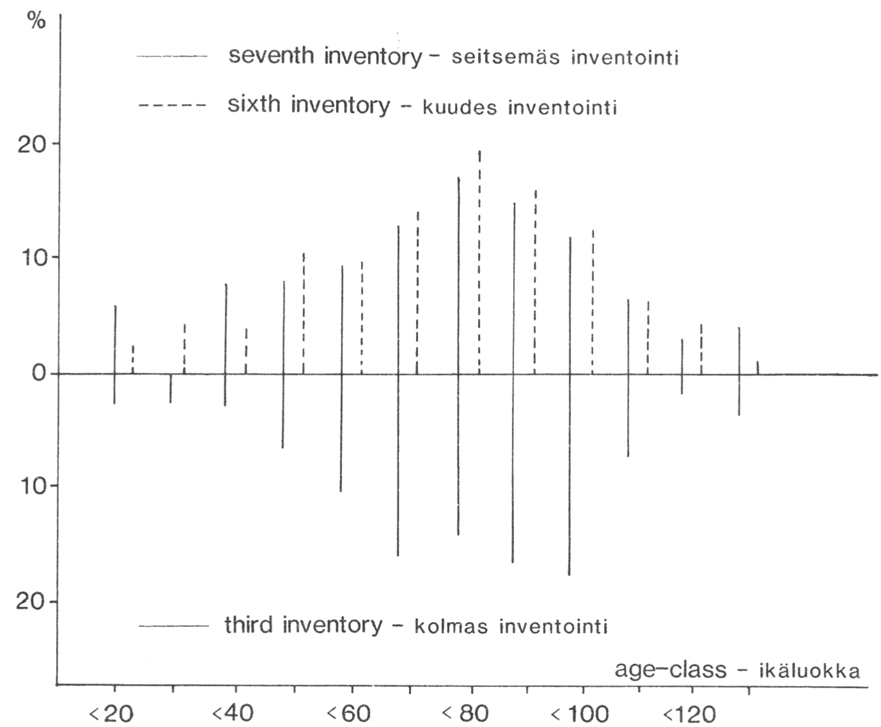


Fig. 5. Age distribution of the sampled stands.
*Kuva 5. Tutkimusmetsiköiden ikäjakauma.*

Stand characteristics used were:

1. Forest site type, sub dry mineral sites, also stony sites included
2. Development class, thinning, preparatory and mature stands
3. Age class, stands over twenty years old
4. Stand quality, good and satisfactory stands
5. Pine-dominated stands
6. One-storeyed stands

See Kuusela and Salminen (1969) for the definition of these characteristics. All volume units were calculated excluding bark. The mean increment percentages in different age classes and in the material as a whole, and mean age were computed from the material of these three inventories by weighting with volume. Comparison of the increment in different inventories was possible, because the age composition of the compared material is approximately the same in these three inventories (Fig. 5).

However, there might be a possibility that the change in increment based on calculations in which the material from each inventory was treated as a single group originates from a random event or from an exceptionally strong change in some part of the material. To avoid this kind of bias, a function predicting the increment percentage of a stand excluding bark was determined from the material obtained from the 7th inventory. Stand age and volume without bark were used as independent variables. The function and some data

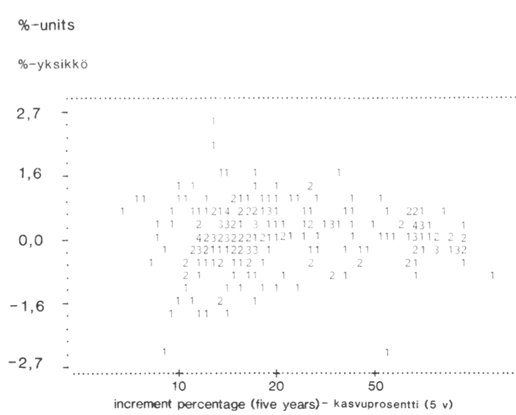


Fig. 6. Residual deviation of the function in Table (2), (1—4, number of stands).
*Kuva 6. Taulukossa (2) esitetyn mallin jäännösvaihtelu, (1-4, metsiköiden lukumäärä).*

are available in Table (2) and Fig. (6). The increment percentage of the stands of the 3rd and 6th inventory were predicted then using this function.

There are of course difficulties when comparing different inventories. The methods used to calculate increment, stand age and stand volume, have changed. The method used in the sixth and seventh inventory for stand volume estimation gives on the average 3 %

Table 2. The function predicting volume increment percentage.
The correction coefficient ($s^2/2$) has been added to the constant of the equation (Meyer 1941).

*Taulukko 2. Viiden vuoden kuutiokasvuprosenttia ennustava yhtälö.*
*Korjaustekijä ($s^2/2$) on lisätty yhtälön vakiotermiin (Meyer 1941).*

| Variable *Muuttuja* | Coefficient *Kerroin* | t-value *t-arvo* | |
|---|---|---|---|
| Constant *Vakio* | 5,287 | | |
| ln (age) [2,5] *ln (ikä)* [2,5] | —0,048 | —21,87 | $s_e$=0,244 r =0,934 $r^2$=0,872 |
| ln (vol.) [2] *ln (tilav.)* [2] | —0,027 | —6,35 | |

more volume, which must be corrected. In this study it is not possible otherwise to evaluate the effects of changes in increment calculation method quantitatively. It is therefore concluded according to Kuusela and Ervasti (1969), that the methods used in the third, sixth and seventh inventory do not give systematic differences in estimating volume increment.

The most difficult characteristic is stand age. In the sixth and seventh inventory, age is automatically weighted by basal area. In the third inventory stand age was determined using different numbers of sample trees. The difference depends on the age heterogeneity of the stand. Pure pine stands are usually even-aged, but mixed stands may be more heterogeneous.

It is also possible that age determination in the third and the later inventories would give systematic differences in stand age (Ilvessalo 1952, Valtakunnan metsien ... 1977). Knowing that this method is sensitive to differences in stand age, sensitivity analyses is carried out for this method.

# 3. RESULTS

The change in volume increment from the middle of this century up until today is depicted in Fig. (7a). The relative climatic growing conditions as mean growth indices (Thammincha 1981, Tiihonen 1983) and the temperature sum development for the increment calculation period are also presented in the lower part of the Figure (7b). Temperature sums are calculated by the method presented by Ojansuu and Henttonen (1983). In this figure the climatic conditions during the third inventory have the value of 100. It appears from Fig. (7) that the increase in volume increment is clear, when comparing the 3rd, 6th and 7th inventories. According to the t-test, the difference between the third and seventh inventory is statistically significant at the risk level of 0,1 %.

The increment percentages for each stand in the material selected from the third and sixth inventory were predicted according the regression determined from the material from the seventh inventory (Table 2). The means of the predicted and measured increment percentages in different stand age classes are depicted in Fig. (8) and (9). According to these figures the difference is rather systematic in all age classes. The number of sample plots is, however, not very high in most of the classes. The difference is much more pronounced in volume increment than

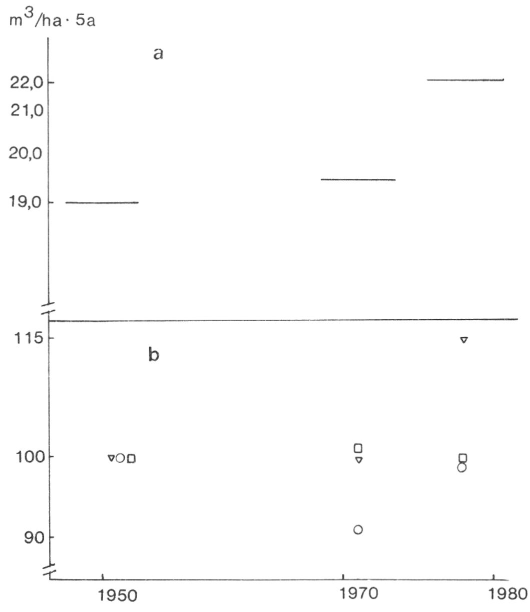


Fig. 7. a) Five-year volume increments from third to seventh inventory.
b) Relative mean growth-indices (according to Tiihonen (1983) ( ▽ ) and Thammincha (1981)(o) and relative mean temperature sum (□) of increment calculation period in the sampled material in each inventory.

*Kuva 7. a) Tutkimusaineiston viiden vuoden tilavuuskasvut kolmannesta seitsemänteen inventointiin.*
*b) Suhteelliset kasvuindeksit (Tiihonen (1983) ( ▽ ) ja Thammincha (1981)(o) ja suhteellinen keskimääräinen lämpösumma (□) tutkimusaineistojen kasvunlaskentajakson aikana.*

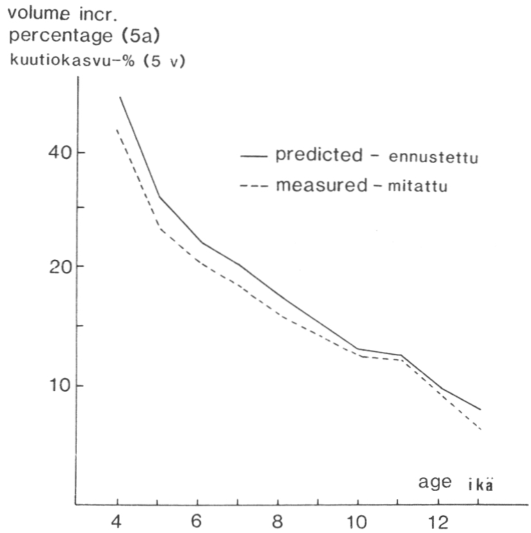


Fig. 8. Mean of the volume weighted increment percentage in different age-classes, (e.g. 6 = 60—69 a). Solid line: according to the function in Table (2). Dashed line: estimated from the material sampled from the third inventory data.

*Kuva 8. Kuutiomäärällä painotettujen kuutiokasvuprosenttien keskiarvo eri ikäluokissa (esim. 6=60–69 a). Yhtenäinen viiva: taulukon (2) yhtälöllä ennustettu. Katkonainen viiva: kolmannesta inventoinnista valitun otoksen perusteella laskettu.*

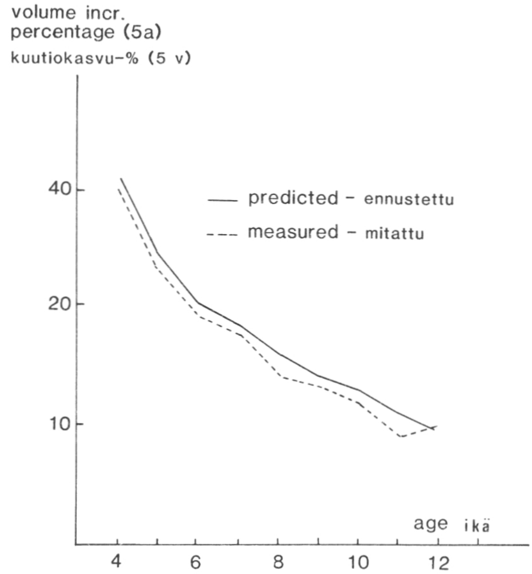


Fig. 9. Mean of the volume weighted increment percentage in different age-classes, (e.g. 6=60—69 a). Solid line: according to the function in Table (2). Dashed line: estimated from the material sampled from the sixth inventory data.

*Kuva 9. Keskimääräinen kuutiomäärällä painotettu kuutiokasvuprosentti eri ikäluokissa (esim. 6=60–69 a). Yhtenäinen viiva: taulukon (2) yhtälön avulla ennustettu. Katkonainen viiva: kuudennesta inventoinnista valitun otoksen perusteella laskettu.*

Table 3. Mean volume, mean volume increment percentage for a five year period and mean volume increment for a five year period (all without bark) in different age-classes in 3rd and 7th inventory.

*Taulukko 3. Keskikuutio, keskim. viiden vuoden kuutiokasvuprosentti ja kuutiokasvu (kaikki kuoretta) eri ikäluokissa kolmannesta ja seitsemännestä inventoinnista valitussa aineistossa.*

| | 3rd inventory — *3. inventointi* | | | | 7th inventory — *7. inventointi* | | | |
|---|---|---|---|---|---|---|---|---|
| Age (x10) | Mean volume | Mean volume increment percentage (5a) | Mean volume increment (5a) | Number of stands | Mean volume | Mean volume increment percentage (5a) | Mean volume increment (5a) | Number of stands |
| *Ikä (x10)* | *Keskikuutio* m$^3$/ha | *Keskim. 5 v. kuutiokasvuprosentti* | *Keskim. 5 v. kuutiokasvu* m$^3$/ha | *Koealojen lukumäärä* | *Keskikuutio* m$^3$/ha | *Keskim. 5 v. kuutiokasvuprosentti* | *Keskim. 5 v. kuutiokasvu* m$^3$/ha | *Koealojen lukumäärä* |
| 1—2 | 29,77 | 75,00 | 22,32 | 3 | 34,09 | 67,29 | 22,87 | 11 |
| 2—3 | 50,30 | 37,54 | 18,88 | 3 | — | — | — | — |
| 3—4 | 108,43 | 24,46 | 26,52 | 3 | 58,55 | 39,54 | 22,87 | 16 |
| 4—5 | 110,01 | 24,79 | 27,26 | 7 | 92,21 | 29,74 | 27,42 | 16 |
| 5—6 | 127,00 | 20,59 | 26,15 | 11 | 115,75 | 24,01 | 27,79 | 19 |
| 6—7 | 116,02 | 18,07 | 20,96 | 17 | 146,31 | 18,40 | 26,88 | 26 |
| 7—8 | 111,49 | 15,34 | 17,10 | 15 | 137,59 | 16,24 | 22,34 | 35 |
| 8—9 | 109,89 | 13,82 | 15,19 | 18 | 145,97 | 13,33 | 19,45 | 30 |
| 9—10 | 132,49 | 12,04 | 15,95 | 19 | 134,59 | 12,39 | 16,68 | 24 |
| 10—11 | 94,28 | 11,83 | 11,15 | 8 | 144,83 | 10,93 | 15,83 | 13 |
| 11—12 | 122,55 | 9,77 | 11,97 | 2 | 113,80 | 10,37 | 11,80 | 6 |
| 12— | 70,70 | 7,91 | 5,57 | 4 | 145,04 | 8,52 | 12,35 | 8 |

Table 4. Mean volume, mean volume increment percentage for a five year period and mean volume increment for a five year period (all without bark) in different age-classes in 6th and 7th inventory.
*Taulukko 4. Keskikuutio, keskim. viiden vuoden kuutiokasvuprosentti ja viiden vuoden kuutiokasvu (kaikki kuoretta) eri ikäluokissa kuudennesta ja seitsemännestä inventoinnista valitussa aineistossa.*

| | 7th inventory — *7. inventointi* | | | | 6th inventory — *6. inventointi* | | | |
|---|---|---|---|---|---|---|---|---|
| Age (x10) | Mean volume | Mean volume increment percentage (5a) | Mean volume increment (5a) | Number of stands | Mean volume | Mean volume increment percentage (5a) | Mean volume increment (5a) | Number of stands |
| *Ikä (x10)* | *Keski-kuutio* m³/ha | *Keskim. 5 v. kuutiokasvu-prosentti* | *Keskim. 5 v. kuutiokasvu* m³/ha | *Koealojen lukumäärä* | *Keski-kuutio* m³/ha | *Keskim. 5 v. kuutiokasvu-prosentti* | *Keskim. 5 v. kuutiokasvu* m³/ha | *Koealojen lukumäärä* |
| 1—2 | 34,09 | 67,29 | 22,87 | 11 | 29,80 | 72,30 | 21,54 | 3 |
| 2—3 | — | — | — | — | 33,85 | 58,25 | 19,71 | 6 |
| 3—4 | 58,55 | 39,54 | 22,87 | 16 | 51,63 | 35,71 | 18,43 | 5 |
| 4—5 | 92,21 | 29,74 | 27,42 | 16 | 78,54 | 28,14 | 22,10 | 15 |
| 5—6 | 115,75 | 24,01 | 27,79 | 19 | 127,74 | 20,61 | 26,32 | 14 |
| 6—7 | 146,31 | 18,40 | 26,88 | 26 | 119,23 | 18,30 | 21,82 | 20 |
| 7—8 | 137,59 | 16,24 | 22,34 | 35 | 138,99 | 14,14 | 19,65 | 25 |
| 8—9 | 145,97 | 13,33 | 19,45 | 30 | 135,00 | 12,99 | 17,54 | 23 |
| 9—10 | 134,59 | 12,39 | 16,68 | 24 | 119,25 | 11,92 | 14,21 | 18 |
| 10—11 | 144,83 | 10,93 | 15,83 | 13 | 135,11 | 9,14 | 12,35 | 9 |
| 11—12 | 113,80 | 10,37 | 11,80 | 6 | 150,25 | 9,69 | 14,56 | 6 |
| 12— | 145,04 | 8,52 | 12,35 | 8 | 113,05 | 10,68 | 12,07 | 1 |

in increment percentage. The reason for this is that there has also been a simultaneous increase in mean volume (Table 1). The change in volume increment in different age classes is presented in Table (3) and (4). The figures in these tables are the increments measured in each inventory.

There are, however, certain differencies in the sampled material (Table 1), which must be corrected. Stand age is an important factor determining volume increment. In order to have a more reliable comparison this difference must be corrected. However, if we change age we must also change volume, because of their multicollinearity. In the material sampled from seventh inventory, the correction for volume was obtained from the correlation of age and volume in Table (3). The corrected volume increment percentage was obtained using the function in Table (2). In the case of sixth inventory the corrected volume was obtained from the correlation between stand age and volume in Table (4). Because the function (Table 2) was constructed for seventh inventory it can not be used straight for estimating the corrected volume increment for the material sampled from sixth inventory. For the approximative correction following procedure was applied. The volume increment percentage was at first calculated with original mean age (71,7 a) and volume (116,3 m³) in Table (1). Then it was calculated with corrected age (74,9 a) and volume (120,3 m³) which was obtained from correlation between stand age and volume in Table (4). The difference of these two percentages was subtracted from the original volume increment percentage (16,5, in Table 1). Results are presented in Table (5). It appears from the Table (5) that the difference between 3rd an 7th inventory is still statistically significant. The difference between 6th and 7th inventory is also significant.

The difference in mean age and volume in Table (4) was further varied for the sensitivity analyses. It was assumed that stand age would have been determined five years too old in seventh inventory. The correction of mean volume and volume increment percentage after change in mean age was carried out in the same manner as above. Some results are presented in Table (6).

The difference in the predicted and estimated volume increment percentage in the material sampled from the third inventory diminished from 1,81 percentage units to 0,26 percentage units. This difference can then be evaluated statistically significant only at the risk level of 10 %.

The difference between the volume increment for five year period in the 3rd and 7th inventory would be diminished to 1,7 m³/ha x a, which is about 9 %. This differ-

Table 5. Some characteristics of the material after correcting the age-difference between different inventories in Table 1.

*Taulukko 5. Eräitä tietoja tutkimusaineistosta sen jälkeen, kun taulukossa 1 oleva ikäero on korjattu.*

| Inventory<br>*Inventointi* | Mean volume without bark<br>*Keskimäär. kuutiomäärä kuoretta* m³/ha | Mean age<br>*Keski-ikä* | Mean volume incr. -% (5a) without bark<br>*Keskim. 5 v. kuutiokasvu-% kuoretta* | Mean volume incr. (5a) without bark<br>*5 v. kuutiokasvu kuoretta* m³/ha |
|---|---|---|---|---|
| 3. | 113,6 | 74,9 | 16,5 | 18,76 |
| 6. | 120,3 | 74,9 | 15,6 | 18,81 |
| 7. | 124,3 | 74,9 | 16,9 | 21,04 |
| Diff. between 7. and 3. | 10,7 | 0,0 | 0,4 | 2,28* |
| " " 7. " 6. | 4,0 | 0,0 | 1,3 | 2,23* |
| " " 6. " 3. | 6,7 | 0,0 | —0,9 | 0,05 |
| *Erot eri inventointien välillä* | | | | |

Table 6. Some characteristics of the sampled material. The age-difference in Table 1. is corrected, and the material from 7th and 6th inventory is assumed to be estimated five years too old.

*Taulukko 6. Eräitä tutkimusaineistojen ominaisuuksia. Taulukon 1. ikäero korjattu ja sen lisäksi oletettu, että 7:stä ja 6:sta inventoinnista oleva aineisto on määritetty 5 vuotta liian vanhaksi.*

| Inventory<br>*Inventointi* | Mean volume without bark<br>*Keskimäär. kuutiomäärä kuoretta* m³/ha | Mean age<br>*Keski-ikä* | Mean volume incr. -% (5a) without bark<br>*Keskim. 5 v. kuutiokasvu-% kuoretta* | Mean volume incr. (5a) without bark<br>*5 v. kuutiokasvu kuoretta* m³/ha |
|---|---|---|---|---|
| 3. | 113,6 | 74,9 | 16,5 | 18,76 |
| 6. | 124,0 | 74,9 | 14,5 | 17,98 |
| 7. | 128,0 | 74,9 | 16,0 | 20,48 |
| Diff. between 7. and 3. | 14,4 | 0,0 | —0,5 | 1,42 |
| " " 7. " 6. | 4,0 | 0,0 | 1,5 | 2,24* |
| " " 6. " 3. | 10,4 | 0,0 | —2,5 | —0,78 |
| *Erot eri inventointien välillä* | | | | |

ence would no longer be statistically significant. These analyses show that the above method is rather sensitive to systematic errors in determining stand age and other stand characteristics.

The comparison between the sixth and seventh inventory can be considered as more reliable, because the same method was used in the inventories. It is also specially interesting to discover the reason behind the surprisingly high increase in volume increment in such a short period from the sixth to the seventh inventory. By using the sixth and seventh inventory in the comparison, we can then omit most of the former speculations. The observed difference in the 5-year volume increment is 13,4 % (see Table 1 and Fig. 7a). Explaining this difference on the basis of climatic data is not unambiguous (Fig. 7). If it is corrected using temperature sums the difference would be enlargened. If it is corrected using the growth indices presented by Thammincha (1981), the unexplained difference would diminish to half and if it is corrected using the growth indices presented by Tiihonen (1983) the difference would diminish to zero.

# 4. DISCUSSION

The observed change in tree growth in this material is surprisingly high. If we are only considering the fact that the material is very similar in respect to forest site type, stand quality, stand structure and age structure the change in increment would be expected to be very small. The change must then be caused by climatic or other factors.

The similarity of the stands was ensured by setting some contraints for the sampling procedure. For instance the effect of fertilization was eliminated by sampling stands on such poor sites that they are not worth fertilizing. The effect of an improving level of silviculture was eliminated by sampling stands of high quality. The increment-reducing effect of understorey was eliminated by sampling one-storeyed stands and so on.

There are of course many uncontrolled factors which make the conclusions drawn from these results a bit uncertain. One is the use of qualitative classifications of stand characteristics, which are partly used as the basis for the selection of material for this analysis. Another point is that there is not very much information about the history of the stands. It is possible, that the present increment in two otherwise equal stands would be different because of different stand history. Possible differences in inventory method, e.g. determination of age, may also generate differences, the effect of which may be interpreted incorrectly.

It is also difficult to eliminate the effect of changing climatic factors. The available growth indices, which mostly reflect the reaction of trees to changing growing conditions, differ from each other very much, hence it is difficult to use them as a means of correcting the effect of weather. The covariation of the temperature sum for the growing season and the variation in volume increment cannot be considered as being strong.

The annual increment has increased from the time of the third inventory to that of the seventh inventory in the material under consideration. The increase in the sample is about 16 %, nearly as much as the increase in the total volume increment from 1950 to 1980 for the forests of Finland as a whole. It is therefore obvious that the possible increment increase due to changes in atmospheric composition is less than 16 %. It is difficult or impossible to estimate how large the effect of more unfavourable age structure and different climatic conditions on total increment is, in other words how much more it would be, if the age structure and climatic conditions would be the same as during the third inventory.

The mean volume increment percentage is much higher in the 7th inventory, despite the fact that the mean volume per hectare has increased at the same time. This would be interpreted as being a result of better growing conditions. The increase from late 1960's to the middle of the 1970's especially is very pronounced. This is the same kind of phenomenon which can be seen in radial growth based on material collected from old protected stands (Hari, et al. 1984, in print).

In any case, it seems that all of the increase in volume increment cannot be interpreted as being a result of climatic conditions or improved silviculture or forest fertilization. Thus the result gives evidence to support the hypothesis that the yield of forests in southern Finland has increased due to increase in the atmospheric $CO_2$ concentration and/or nitrogen deposition. The uncertainty in the effect of weather on growth, seen as a great difference in growth indices by Tiihonen and Thammincha, makes, however, the interpretation of the results difficult.

The results obtained concern pine growing on rather poor sites in Southern Finland. This is why no general conclusions can be drawn from these results. There are many uncertainties in comparing the results of 3rd and 7th inventory. However, the results obtained in this study are in correspondence with other results obtained in Finland concerning the effect of energy production on forest increment (Hari and Raunemaa 1984). A more thorough analysis of other possible causes for the changes in volume increment is therefore needed.

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# SELOSTE

## Ilmakehän ominaisuuksien muutosten ja happaman laskeuman mahdollinen vaikutus puuston kasvuun

### Valtakunnan metsien inventointien tuloksiin perustuva analyysi

Teollistumisen seurauksena eräät kasvien toimintaan vaikuttavat ympäristötekijät ovat muuttuneet ja muuttumassa. Ilmakehän hiilidioksidipitoisuus on noussut tasaisesti (kuva 1) ja ilmasta tulevan laskeuman koostumuksessa on tapahtunut suuria muutoksia. Erityisen huomion ansaitsee tähän mennessä tapahtuneista muutoksista laskeuman mukana tuleva typpi (kuva 3), joka on pääasiassa kasveille käyttökelpoisessa muodossa. Tutkimuksen tarkoituksena on etsiä em. tekijöiden aiheuttamia mahdollisia metsän kasvun muutoksia valtakunnan metsien inventointien antamista tuloksista.

## Aineisto ja menetelmät

Tutkimusaineisto on näyte valtakunnan metsien 3., 6. ja 7. inventoinnin tuloksista. Alue, jolle sattuneista kasvukoealoista näyte poimittiin, käy ilmi kuvasta 4. Tämä alue valittiin lähinnä siksi, että se muodostaa laajan, maantieteellisesti melko yhtenäisen alueen.

Aineisto pyrittiin valitsemaan siten, että metsänhoidollisista toimenpiteistä ja metsiköiden rakenteen muutoksista aiheutuneet erot metsän kasvussa tulisivat eliminoiduiksi. Luonnollisesti myös kasvupaikan aiheuttamat erot pyrittiin eliminoimaan. Tähän toivottiin päästävän määrittämällä keskeisesti metsikön tilavuuskasvuun vaikuttavia metsikkötunnuksia ja valitsemalla näiden tunnusten tiettyihin luokkiin kuuluvia metsiköitä mukaan analyysiin. Kriteereinä käytettävät tunnukset olivat:

| | |
|---|---|
| Metsätyyppi: | kuivahkot kankaat, myös kiviset. |
| Kehitysluokka: | harvennusmetsiköt, varttuneet kasvatusmetsiköt ja uudistuskypsät metsiköt. |
| Ikäluokka: | yli 20-vuotiaat metsiköt. |
| Metsikön laatu: | hyvät ja tyydyttävät metsiköt |

Mäntyvaltaiset metsiköt

Yksijaksoiset metsiköt

Taulukossa 1 on annettu eräitä tietoja siitä, miten tässä onnistuttiin. 6. ja 7. inventoinnin koealojen keski-ikä on hieman alhaisempi, kuin 3., mutta puuston keskitilavuus on tarkasteluajanjaksona noussut. Aineiston ikäjakaumat on esitetty lisäksi kuvassa 5.

7. inventoinnin tuloksiin nojaten laadittiin metsikön kuoretonta tilavuuskasvuprosenttia ennustava yhtälö (taulukko 2). Yhtälön selittäjinä olivat metsikön ikä ja kuutiomäärä. Sen jälkeen 3. ja 6. inventoinnin kuorettomia tilavuuskasvuprosentteja ennustettiin tällä yhtälöllä. Lisäksi verrattiin kustakin inventoinnista saadun osa-aineiston perusteella laskettuja keskimääräisiä kasvulukuja keskenään. Tämän vuoksi 6. ja 7. inventoinnista poimittujen osa-aineistojen eräitä tunnuslukuja (ikä, puuston keskitilavuus ja tilavuuskasvuprosentti) jouduttiin ennustamaan tiettyä ikää (74,9 vuotta) vastaaviksi (taulukko 5). Ennustaminen tapahtui käyttämällä hyväksi iän ja tilavuuden ja iän ja tilavuuskasvuprosentin välistä riippuvuutta taulukoissa 3 ja 4 sekä taulukon 2 yhtälöä.

## Tulokset

Kuvassa 7 on esitetty kuorettoman viiden vuoden tilavuuskasvun kehitys eri inventoinnista toiseen. Samassa kuvassa on esitetty myös ilmastollisten kasvuolosuhteiden kehittyminen suhteellisina kasvuindekseinä ja suhteellisena lämpösummana. Mitattujen ja ennustettujen tilavuuskasvuprosenttien erot 3. ja 6. inventoinnissa on esitetty kuvissa 8 ja 9. Kuvista käy ilmi, että erot ovat varsin selviä ja systemaattisia kaikissa ikäluokissa. Taulukossa 1 ja varsinkin taulukossa 5 huomiota herättää vielä se, että tilavuuskasvuprosentti on 7. inventoinnin tulosten mukaan suurempi kuin 3. inventoinnissa, vaikka jälkimmäisessä puuston keskitilavuus on huomattavasti pienempi.

Tulokset ovat kuitenkin herkkiä varsinkin metsikön iän määrityksessä tapahtuville systemaattisille virheille. Mikäli 3. inventoinnin jälkeen tehdyissä inventoinneissa metsikön ikä olisi määritetty 5 vuotta liian korkeaksi, ero tilavuuskasvuprosentissa ja viiden vuoden tilavuuskasvussa vähenisi tilastollisesti merkityksettömäksi 3. ja 7. inventoinnin välillä (taulukko 6). Koska 6. ja 7. inventointi on suoritettu lähes samalla menetelmällä, herkkyysanalyysin tulos ei vaikuta näiden inventointien tuloksissa havaittuun eroon.

## Tulosten tarkastelu

Tutkimuksessa havaittu kasvun muutos on yllättävän suuri, jos ajatellaan sitä, että vertailtavat otokset pyrittiin saamaan toistensa kaltaisiksi ja keskimääräiset kuutiomäärät ovat nousseet melko huomattavasti tarkasteltavana ajanjaksona. Muutoksen on siis johduttava muista tekijöistä esim. ilmastosta ja/tai kasveille käytettävissä olevan $CO_2$ ja/tai typen laskeuman lisääntymisestä. Tässä yhteydessä ei voida myöskään lukea pois jotakin kolmatta, vielä tuntematonta tekijää.

Ilmaston huomioonottamista vaikeuttaa toistaiseksi kasvuindeksin lukuarvojen huomattava vaihtelu tarkasteltavana ajanjaksona (kuva 7b). Mikäli korjaus tehdään lämpösummien avulla, ero pysyy lähes samana. Jos korjausta yritetään Thamminchan (1981) esittämien kasvuindeksien avulla, kasvun muutoksesta selittyy lähes puolet ja jos korjaus tehdään Tiihosen (1983) esittämien indeksien avulla, ero selittyy kokonaan ilmastollisilla syillä.

Tulosten tulkinta on siis varsin vaikeaa. Ne antanevat kuitenkin tukea sille hypoteesille, että metsien kasvussa olisi tapahtunut kiihtymistä ilmakehän $CO_2$ -pitoisuuden lisääntymisen ja/tai lisääntyneen typen yhdisteiden laskeuman johdosta.

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Increment of pine stands growing on poor sandy soils are compared. The material is from 3rd, 6th and 7th inventory. The analyses gives support to the hypothesis that nitrogen deposition and/or increase in the $CO_2$ concentration of the atmosphere have increased tree growth in southern Finland.

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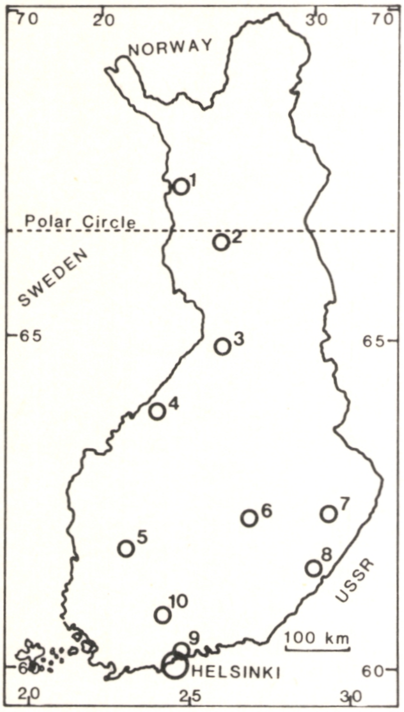


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2 Rovaniemi
3 Muhos
4 Kannus
5 Parkano
6 Suonenjoki
7 Joensuu
8 Punkaharju
9 Ruotsinkylä
10 Ojajoki

## FACTS ABOUT FINLAND

*Total land area:* 304 642 km$^2$ of which 60—70 per cent is forest land.

| *Mean temperature, °C:* | Helsinki | Joensuu | Rovaniemi |
|---|---|---|---|
| January | -6,8 | -10,2 | -11,0 |
| July | 17,1 | 17,1 | 15,3 |
| annual | 4,4 | 2,9 | 0,8 |
| *Thermal winter (mean temp.* < 0°C): | 20.11.—4.4. | 5.11.—10.4. | 18.10.—21.4. |

*Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens*

THE FINNISH FOREST RESEARCH INSTITUTE ● METSÄNTUTKIMUSLAITOS

## Communicationes Instituti Forestalis Fenniae

119 Uotila, A. Physiological and morphological variation among Finnish *Gremmeniella abietina* isolates. Seloste: Suomalaisten Gremmeniella abietina -isolaattien fysiologisesta ja morfologisesta vaihtelusta.

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121 Hallaksela, A-M. Bacteria and their effect on the microflora in wounds of living Norway spruce *(Picea abies).* Seloste: Bakteerit ja niiden vaikutus elävien kuusien vaurioiden mikrobilajistoon.

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