ALEXE ALEXE

WORLDWIDE FOREST MENSURATION HISTORY

I

FOREST MENSURATION HISTORY OF NORDIC AND NORTH – WESTERN EUROPEAN COUNTRIES

BUCHAREST
2006 (2003)

Worldwide Forest Mensuration History

An outline of 19th and 20th centuries

Volume I: Forest Mensuration History of Nordic and North-Western European Countries

Volume II: Forest Mensuration History of Central Eastern European Countries

Volume III: Forest Mensuration of Southern Europe, Russia and other Countries of the Former USSR

Volume IV: Forest Mensuration History of Developed Asia/Oceania, Africa, Asia, Pacific, Latin America and Carribean Countries

Volume V: Forest Mensuration History of Canada

Volume VI: Forest Mensuration History of the United States of America

Volume VII: A Selected Bibliography of the United States of America's Forest Mensuration with References from Allied Fields 1805 – 2000 (2003)

WORLDWIDE FOREST MENSURATION HISTORY

I

FOREST MENSURATION HISTORY OF NORDIC AND NORTH – WESTERN EUROPEAN COUNTRIES

An outline of 19th and 20th centuries in:
Finland, Norway, Sweden, Belgium, Denmark,
Ireland, Netherlands and United Kingdom

ALEXE ALEXE, Ph. D.
Correspondent Member of
Romanian Academy of Agricultural and
Forestry Sciences, Bucharest, Romania

BUCHAREST
2006

FOREWORD

History is important – not only to understanding the past, but to guiding the future. Dr. Alexe Alexe completed a monumental task by compiling an eight-volume set on **Worldwide Forest Mensuration History**. The material is presented by country in order to highlight the contribution of each country to the development of forest mensuration.

The chapters begin with a description of the land area, round wood production, main species, forestry education and research organizations, and primary forestry and related journals in the subject country. Where sufficient information exists, this introductory material is followed by a review of important contributions made to the topic areas of (1) tree volume, taper, and form, (2) tree growth, (3) site evaluation, (4) stand structure, (5) growth and yield prediction, (6) weight and biomass, (7) tree-ring studies, and (8) forest inventory. A chronology of selected noteworthy events is given, as well as a list of selected contributors (by time period and topic), and each chapter is concluded with additional comments by the author. The complete work contains information from 93 countries and is based on over 10,000 bibliographical references. The focus is on literature of the 19th and 20th centuries (the most recent citations included--except for a few cases -- are for 1999), but in instances where significant work on forest mensuration was published prior to the 19th century (e.g., in Germany and France), reference is made to that literature. It varies from volume to volume, but typically around 40 percent of the citations are for literature published in 1980 or later. Criteria used for selecting what literature to cite included: originality (at the time when the work was completed), methodological features, frequency of citation in the primary literature, and publication in main-line journals. Special attention was also given to listing books on forest mensuration and on review articles and bibliographies.

In preparing a history of forest mensuration, the author had three primary purposes. First, was to organize the material at the country level in order to provide a better understanding of the development of this discipline in given geographical areas and within an overall historical framework. Second, was to supply a reasonably comprehensive base of information about important aspects of forest mensuration. And third, was to enable those desiring information on the roots of forest mensuration to locate key literature in the shortest possible time. This bibliographical material fulfills many informational needs, including identifying key contributions and important milestones in forest mensuration.

Although the past is unchanging, it can be interpreted in different ways. Subjectivity is inherent in any account of history. Dr. Alexe did an admirable job of seeking out the most important contributions to forest mensuration in each country and organizing the material chronologically and by topic area. **Worldwide Forest Mensuration History** is a treasure trove that can aid students, instructors, researchers, and practitioners in gaining a perspective on the development of forest mensuration around the world and in finding key information quickly and efficiently. Forestry professionals worldwide, especially those specializing in, and devoted to the measurement of trees and forests, are indebted to Dr. Alexe for his Herculean effort to compile a comprehensive global history of forest mensuration.

Harold E. Burkhart
Department of Forest Resources and Environmental Conservation
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061, U.S.A.

PREFACE

This is the first volume of "Worldwide Forest Mensuration History" and refers to "Forest Mensuration History of Nordic and North-Western Europeean Countries": Finland, Norway, Sweden, Belgium, Denmark, Ireland, Netherlands and United Kingdom.

We adopted the concept of forest mensuration "*in sensu lato*" by including in this discipline all its main four branches: (1) timber mensuration (including biomass studies), (2) evaluation of forest site productivity (which has strong connections with ecology and soil science), (3) tree-ring studies (or dendrochronology "*in sensu loto*" containing dendrochronology "*in sensu stricto*", dendroclimatology and dendroecology), and (4) forest inventory including sampling, remote sensing and GIS techniques.

The text is organized on country level and depending on the availability of information, mentioned papers or events are grouped as follows: (1) tree, (2) site evaluation, (3) stand structure, (4) stand growth and yield, (5) weight and biomass studies, (6) tree ring studies, (7) forest inventory. In the countries with reasonably reviewed works the text is supplied with: a) a chronology of selected works or events, b) a list of selected contributors, and c) comments. In all cases presentation of works or events is given in chronological order. The text for every country contains "General information" which refers on the total land area, forest area, vegetation (species and forest types), volume and biomass per hectare, round wood production, teaching and research institutions involved in forest mensuration, leading journals and periodicals, and general literature with forestry or historical information - if available.

In all countries the methodological aspects were underlined, especially modelling of growth and yield, bio-mathematical oriented models, sampling methods, remote sensing and GIS techniques.

In our opinion a history of forest mensuration on country level offers a better understanding of the development of this discipline in a given geographical and historical frame. On the other hand, the knowledge of the forest mensuration history in a large number of countries represent a valuable premise for elaboration of different syntheses on regional or global level by topics. This was the first purpose of our book. The second purpose was to supply the reader with a reasonable data base of information. In the first volume 1046 references have been included out of which 38 % refer to papers published after 1980 and 16 % to that published between 1991 and 1999.

Many works published before 1980 contain information which are still valid today and have been "rediscovered" later and presented as new ideas because the original text was ignored or forgotten. The early literature has its high historical importance and helps to the understanding of the evolution of a specific subject.

As criteria for the selection of cited paper we used: originality (at the time when the considered work was completed), methodological features, originality or/and uniqueness of the case studies, frequency of citations in the core monographs, forest mensuration books, and articles published in main-line journals and serials in forestry and adjacent disciplines.

The most difficult problem was the selection of cited papers in our book. Any selection is strongly correlated with the problem of the sample representativity.

We discussed this problem with many specialists in forestry, statistics and history. The general opinion was that in any book of history there is a doubt and the risk of subjectivity which cannot be avoided in totality. This is the reason why we hesitated a long time to prepare our texts for publication. We are not sure that we succeeded to perform the huge task to present the facts in a proper manner, at least acceptable as a first valid version.

We are aware that our available bibliographical material could be presented in other different versions. It is said that the past is unchanging and the future is open to many directions (at least sometimes) but the past could be interpreted in different ways and this is why we consider that the history is more than the knowledge of the past, it is a background for forecasting different possible alternatives and scenarios.

We would like that this book on the history of forest mensuration to be considered above all as an act of culture because it is dedicated to all people interested in the preservation of forests and whose profession is connected in a way with forestry.

Alexe Alexe

Bucharest, May 25, 2003

TECHNICAL NOTE

There are different opinions on the content of timber mensuration.

In this book the term "forest mensuration" when used it is considered "*in sensu lato*" including the following branches which are accepted by many authors as independent disciplines of forestry: (1) timber mensuration including tree and stand, weight and biomass measurement; (2) evaluation of forest site productivity by different methods including site index systems; (3) tree-ring studies (dendrochronology in sensu lato: tree-ring chronologies, dendroclimatology, dendrohidrology, dendroecology); (4) forest inventory and assessment of woody and non woody forest resources conducted on large areas (forest, region, country) and associated as a rule with remote sensing and GIS techniques.

The history is presented for each country separately. In this respect the principle of "land priority" was applied, in the sense that all references on a given country are included in the text for this country regardless of the nationality of the author(s). The papers which refer to more than one country are mentioned in all the involved countries. If the nationality of the author(s) is unknown, the paper was included under the headline of the country in which is has been published.

The definition of terms as forest land, other wooded land and biomass are adapted according to that specified in FAO forestry paper 124/1995: "Forest resources assessment 1990" pp. 41 and 42 as follows:

Forest land: "with tree crown cover (stand density) of more than about 20% of the area. Continuous forests with trees usually growing more than about 7 m in height and able to produce wood. This included both closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground and open forest formations with a continuous grass layer in which tree synusia cover at least 10% of the ground." (p. 41).

Other wooded lands: "Land which has some forestry characteristics but is not forest as defined above. It includes: open woodland and scrub, shrub and brushland (see below), wheter or not used for pasture or range. It excludes land occupied by "Trees outside the forest" (see below), (p. 41).

Scrub, shrub and bushland: "Land with scrub, shrub or stunted trees where the main woody elements are shrubs (usually more than 50 cm and less than 7 m in height), covering more than about 20 % of the area, not primarily used for agricultural or other non-forestry purposes, such as grazing of domestic animals. Trees outside the forest are excluded" (p. 42). Scrub is a land covered with trees and bushes of poor quality.

Biomass is the oven-dry weight of all species of trees to a minimum dbh of 10 cm, above ground only, and includes main stems, branches, twigs, leaves and fruits.

Biomass was determined according to a model detailed in the above-mentioned FAO work.

For site and forest site productivity the following definitions have been adopted (unless otherwise specified) after European Forest Institute, Research Report No. 5, 1966, p. 2:

"The term **site** is used to describe the sum of environmental conditions (biotic, edaphic, topographic and climatic conditions, including atmospheric composition) in existence at a particular location".

"**Forest site productivity** is defined as the woody biomass production potential of a site. In this project the term site productivity is limited to the wood production potential of a site for a particular tree species, provenance or forest type. For example, growth of volume, basal area or height may serve as an indicator of site productivity" (From the Introduction of EFI Research Report No. 5/1996 written by Heinrich Spiecker).

CONTENTS

NORTHERN AND NORTH-WESTERN EUROPE

NORDIC: 1. FINLAND, 2. NORWAY, 3. SWEDEN
NORTH WESTERN: 4. BELGIUM, 5. DENMARK, 6. IRELAND, 7. THE NETHERLANDS, 8. UNITED KINGDOM

1. FINLAND

General information

Land area: 304,620 sq. km (111,618 sq. mi.), forest and other wooded land: 233,730 sq. km. (90,274 sq. mi.), forest: 20,112,000 ha or 77,656 sq. mi. (66 % of land area), volume: 85 m^3/ha, biomass: 47 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: industrial round wood 34.3 million m^3, fuel and charcoal 3.3 million m^3, total round wood 37.6 million m^3 (World Resources 1996-97, p. 220).

Forest vegetation: Cool coniferous forests (Boreal forests). A small area of temperate mixed forest toward the southern border of the country. Repartition by species groups:

• Conifers: 88 %

• Broad-leaved: 12 %

The most productive forests are located in the southern part of the country (*Oxalis - Myrtillus* and *Myrtillus* types), and the low productive are concentrated in the middle and northern Finland: *Vaccinium, Calluna, Empetrum, Empetrum - Vaccinium* types (Cajander 1921).

Main species: Scots pine (*Pinus sylvestris*), spruce (*Picea abies*), birch (*Betula verrucosa, Betula* spp.), tremble aspen (*Populus tremula*), alder (*Alnus* spp.).

Forestry education and research organizations involved in the areas of forest mensuration and forest management (date of establishment in brackets):

• Evo Forestry Institute, Forest Technicians School, Evo (1982);

• Joensuu Institute of Forestry and Wood Technology, Joensuu (1993);

• Kotka Polytechnic, College of Forestry Wood Technology, Kotka (1921);

• Kullaa Forestry and Wood Technology Institute, Kullaa (1967);

• Rovaniemi Forestry Institute, Forest Owner's School (1905);

• The Ekenäs College of Forestry, Ekenäs (1908);

• Tuomarniemi Forestry Institute, Tuomarniementie (1905);

• University of Helsinki, Department of Forest Ecology, Helsinki (1992);

• University of Helsinki, Department of Forest Mensuration and Management, Helsinki (1926);

• University of Joensuu, Faculty of Forestry, Joensuu (1982);

• Valtimo Forestry Institute, Valtimo (1970);

• European Forest Institute, Joensuu (1993);

• The Finnish Forest Research Institute, Helsinki (1918).

Publications (Primary Journals and Serials):

* Acta Forestalia Fennica (published by Suomen Metsätieteelinen Seura: Society of Forestry in Finland; other society is 'Metsanhoitaja' (Society of Finnish Foresters) Helsinki;

* Communicationes Instituti Forestalis Fenniae;

* Folia Forestalia Institutum Forestale Fenniae;

* Annales Botanici Fennici;

* Acta Botanica Fenica;

* Silva Fennica.

Literature.

CAJANDER, A. K. 1909, 1913. Über Waldtypen. (On forest types). Acta Forestalia Fennica, Heft 1: 1-175.

CAJANDER, A. K. 1949. Forest types and their significance. Acta Forest. Fenn. 56 (4): 1-71.

ERVASTI, SEPPO; LAURI HAIKINHEIMO; KULLERVO KUUSELA; VEIKKO O. MÄKINEN. 1970. Forestry and forest industry production alternatives in Finland, 1970-2015. Folia Forestalia, 88.

ILVESSALO, Y. 1956. Suomen metsät vuosista 1921-1924 vuosun 1951-53. (Forests of Finland from 1921-24 up to 1951-53). Helsinki, 227 pp. Every “forest type” of this country is named after a characteristic species from the ground vegetation which corresponds in the case of spruce, pine or birch to a determined production. This is a current practice in Finland.

MIKOLA, P. 1958. Forêts et Foresterie en Finland. (Forest and Forestry in Finland). Bull. Soc. Royal For. Belg. no. 2.

NYYSÖNEN, A. 1959. Finnish research in the fields of forest mensuration and management in 1909-1959. Acta Forestalia Fennica 70.

TOMPPO, E. et al. 1997. Country report for Finland. In: Study on European Forestry Information and Communication System. Reports on forest inventory and survey system. Volume 1 CH-11-97-001-EN-C. Luxemburg: European Commission, pp. 145-226.

1.1. Measurement and volume determination of trees

Among early Finnish works on the tree measurement will be mentioned Lönnroth’s description of a dendrometer (1926) and the formulae used in Finland for stem volume determination (1927).

In 1953 Lahti presented information on the measurement of the contents of pulpwood bundles and Nyyssönen (1955) described how to estimate cut from stumps.

The Finnish curve caliper - a characteristic tool used in Finland for the measurement of diameter heights - has been presented by Vuokila (1955) and it is shown in Figure 1.1.-1.

In 1947 Ilvessalo published extensive volume tables (149 pp.) for standing trees and improved these tables in the next year by adding the increment tables for these trees.

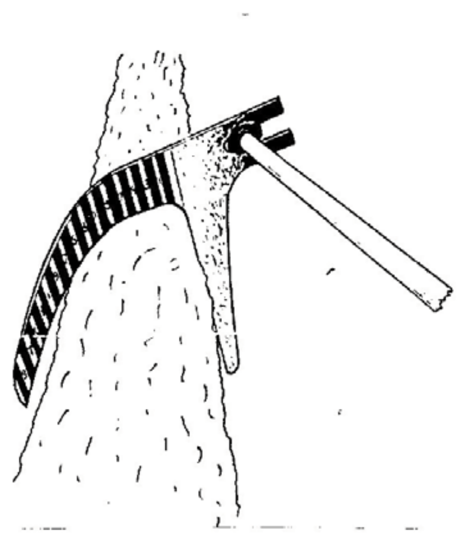


Fig. 1.1.-1. Finnish caliper for measurement of upper diameters
SOURCE: Reproduced after Pardé, Dendrometrie, p. 208, fig. 98

Cited authors:

Ilvessalo 1947, 1948; Lahti 1953, Lönnroth 1926, 1927; Hyyssönen 1955, Vuokila 1955.

1.2. Tree form

The earliest work on tree form available to the authors are the Lappi-Seppäla researches on stem form of Scots pine and birch published in 1936.

In 1952 Ylinen discussed the mechanical theory of stem form.

Kilkki et al. (1978) developed a simultaneous equation model to determine taper curve, and Lathinen and Laasasenaho (1979) used the spline function for construction of taper curves, and later (1982) published another paper on taper curve and volume functions for pine, spruce and birch.

The Laasasenaho taper curve model (1982) is a polynomial function whose powers are in accordance with the so-called Fibonacci series:

$$\frac{d_1}{d_{\bullet 2h}} = b_1x + b_2x^2 + b_3x^3 + b_4x^5 + b_5x^8 + b_6x^{13} + b_7x^{21} + b_8x^{34}$$

where:

d_1 = the diameter of a height of l from the ground;

$d_{\bullet 2h}$ = the basic diameter at 20 % height;

x = 1-l/h or the relative distance from the top.

The standard deviations of the stem diameter estimates derived with the above taper curve model at relative stem heights are shown in Figure 1.1.-2., the measured characteristics being dbh and height.

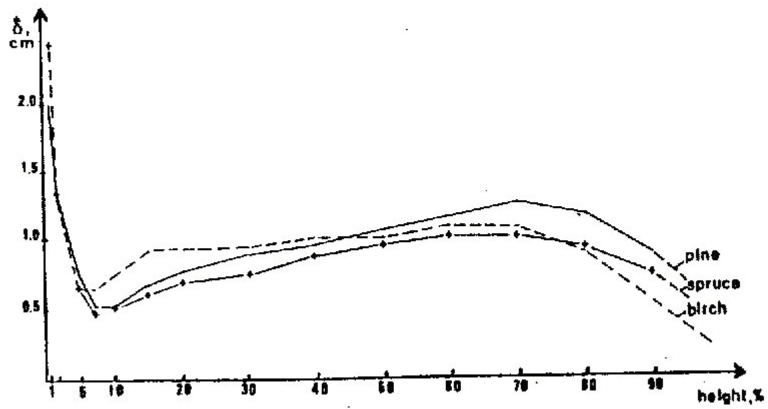


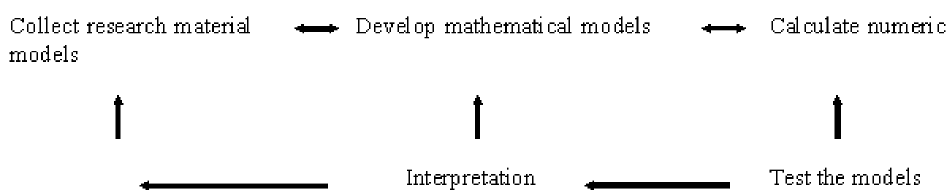
Fig. 1.1.-2. The standard deviations (⌒, cm) of the diameter estimates at relative stem heights derived from the taper curve Laasesenaho's model, when the breast height diameter and total height are known.
SOURCE: Laasasenaho, Jouko 1988: "Use of taper curve in determining tree branchiness and preparing instructions on stand densities", p. 1015. Presented at the IUFRO Forest Growth Modelling and Prediction Conference, Minneapolis, MN, August 24-28, 1987, pro ceedings published in 1988: "Forest growth modelling and prediction", A. Ek, R. Shifley, R. Stephen and J. Burk" eds., North Central Forest Experimental Station, General Technical Report NC-120, vol. 1 and 2, 1153 pp., St. Paul, Minnesota, U.S.A.

It is clear that taper curve models are more accurate in the middle and upper parts of the stem if the upper diameter has been measured. On the other hand, a clear relationship between the basal area of the stem and the cumulative cross-sectional area of branches was reported by Laasasenaho (1982, 1988). He discovered that taper curve can be used for computing the quantity of cross-section area of the branches per unit of stem volume and in this way taper curve can be also used for estimating the area of the cambium layer, but the fact that the degree of branching is also a genetically determined property should not be forgotten (Ehrenberg 1970).

Lappi (1986) presented mixed linear models for analyzing and predicting stem form variation of Scots pine, whereas Lathinen (1988) discussed the problem of the monotony preserving taper curves.

Ojansuu (1988) used mixed linear models for stem size and form development as a result of growth.

The problem of modelling taper curves and stem increment was discussed again by Laasasenaho in 1993, when he proposed the following phases in the development of a taper curve model:



Cited authors:

Ehrenberg 1970, Kilkki et al. 1978, Laasasenaho 1982, 1988, 1993; Lappi 1986, Lappi-Seppäla, Lathinen 1988, Lathinen and Laasasenaho 1979, Ylinen 1952.

1.3. Tree growth

In 1950 Mikola analyzed the variations of the tree growth and their significance.

The relationship between pruning and growth was investigated by Vuokila (1968) and the influence of environmental factors on the diameter growth (an auxometric study) was presented in an extensive paper published in 1969 by Leikola; later, in 1974, Raulo and Leikola disclosed their results on annual height growth of trees. A dynamic model of the daily height increment of plants was developed by Hari et al. in 1970.

The annual cycle development of forest trees during the active period was investigated by Sarvas (1972).

In 1972 Kärkkäinen published probably the first Finnish information on the proportion of hartwood in Norway spruce and Scots pine; later, in 1990 and 1992, as mentioned in 1.7., Mäkerla underlined that for the development of process-oriented models "more information is needed on branch and height growth and hartwood formation".

In 1977 Gustavsen published Finnish volume increment functions, Servas presented a mathematical model for the physiological clock and growth, and Vajsänen et al. (1977) considered annual growth level of some plant species as a function of light available for photosynthesis.

A core monograph (208 pp, Kolari, ed.) on growth disturbances of forest trees (Proceedings of an International Workshop held in Finland in October 1982 at Jyvaskyla and Kivisuo) was published by the Finnish Forest Research Institute in 1982.

Mäkelä (1986) revealed the implications of the pipe-model theory on dry matter partitioning and height growth in trees.

In 1987 Pukkala and Kolström established a connection between competition indices and the prediction of radial growth in Scots pine stands, and in the next year Pukkala (1988) underlined the effect of spatial distribution of trees on the volume increment in the case of young Scots pine stands.

An original way to determine stem growth was proposed by Ojansuu (1988) who used mixed linear models to model the growth of tree size and changes in stem form. Ojansuu defined the stem in polar coordinate system as the logarithmic lengths of rays at different angles, technique originally developed by Lappi (1986) to analyze static form variation whose model is based on the mixed linear model methodology. In Ojansuu's paper the polar coordinate system is used to define the position of the points of the tree stem, tree dimensions being expressed as the length of the rays; R(u) where "u" is the angle. The fixed angles in his model are 0.25^0, 5^0, 14^0, 31^0, 56^0 and 90^0, the ray length at angle 0^0 is equal to the diameter of the stem base and the ray length at angle 90^0 is the stem height, and the co-ordinate system units are cm for the horizontal axis and meters for the vertical axis. In Ojansuu's model stem size is defined as the weighted mean of the logarithms of the rays at the seven fixed angles and the growth model consists of seven regression models of equal structure, one for each fixed angle and the factors affecting the tree growth are divided into three components: (1) the site type of plot, (2) the state of tree and (3) the competition measure of tree, and the model for relative growth is written in the form:

$$R_{ki}^{+}(u)/R_{ki}(u)=H_{k}F_{ki}C_{ki}E_{ki}(u)$$

where $R_{ki}(u)$ is the ray length of tree i on plot k at angle u, $R_{ki}^{+}(u)$ is the length of the same ray, one year later and $E_{ki}(u)$ is the error term (abbreviated after Ojansuu p. 724 and 725). In our opinion this elegant model is difficult to apply and it was mentioned more for historical reasons.

Growth of Norway spruce in relation to stem cross-sectional area at the crown base, based on stem analyses of 1119 trees, was completed by Koivuniemi (1993) who computed annual taper curves with quadratic polynomial spline functions. His results indicate "...that during the 22 years study period, volume growth depends linearly on the cross-sectional area at the crown base and the relationship does not change systematically with stand age.

According to earlier studies, the crown limit basal area of a stand is fairly constant after crown closure. The relationship describes how efficiently trees use their cross-sectional areas at the crown base for volume growth" (p. 118). The results of Koivuniemi's work do not support Assmann's conclusion (Assmann, 1970, p. 121 yield study, English edn.) who reported "that the efficiency in producing wood (= ratio of volume growth to crown surface area of dominant trees is constant within a stand but co-dominant and dominant trees use their smaller crowns more efficiently, the efficiency tending to increase with decrease in crown size" (Assmann 1970, p. 121). According to Kovuniemi (1993, p. 124) "... a possible explanation being that the study material was limited and did not cover the whole rotation of a tree generation or a range of site types and geographical regions. However, the kind of approach reported here might enable useful connections to be made between traditional empirical growth modelling systems we can estimate stem characteristics that are closely related to crown dimensions and tree growth."

Jouko Laasasenaho (1993) noted that "Many studies have shown that the width of the annual rings at different heights along a tree bole correlate strongly. This is natural because trees of different size have much the same form. So this is the natural starting point for constructing better models for calculating the stem volume increment of a tree. In this way we can obtain more accurate estimates of volume increment without measuring height growth. Nevertheless, one simultaneously obtains estimates of height growth using the method" and concluded: "The diameter increment of a tree depends on so many factors that it requires much research to develop a model which will give unbiased estimates of increment at different heights along the bole. Without such a model, obtaining accurate results for changes of assortment volumes in a tree or stand is difficult." (p. 57).

In 1995 “A scheme to derive growth models which are based, on one hand, on primary growth factors and, on the other hand on measurable tree and stand variables, is presented . Central internal growth factors are related to the cambium (area and age) and foliage (amount and condition) of a tree. Foliage amount is estimated with stem basal-area and sap-wood proportion at crown height. Attention is especially paid to predicting diameter growth in different parts of the stem. The derived models are intended to enhance an existing and in Finland commonly used stem curve system” (Laasasenaho and Waite 1995, p. 286).

Cited authors:

Assmann 1970, Gustavsen 1977, Hari et al. 1970, Kärkkäinen 1972, Koivuniemi 1993, Kolari 1983, Laasasenaho 1993, Laasasenaho and Waite 1995, Lappi 1986, Leikola 1969, Mäkelä 1986, 1990, 1992; Mikola 1950, Ojansuu 1988, Pukkala 1988, Pukkala and Kolstrom 1987, Raulo and Leikola 1974, Sarvos 1972, Servas 1977, Väjsänen et al. 1977, Vuokila 1968.

1.4. Forest site evaluation and Finnish forest types

In Finland site classification and evaluation of productive forest land is based on ground vegetation. Site type classification has been formulated since 1903 by Aimo Kaarlo Cajander (1879-1943) who described the forest types and developed his theory of forest types on this basis (1909, 1913, 1926, 1930, 1949-postume edn.)

The use of ground vegetation types to classify forests was adequate for Finland because of limited topographic variability, the dominance of 3-4 tree species (Scots pine [*Pinus sylvestris*], Norway spruce [*Picea abies*] and birch [*Betula pendula*], and *B. pubescens*), and the prevalence of only two major soil types (histosols and spodosols) developed over a granitic Precambrian bedrock. Cajander was not in favour of direct methods (forest growth) in evaluating site productivity because of the influence of stocking density on forest growth that affects the conditions of trees themselves, and because site classes based on yield tables are specific only for one species. Cajander did not accept also that a site classification based on soil chemical factors would be useful because the real fraction of nutrients that are available for uptake by trees (available forms) is very difficult to determine. The result was a “natural biological” classification in which the usual description of the forest types is based on the data and aspect of mature stands of normal stocking density and form (“normal stage” which was considered to correspond to climax of forest community (in Clements’ sense)). The use of ground vegetation has the following reasons: (1) there are many more ground vegetation species than three species, and (2) ground vegetation species have smaller ecological ranges and the composition and structure of the ground flora is more stable after different disturbances such as fire and reaches a climax after about 70 years, while in the case of Norway spruce there are necessary 300-400 years for a disturbed forest to complete its climax (equilibrium). On the other hand, Cajander assumed that both ground vegetation and wood production are influenced by the same properties in spite of the fact that no causal relationship is implied between ground vegetation and trees layer. This aspect is disputable and today it is well-known that there are different relationships in soil between the roots of trees and ground vegetation.

Cajander’s approach has been used with minor modifications in other European countries and North America but not on a national level.

Cajander’s studies have been confirmed by many researchers such as Ilvessalo (1920), Lönnroth (1925), Aaltonen (1937), Heikurainen (1971) and others.

Ilvessalo (1920) established the following values of trees average height in stands belonging to different Cajander’s floristic types:

Cajander's floristic type	Symbol	Average stand height in meters at the age of 90 years		
		Scots pine (*Pinus sylvestris*)	Norway spruce (*Picea abies*)	Birch (*Betula verrucosa*)
Oxalis	OT			25.4
Oxalis-Myrtillus	OMT	25.1	17.7	23.8
Myrtillus	MT	24.1	15.8	21.6
Vaccinium	VT	19.8		16.6
Calluna	CT	14.7		
Calluna-Cladina	C-CIT	7.8		
Cladina	CIT			

In 1923 Ilvessalo investigated the correlation between soil properties and stand growth. Later, in 1937 Aaltonen showed that trends in site productivity are accompanied by the same trends in humus, pH and soil contents in nutrients, especially nitrogen and calcium.

After the end of the Second World War Kujala (1945) was thinking about the improvement of species composition in Finnish forests and developed researches on Canadian forest vegetation with the purpose of establishing the possibilities of growing Canadian species in Finland. It seems that the results were not so promising.

Site productivity can be improved by drainage, and the revival of the tree growth after this work and its dependence on the tree size and age was investigated by Heikurainen and Kuusela (1962).

The problem of site quality was examined also by Heikurainen in 1971 (virgin peatland forest in Finland), by Huikari in 1974 (site quality estimation on forest land), by Westman in 1981 (fertility of surface peat in relation to the site type and potential stand growth).

In 1986, according to Starr, site classification and evaluation of productive forest land was based on site type classification of Cajander, and there was a separate classification for mineral soils (referred to as forest types) and for peatlands. There were about 22 forest types divided into six site types and three vegetation zones: southern, middle and northern Finland, and for peatland forestry were identified 25-35 site types - divided into three groups based on tree stand: hardwood-spruce mires (swampy ground), pine mires and mires without trees.

Lappi and Bailey (1988) discussed how the height development of dominant trees can be predicted using site information and available height measurements as a result of the fact that the average stand height at a given age is a function of site variables because the deviations from the average height curve have a special variance-covariance structure. The mentioned authors tried to determine optimal prediction of dominant height curves based on an analysis of variance components and serial autocorrelation.

Nieppola (1993a) tried an alternative to Cajander's evaluation of site productivity at least in the case of Scots pine forests in southern Finland. His proposal refers to an improvement of "classical" method by: (1) developing a classification key based on Two-Way Indicator Species Analysis (TWINSPAN) and (2) for inclusion of soil texture, stonines and the humus layer depth in the classification method, but suggested that the proposed classification cannot replace the Cajander's system. The mentioned TWINSPAN key may be used according to Nieppola, to aid the identification of forest site types and recommended to perform observation of dominant soil texture within each forest site type.

The capabilities of understorey plant species (especially ground species) to indicate site productivity as expressed by site index (H100, as 100 years reference age) were examined in detail by Nieppola (1993 b) using data from Scots pine stands in southern Finland. After the examination of data from 222 sample plots Nieppola concluded that the number of herb species was relatively strongly correlated with site index ($r = 0.81$) and a presence of 20-30 species indicated well the site index. The connexion between understorey vegetation and site productivity was primarily based on the distribution patterns of these indicators. Where site index was less than 21 m no good indicators existed. Inclusion of soil deposit types (soil texture) in the prediction model compensated the poor prediction of understorey plants (on poor sites) and increased it by about 15 %. Two years later (1995) Lathi used H100 site index as an independent measure of site quality and introduced a new model for the estimation of site quality at sites with a known understorey vegetation composition .

A site index model approach for drained peatland forest stands was presented in 1996 by Gustavsen describing the post-drainage development of stand dominant height as a function of drainage age, respectively time elapsed since the drainage, and is based on successive measurement data. Gustavsen's site index model should be seen as an outline than a final system for practical application.

Cited authors:

Aaltonen 1937, Cajander 1903-1909, 1909, 1913, 1926, 1930, 1949; Gustavsen 1996, Heikurainen 1971, Heikurainen and Kuusela 1962, Huikari 1974, Ilvessalo 1920, 1923; Kujala 1945, Lahti 1995, Lappi and Bailey 1988, Nieppolla 1993 a, 1993 b, Starr 1986, Westman 1981.

1.5. Structure and development of stands

Research in undisturbed forest in Finland started in the early 1900s (Cajander 1909, 1913, 1926; Ilvessalo 1920, 1923). Cajander developed pioneer research in the field of structure, growth and yield in natural forest stands. A part of the Finnish forest, especially in the northern part of the country may be considered primeval forests which according to the "Finland National Report to UNCD 1992 are "areas that usually consist of old forest which has been left in a virgin condition without any human intervention".

Examples of development and vertical profile of some Finnish forest is given in Figure 1.5.-1. and Figure 1.5.-2.

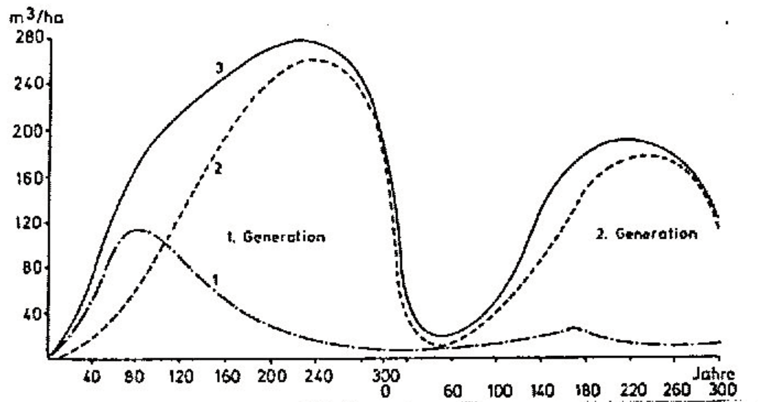


Fig. 1.5.-1. Development of stand wood volume during two generations in northern old natural forest. Site type: *Hylocomium-Myrtillus* in northern Finland. 1 = Birch, 2 = spruce, 3=Total volume SOURCE: Sirén, G. 1955: "The development of spruce forest on raw humus sites in northern Finland and its ecology". Fig. reprinted after Schmidt-Vogt 1986: "Die Fichte", Band II/1, p. 199, Verlag Paul Parey, Hamburg and Berlin.

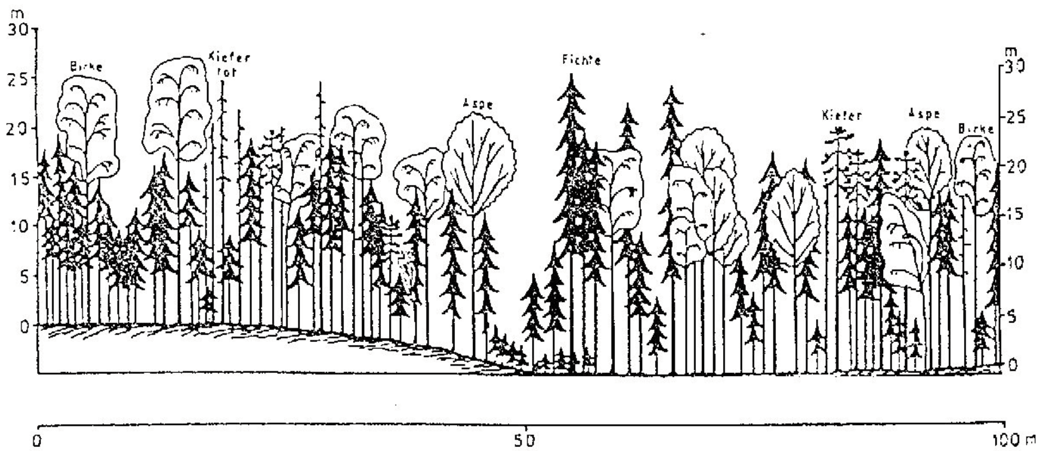


Fig. 1.5.-2. Profile drawing from a natural spruce forest mixed with birch and aspen in Pyhähäkki National Park in Finland. The Forest has developed after a major forest fire. SOURCE: Schmidt-Vogt 1991, Die Fichte, II/3, Parey Verlag, Hamburg and Berlin.

Cajanus (1914) was one of the first Finnish researchers who investigated the structure of even-aged forest stands, namely the repartition of trees by diameter categories applying statistical methods, and as far as we know, he completed the first successful analysis in this field in Finland. Cajanus rejected the use of graphical methods and used the Charlier distribution for the study of diameter distributions.

In relation to stand structure it should be mentioned Heikinheimo's (1915) detailed study on the influence of shifting cultivation in the forests of Finland.

A sample of studies on stand structure and development is given in Table 1.5.-1.

In 1950 Ilvessalo published his investigations on the correlation between the crown diameter and the stem of trees.

An interesting study was completed in 1958 by Heikurainen on the root structure in mixed forests on drained bogs.

The variation and size of the breast height form factor (artificial form factor) for stands of pine, spruce and birch in the northern, southern and in the whole Finland was studied by Gustavsen and Fagerström (1983), who presented twenty-six functions for estimating stand form factor based on measurable stand criteria. These functions can be used for estimation of the stand volume from the form factor (F), basal area (G) and mean or dominant height (H), the classical formula being V=G*H*F.

Tamppo (1986) presented models and methods for analysing spatial patterns of trees.

Table 1.5. -1. A sample of the studies on forest stand structure and development in Finland

Year	Author(s)	The subject of the study on structure and development
1914	V. Cajanus	Development of even-aged forest stands.
1930	Lappi-Seppälä	Growth and development of even-aged mixed stands of pine and birch.
1930	E. Lönnroth	Structure and development of even-aged, naturally normal pine stands in southern Finland.
1937	E. K. Kalela	Growth and development of mixed stands of spruce and *Alnus incana* belonging to the *Oxalis-Majanthemum* type in eastern Finland.
1953	A. Nyyssönen	Structure and development of pine stands treated with different cuttings.
1955	G. Sirén	Development of spruce virgin boreal forest of *Hylocomium-Myrtillus*-type on raw humus sites in northern Finland.
1957	K. Kallio	Development of spruce forests of the *Oxalis-Myrtillus* site type in the southwest of Finland.
1980	K. Mielikäinen	Structure and development of mixed pine and birch stands.
1982	P. Hari et al.	Dynamics of early development of tree stand.
1985	K. Mielikäinen	Effect of an admixture of birch on the structure and development of Norway spruce stands.
1986	L. T. Valsta	Optimizing thinnings and rotation for mixed, even-aged pine-birch stands.
1988	Martti Varmola	A stand model for simulating the early development of Scots pine cultures in Finland.
1988	T. Pukkala T. Kolström	Simulation of the development of Norway spruce using a transition matrix
1992	T. Kolström	Dynamics of uneven-aged stands of Norway spruce - a model approach.
1995	Jari Hynynen	Models for predicting the development of Finnish Forests. (Refers to the Finnish MELA System which is an operational information system for solving problems related to forest management designed originally in the late 1970s. MELA is also applied on stand level. In this paper a revised set of growth and yield models for the MELA system was developed, and the models for prediction of regeneration and mortality were included.

Pukkala analyzed the effect of spatial distribution of trees on the volume increment of a young Scots pine stand (1988), presented methods to describe the competition process in a tree stand (1989 a), and described a technique for prediction of tree diameter and height in a Scots pine stand as a function of the spatial pattern of trees.

Valsta (1987/1988) analyzed optimization of species composition in mixed, even-aged spruce-birch stands based on optimum thinning and rotation management regimes and confirmed the generally accepted idea that the mixed stand with an optimal species composition was superior to both of the single stands if the object of maximization is volume and net revenue. Valsta discussed in this paper different types of mixed species growth models.

Lappi and Bailey (1988) proposed a model for predicting the height development which is considered by its authors as an alternative to traditional site index method. According to the proposed model the average height of dominant and co-dominant trees in a population (stand) is expressed as a function of age; then a model is developed for the variance/covariance structure of deviations from this average height curve due to stand tree within stands.

Dependence of some stand characteristics on stand density was analyzed by Laasasenaho and Koivuniemi (1990), and the ability of competition indices to describe stand dynamics by Ojansuu (1995) who concluded that total residual variance is not an adequate measure for the goodness of a competition index; with this conclusion we should remember that for the comparison of different competition indices correlation or residual variance of the growth model prediction it is usually used.

The impact of fire on Finnish forest (in the past and today) and its influence on structural characteristics of stands was examined by Parviainen (1994).

A method for predicting tree dimensions in Scots pine and Norway spruce stands was developed in 1994 by Pukkala et al.

In 1997 Hökka developed models for predicting tree height of Scots pine, spruce and birch (*Betula pubescens*), the result being height-diameter curves with random intercepts and slopes for trees growing on drained peatlands. A logarithmic height-diameter curve with one non-linear parameter proper for each species was applied and it was assumed that the intercept and slope of the curve would vary randomly from stand to stand, the mean intercept and slope were determined using stand characteristics; in order to fit the model a mixed linear technique was applied.

Maltamo (1997) used the Weibull distribution comparing the basal area, diameter distribution estimated by tree species, and the entire growing stock in a mixed stand of Scots pine and Norway spruce. The results of this study demonstrated that "far more accurate results were obtained when the distributions were formed using parameter models separately for different tree species than when using parameter models for the entire growing stock".

Cited authors:

Cajander 1903-1909, 1909, 1913, 1926; Cajanus 1914, Gustavsen and Fagerström 1983, Hari et al. 1982, Heikinheimo 1915, Heikurainen 1958, Hökka 1997, Hynynen 1995, Ilvessalo 920, 1923, 1950; Kalela 1937, Kallio 1957, Kolström 1992, Laasasenaho and Koivuniemi 1990, Lappi and Bailey 1988, Lappi and Seppälä 1930, Lönroth 1930, Maltamo 1997, Mielikäinen

1980, 1985; Nyyssönen 1953, Ojansuu 1995, Parviainen 1994, Pukkala 1988, 1989 a, 1989 b; Pukkala and Kolström 1988, Pukkala et al. 1994, Schmidt-Vogt 1986, 1991; Sirén 1955, Tomppo 1986, UNCED 1992, Valsta 1986, 1987; Varmola 1988.

1.6. Stand volume estimation, growth and yield modelling, yield tables

Among the early works on stand volume determination based on sample plots should be mentioned Ilvessalo – 1932 (establishment and measurement of permanent sample plots), Lönnroth – 1936 (about volume line in the stands), Nyyssönen – 1955 a, 1955 b (estimation of the growing stock from aerial photographs and estimation of stand volume by means of the relascope).

In 1920 Ilvessalo adopted Cajander's site type classification in the Finnish forest mensuration, based on ground flora and constructed the first Finnish yield tables for Scots pine, spruce and birch growing in southern Finland. Ilvessalo's yield tables refer to site types *Oxalis-Myrtillus* (OMT) and *Myrtillus* (MT), and in the case of spruce the tables contain data for stands of age 10 to 130 having at 80 years 19.5-23.0 m dominant height and mean annual increment 5.9 - 6.3 m^3/ha for wood with diameter above 10 cm. In 1927 Ilvessalo summarized the methods for preparing yield tables.

In 1960 Koivisto completed a new generation of growth and yield tables based also on Cajander's site classes. For spruce the following figures show the difference between site classes (forest types):

Site type (Cajander's floristic type)	Ages (years)	Age for height (years)	Dominant height (m)	Mean annual increment m^3/ha/year diameter > 10 cm
OMT[1)] closed canopy	20-130	80	22.9-25.1	6.6-8.5
OMT unclosed canopy	20-130	80	19.5-23.0	5.6-6.0
OMaT[2)] man made	15-70	50	21.8	
		70	25.1	
OMT man made	15-70	50	18.0-20.6	
		70	21.3-23.5	
OMT plantation in rows	20-100	80	20.9-22.2	

1) *Oxalis-Myrtillus* Type;
2) *Oxalis-Majanthemum* Type

Vuokila (1965) developed functions for variable density yield tables of pine based on temporary sample plots, and in 1966 constructed growth and yield tables for pine stands treated with intermediate cuttings (thinnings) of varying degree for southern-central Finland, and in 1980, with Väliaho, as second author, he developed growth and yield models for conifer cultures in Finland. The Vuokila-Väliaho models refer to five site classes, 50-120 years rotation period, having age and dominant height as entry characteristics.

Assessment of timber assortments, value and value increment of tree stand was completed in 1982 by Nyyssönen and Ojansuu.

Growth. Determination of stand growth has been a major subject for Finnish forest practice and research since the beginning of the 20th century.

In 1930 Ilvessalo presented at the International Congress of the Forestry Experimental Stations the possibilities of finding a uniform basis for the study of growth and yield in different countries and in 1937 he published his results on growth value of natural, "normal" stands in Central-North Finland.

Hustich (1943), who was a dendrochronologist, determined the annual variations in "the growth and crop values in Lapland", and Mikola (1952) underlined the effect of climatic variations on forest growth in Finland. Kuusela (1953/1954) discussed the determination of growth based on periodical measurements of plots and Ilvessalo (1956) summarized the methods for determination of increment, generally used in Finland.

For the use of forest management a long-term timber production model on a large forest area was developed by Kilkki and Pökälä (1975).

New information on estimation of stand increment are given by Nyyssönen and Mielikäinen (1978). Laine and Starr (1977) studied the post-drainage stand increment in relation with the peatland site type classification in Finland.

Vuokila (1980) showed the dependence of growth and yield on the density of spruce plantations. Oikarinen (1983) prepared growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland. Other growth models were developed by Vuokila – 1983 (thinning models for forest cultures), Sievanen – 1983 (growth models for minirotation plantations), Pukkala – 1989c (predicting diameter growth in even-aged Scots pine stands with a spatial and non-spatial model), Pukkala and Kolström – 1991 (effect of spatial pattern of trees on the growth of Norway spruce stand – a simulation model), Kellomäki et al. – 1993 (FinFor, a model for calculating the response of the boreal forest to climate change), Nyynynen – 1995 (models for predicting the development of Finnish forests within Finnish MELA System which predict growth with individual tree distance independent models and refers to major growing species in Finland, and separate models for trees growing on mineral soils and peatlands; these models are based on data from permanent sample plot network connected with the Finnish National Forest Inventory tracts).

The problem of a large scale forestry modelling and analysis in Finland is examined by Siitonen and Nuutinen (1995) in connection with the MELA System underlining that "with minor software modifications MELA is also applicable for multinational forestry analysis if relevant and compatible local forest information is available" (p. 139).

Sievänen (1995) established some interesting relationships between distance independent (DI) and distance dependent (DD) growth models. Sievänen used a process-based individual tree growth model that uses shading leaf area (as an indicator of competition) as a component of both DI and DD stand growth models and making simulations show that the main of the differences between DI and DD models is the development of stand density: when the leaf area evaluation of the DD model is (locally) identical with that of DI model, the two models offer similar results but when a leaf area evaluation method (which is advantageous to large trees) is applied in both models, the results from DI and DD models differ.

Mielikäinen (1995) stated in his paper "Growth trends of forest in Finland and North-Western Russia" (Kola peninsula) that "The total growth of Finnish forests has increased by more than 40 per cent since the beginning of the 1950s. The main resources for an increase of such magnitude are to be found in changes in forest structure and silvicultural measures" (p. 274) but "In the North, close to the Arctic Circle, both negative and positive growth trends have been measured … Local forest decline covers only a small fraction of the forests around pollution sources. In the major part of the forests in Lapland, the radial increment of Scots pine this century has been at a clearly higher level than in the 19th century. This is at least partly due to more favourable climatic conditions… in southern Finland forest and Russian Karelia growth trends were more difficult to detect because of the impact of forest management and higher competitions between trees in dense stands" (p. 274). In this paper Mielikäinen also discussed the dynamics of mixed forests, cyclic variations in tree growth and effects if increases CO_2 and nitrogen deposition on soil productivity.

Growth trends of Scots pine unmanaged and managed stands in southern and central Finland were investigated by Mielikäinen and Timonen (1996).

Cited authors:

Hustich 1943, Hynynen 1995, Ilvessalo 1920, 1927, 1930, 1932, 1937, 1956; Kellomäki et al. 1993, Kilkki and Pökäla 1975, Koivisto 1960, Kuunsela 1953/1954, Laine and Starr 1979, Lönnroth 1934, Mielikäinen and Timonen 1996, Mikola 1952, Nyyssönen 1955 a, 1955 b; Nyyssönen and Mielikäinen 1978, Nyyssönen and Ojansuu 1982, Oikarinen 1983, Pukkala 1989 c, Pukkala and Kolström 1991, Sievanen 1983, 1995; Siitonen and Nuutinen 1995, Vuokila 1965, 1966, 1980, 1983; Vuokila and Valliaho 1980.

1.7. Process-oriented growth and yield models

After 1970 computerized growth models used in forestry to predict stand growth in terms of tree characteristics (dbh, height, stem volume) became common in the developed countries. The physiological process-models were developed later, in the 1980s, and Finland was one of the advanced countries in this field. In physiological process-oriented models the photosynthesis is the key process and most photosynthesis-based growth models are predicting growth in terms of biomass per unit area.

Apart from photosynthesis other physiological processes can be involved in modelling and such an early attempt was Botkin's et al. (1972) JABOWA model (U.S.A.) which was inspired from agriculture.

The greatest obstacle for a large scale application of this type of models appears to be the difficulties to get data for their validation.

One of the earliest Finnish process-oriented growth models was based on carbon uptake and allocation in individual trees in order to determine stand growth and was proposed by Mäkela and Hari in 1986. In the same year Oker-Blom analyzed photosynthetic radiation regime and canopy structure in modelled forest stands. In 1987 Mäkelä reported the testing and calibration of his carbon balance model (mentioned before). The presented stand-level version of model is compared with growth and yield tables. The analysis applies a generalized sensitivity test using the Monte Carlo techniques.

Mäkelä's (1988) models of pine stand development represent an ecophysiological system analysis. In the same year Mäkelä discussed parameter estimation and testing of a process-based stand growth model using Monte Carlo techniques (1988 a) and presented performance analysis of a process-based stand growth model, using also Monte Carlo techniques. In 1990 Mäkelä reviewed models of resource allocation and tree growth which derive the distribution pattern from balanced growth considerations and optimality principles. He considered the functional balance and the pipe model theories, and the analysis of height growth; the allocation principles are connected with a carbon-balance tree-growth model; this way appeared to be promising, but more empirical data are needed for testing and further developments of models which refer to modelling the structural-functional relationship in whole-tree growth (p. 81).

Sievänen et al. (1988) developed a discrete stand growth model using photosynthesis and respiration relationships in individual trees and expressed tree growth predictions in terms of biomass and basal area.

Some recent process-oriented forest growth and yield models were reviewed by Mäkelä (1993) who analyzed their gaps of knowledge, and the possibility of filling these gaps with empirical submodels. In conclusion, Annikki Mäkelä considered that "Management-oriented stand growth models by applying aggregation and simplifying assumptions in order to make the model more easily manageable, and by substituting the weakest models with purely empirical relations in a wider perspective have potential applications in regional comparisons and scenarios of the effects of global changes in the environment. The example models are readily applicable to predict growth potential analysing stocking density and thinning. Predictions of fertilizer effects are less straight forward because the nutrients only occur indirectly in the models, i.e. the control of carbon allocation" (p. 94).

An individual tree process-based stand growth model of even-aged stands was presented in 1993 by Sievänen and is based on the carbon balance according to which tree growth depends on tree activities of photosynthesis, respiration and senescence. Sievänen compared the stand growth model with a yield table and a sapling stand, comparison which suggests that his model is capable of accounting for basic features of stand growth, using simulation with different initial stand density and some of the model's coefficients concluded that the stand growth model is approximately consistent with the self-thinning rule. In the same year Sievänen and Burk (from the U.S.A.) published a paper with their studies on the problem of estimating the parameters of a process-based growth model, using typical stand growth measurements of tree dimensions for varying site conditions. The analysis of the identification possibility of model parameters shows (according to the above models): "(1) that the structure of the model makes certain parameter contributions unidentifiable and (2) that the data at hand do not support all the parameters. It is not possible the reduce the number of parameters in the model without losing its biological significance" (Can. J. For. Research 1993, 23, p. 1837), and the remedy was a slightly modification of the model by introducing of some restrictions of parameters. In conclusion, stand increment may be predicted as canopy photosynthesis and analysis of the loss function components indicates that for a reliable fitting of the model the following measurements are needed: diameter, height, density and live crown ratio.

Cited authors:

Botkin et al. 1972 (U.S.A.), Mäkelä 1987, 1988 a, 1988 b, 1988 c, 1990, 1992; Mäkelä and Hari 1986, Oker-Blom 1986, Sievänen 1993, Sievänen and Burk 1993, Sievänen et al. 1988.

1.8. Weight and biomass studies

Early Finnish weight and biomass studies were developed by Hakkila: 1969 (weight and composition of the branches of large Scots pine and Norway spruce trees), 1970 (basic density, bark percentage and dry matter content of Alnus incana - grey alder), 1971 a (whole tree chipping in thinning operations), 1971b (branches stump and roots – see Figures 1.8.-1. and 1.8.-2. – as a future raw material source within a joint Nordic research project initiated in 1969 to find industrial uses for these parts of tree).

Harvesting of stump and roof wood by the Paleri stumpharvester was commented by Hakkila and Makela (1973).

Annual primary production and nutrient cycle in some Scots pine stands was investigated by Malkonen (1974).

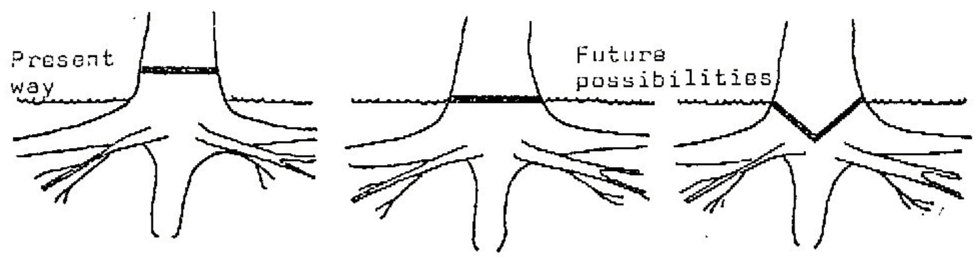


Fig. 1.8.-1. A part of the stump could be harvested by lowering the butt cross-section in felling. SOURCE: Hakkila, P. 1971 b, "Branches, stumps and roots as future raw material source in Finland". In: "Forest Biomass Studies, IUFRO Section 25, Experiment Station University of Maine at Orono", p. 54, fig. 1.

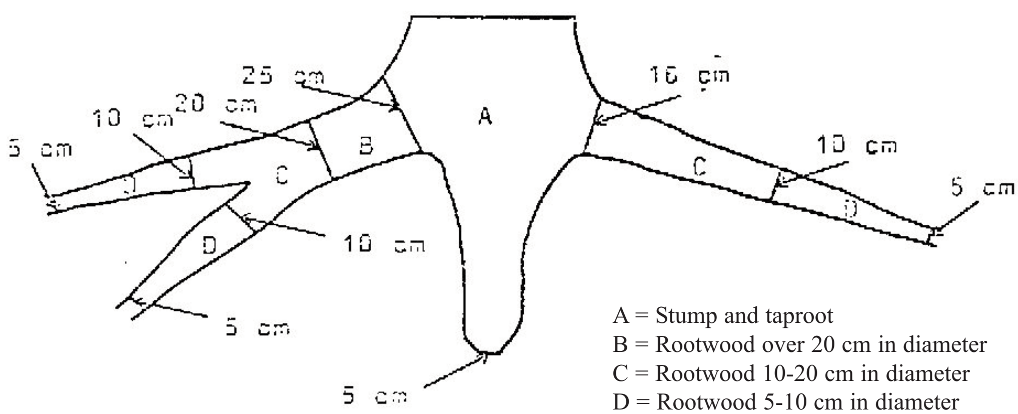


Fig. 1.8.-2. Classification of stump and rootwood. Rootwood under 5 cm in diameter was not taken into account
SOURCE: Ibid. Fig. 1.8-1, p. 54, fig. 2.

In 1979 Hakkila constructed wood density and dry weight tables for Scots pine, spruce and birch stem valid for the whole country.

Vasalder (1982) determined plant biomass and production *in virgin*, drained and fertilized sites in a raised bog in southern Finland while Kaunisto (1983) determined the biomass of *koripajum* (*Salix viminalis*) and its nutrient and water consumption on differently fertilized peats in the greenhouse.

Hytönen et al. (1987) compared four methods for estimating willow biomass (harvesting, mean stool, regression and ratio) and concluded that the regression method and in some cases the mean stool method were the best.

Cited authors:

Hakkila 1969, 1970, 1971a, 1971b, 1979; Hakkila and Makela 1973, Hytönen et al. 1987, Kaunisto 1983, Malkonen 1974, Vasander 1982.

1.9. Tree-ring studies

Tree ring studies were initiated in Finland by Laitakari in 1920 in his “Studies on the effect of weather conditions on the height and diameter growth of Scots pine”. He analyzed the tree-rings of this species which were from the trees growing in southern Finland and discovered, as Hesselman (1904a, 1904b) in Sweden, that height and diameter growth have a different pattern in their relation to climatic factors: the annual height growth depends principally on the temperature of the latter summer of the preceding year while the width of the annual ring depends on the spring temperature of the current year. No correlation could be found between precipitation and tree growth. It should be noted that Laitakari, following the example of Douglass in the U.S.A. (1919), tried to found the existence of the 11-years cycle of sun spot and “according to him this cycle exists and the maxima and minima of diameter growth coincide with the maxima and minima of the sunspots cycles” (Mikola 1956, Tree-Ring Bull., vol. 21, p. 16).

Another detailed work on variations of the radial growth of pine (*Pinus sylvestris*) was completed by Boman in 1927 who used material from all parts of Finland (the oldest trees having over 300 years) and reported several cycles with the length of 7, 11, 21, 35 and 70 years and a possible 105 years cycle, but did not discuss the causes of these cycles. In this preliminary mentioned tree-ring studies their authors did not practice dendrochronological dating.

During the second national forest survey (1936-1938, the first being completed in 1921-1924) numerous samples of pine and spruce tree-rings were extracted with increment borer, but because of war-time this material was sent to Sweden where it was analyzed and the results published in 1944 by Eklund.

According to Ilvessalo (1943) and Eklung (1944) during the period of 10 years between the two forest inventories diameter growth of pine was on a remarkable higher level than before the second survey (106.8 to 109.0 compared with the normal level = 100). Eklund (1944) tried to estimate numerically the effect of climate on the radial growth of pine and spruce in two Finnish national forest surveys.

In 1944 Hustich and Elfving studied the radial growth variations of forest border pine and used for the first time in Finland the simple correlation (as statistical method) to establish the relationship between ring width and climate. Hustich (1947) analyzed variations in climate in crop of cereals and in growth of pine in northern Finland during the 1890-1939 period and in the next two years he determined the dependence of Scots pine in northernmost Finland on the climate in the last decades (1948), and correlation between growth and the recent climatic fluctuations; he used a variation coefficient that he called "climatic hazard coefficient", while Mikola (1950) calculated "mean sensitivity" according to Douglass method.

Hustich (1949) compared Finnish tree-ring analyses to Canadian ones (1950, 1954) from Hudson Bay and James Bay region (eastern Canada), and his comparisons revealed an opposite trend in the 1910-1930 period in climatic development in Europe and Canada: "While a marked growth improvement is characteristic to the Scandinavian timber-line region, a distinct decrease occurred in Eastern Canada in the same time".

In 1956 Mikola published a review of tree-ring researches in Finland and mentioned a previous work of Ording (1941) on annual ring analyses of spruce and pine: this is a detailed work in which the existence of a 23-years cycle (most distinct) was reported, but cycles of 11, 17 and 35 years were also identified. Mikola confirmed the existence of these cycles in his material and mentioned that in the case of spruce the cycles were obscure and the cycle of 11 years was not found at all. According to Mikola in the Finnish research of the 1950s "little attention is paid to eventual cycles in growth fluctuation. On the other hand, the effect of climatic changes on tree growth as well as on other phenomena in fauna and vegetation especially along the northern timber-line, has been the subject of several investigations". (Tree-Ring Bull. vol. 21, p. 17). Mikola affirmed that in Finland "no correlation has been found between precipitation and diameter growth of trees" (ibidem p. 18), and this is probably because Finland is climatically a rather uniform area without high mountains.

The connection between tree-rings and climate (or tree-rings as climate indicators) was also examined by Sirén (1961, 1963).

In 1971 Alestalo presented (one of the earliest works in the world) dendrochronological interpretation of geomorphic processes. Sirén and Hari (1971) disclosed coinciding periodicity in recent tree-rings and glacial clay sediments.

In 1995 Zetterberg and Eronen, using 1265 subfossil Scots pines from 38 sites in northern Fennoscandia, constructed a 7000-year pine master chronology which can be used for dating subfossil pines from a large area of Fennoscandia. An increased variability in tree growth after 3000 B.C. suggested by the data of 4500-300 B.C. period that it may be considered as the result of climatic change in the mid Halocene towards less stable weather conditions. In the next year (1996) Zetterberg et al. succeeded in constructing a 7500 year tree-ring record for Scots pine in northern Fennoscandia and discussed its application to growth variation and paleoclimatic studies.

Cited authors:

Alestalo 1971, Boman 1927, Eklund 1944, Hesselman 1904a, 1904b; Hustich 1945, 1947, 1948, 1949, 1950, 1954; Hustich and Elfving 1944, Ilvessalo 1943, Laitakari 1920, Mikola 1956, Ording 1941, Sirén 1961, 1963; Sirén and Hari 1971, Zetterberg and Eronen 1995, Zetterberg et al. 1996.

1.10. Forest inventory: sampling, remote sensing and GIS

Early groundwork for pilot inventories was done in 1912 and 1921, and Finland was the first Nordic country to publish a detailed report on the result of the general survey of the country forests carried out during the years 1921-1924, and containing 421pp. and 192 pp. tables (Ilvessalo, Y. 1927).

Eight survey cycles of National Forest Inventories (NFIs) have been completed till 1995: 1921-1924,1936-1938, 1951-1953,1960-1963, 1964-1970, 1971-1976, 1977-1984, 1985-1995.

In Finland, Forest Research Institute has been responsible throughout for organizing the inventories (NFIs).

Among many works published in connection with NFIs should be mentioned those signed by (Ilvessalo 1927, 1953; Poso 1978: northern Finland; Kuusela 1978a, 1978b; Kuusela and Salminen 1983: Northermost forestry board districts of south Finland and the whole of south Finland; Paavilainen and Tiihonen 1984; peatland forests in southern and central Finland in 1951-1981; Mattila 1986: Finnish Lapland; Kuusela et al. 1986: North Finland; Kuusela 1987, Paavilainen 1988: peatland forests 1951-1984, Tomppo and Siitonen 1991, Kuusela and Salminen 1991, Nyyssönen 1993: a short synthesis of NFIs in the Nordic countries; Tomppo et al. 1997: country report for Finland on forest inventory and survey systems.

As a rule the following main type of data produced by NFIs in Finland and other Nordic countries (usually classified by ownership categories) are mentioned below after Bengtsson 1987, Kuusela 1987, and Nyyssönen 1993:

- Land use and forest site classes;
- Growing stock (area and volume) by tree species, diameter and quality class, age and development class;
- Annual increment of the growing stock;
- Silvicultural condition and treatment needs.

According to Nyyssönen (1963) “There are two alternatives in the organization of annual work in a NFI: the whole country can be covered every year, or the work can be done county by county. The former procedure has been applied in Sweden since 1953; the latter has been followed in Finland and Norway with few exceptions. The Swedish system appears to have certain advantages though its costs are somewhat higher” (p.31).

During the first three inventories (1921-1953) in Finland was used a special form of line plot sampling: “In addition to measuring sample plots at given intervals, ocular estimation of volume and increment were made using auxiliary tables in every stand through which the line passed “(Nyyssönen 1993). In 1964 was adopted a cluster sampling pattern. Concentric circular plots in size from 100 to 1000 square meters represented the most common type of sample plot but relascopes with a basal area factor of 2 were also used. In 1993 registration, storage and processing of data were almost entirely computerized (Nyyssönen 1993). Sampling techniques in forest inventories including the plot topics were presented by Lindeberg 1924, 1926; Ilvessalo 1949a, 1949b; Kuusela 1956, Nyyssönen 1967.

Like in other Nordic countries NFI has been based on temporary sample plots measured on the ground.

Permanent sample plots have been used since 1932 (Invessalo 1932). Nyyssönen (1967) underlined that “Permanent sample plots were introduced in response to a growing demand for accurate estimates of changes occuring in the forests. In experiments started in Finland as early as 1957, large-scale application of the principles of sampling with partial replacement by inconspicuously marked remeasurable plots indicated its efficiency in management plan inventories and “a systematic network of about 3000 permanent sample plots was established in Finland in 1985 and 1986 for the purpose of monitoring environmental and ecological changes” (Nyyssönen 1993, p.32).

The accuracy of systematic sampling used in National Forest Inventories was discussed frequently in all Nordic countries (e, g. in Finland: Lindeberg 1924. 1926, Kunsela and Salminen 1983, Kuusela et al. 1986) the relative standard errors varying for the whole country: 0.5 % for forest area and mean volume and

0.7 % for total volume while in provinces/counties it was 1-4 % for forest area and mean volume, and 2-5 % for total volume. In Finland forest land (20 million hectares) is divided into 19 units and the annual cost of NFIs in 1991 was estimated at USD 0.07 per hectare in comparison with USD 0.14 in Sweden where NFI has been annually organized for the whole country level (Nyyssönen 1993).

In 1990s modelling was used in the field of forest inventories. In 1991 Korhonen and Päivinen presented a model forest for evaluating forest inventory designs. A two-phase sampling approach to gather data for GIS (Geographic Information Systems) was developed by Poso in the same year. Kangas proposed in 1996 small areas estimates using model-based methods. In small-areas the number of sample plots is usually small and the result is a large variance of classical estimators but “information from nearby areas can be utilized to improve the subarea estimates using either nonparametric or parametric models” (For. Abs. 255/1998).

Modelling interactions between trees by means of field observations were investigated by Särkka and Tomppo (1996).

Aerial photographs were used in Finland in the early 1950s as field maps for survey crews. In 1950 the correlation between the crown diameter and the stem diameter was established (Ilvessalo 1950) and estimation of the growing stock from aerial photographs became possible (Nyyssönen 1955-a 57pp. paper). A two-step sampling design based on sampling design with photo-interpretation and field sample plots was applied since 1970. The first sample was used for area estimation and stratification while three-stand information was based on the second sample established with remeasured plots (Poso 1972; Mattila 1985- in North Finland: Finnish Lapland).

Since the end of 1980s there was a strong movement towards the use of satellite imagery for development of forest inventories. In 1987 Poso, Paananen and Simila presented the results of “Forest inventory by compartments using satellite imagery” in Southern Finland with correlation coefficients for stand (volume, age and mean height) 0.85 between estimates from satellite and field measurements.

Häme and Tomppo (1987) presented their first experiments on stand based forestry inventory from SPOT image. This preliminary inventory was obtained by numerical interpretation of SPOT satellite and/or Landsat Thematic (TM) Mapper images. Cited above authors concluded that SPOT image supplies more spatial information than Landsat TM. The early (possible the first) use for satellite microwave radiometry of forest and surface types in Finland was completed by Hallikainen, Jolma and Hyyppä. They used Nimbus-7 Scanning

Multichannel Microwave Radiometer (SMMR) for investigating the brightness temperature of various forest types and land-cover categories (For Abs. 3099/1989).

Poso (1988) was seeking for an optimal path for using satellite imageries for forest inventory and monitoring.

In 1990 Tomppo presented information on satellite image-based national forest inventory of Finland.

Hyyppa and Hallikainen discussed in 1993 forest inventory methods based on data obtained with an airborne ranging radar. They used a helicopter-borne eight-channel ranging scatterometer HUTSCAT (Helsinki University of Technology SCAT terometer) which can measure a radar canopy profile (FCP) with a range resolution of 65 cm and tested it for "feasibility in determining total stem volume and total basal area per hectare, dominant and mean heights and crown base of pine and spruce stands. Using these methods, the mean and dominant tree height were measured with a standard deviation of about 1m. The stem volume and total basal area per hectare were estimated with a relative accuracy of 15 % and 20 % respectively" (For. Abstracts 6233/1993). The same authors developed in a 1996 paper the applicability of airborne profiling radar to forest inventory and proposed "…that radar measurements waild be employed with helicopter-borne ocular inventories in order to improve the estimation accuracy and to speed up the measurements" (For. Abs. 9451/1996).

Tokola and Heikkilä (1997) suggested the improvement of forest inventory based on satellite imagery by using a priori site quality information.

Varjo (1996) developed a method for controlling the quality of continuously up-dated forest information by satellite remote sensing using Landsat Thematic Mapper (TM) data.

Landsat MSS images (multitemporal image analysis) were used in 1997 by K. Mikkola for the analysis of vegetation damage around metal smelters.

In 1981 Kuusela was probably the first researcher who open in Finland the period of Multi Resource Inventories (MRI) in his paper "From Timber Surveys to Monitoring of the Forest Ecosystem".

In 1993 Nyyssönen concluded that "The common trend in an increasingly complex world is diversification of inventory objectives. That is not to say that earlier NFIs were in any way limited to the quantitative measurement of growing stock and increment; there are plenty of examples of additional objectives: biological studies on flora and fauna in Finland in the 50s, inventory of the road network in Sweden around the year 1960, estimates of woody biomass, and serious efforts in all the Nordic countries since the early 80s to monitor the vitality of trees and environmental changes" (p.33).

In 1987 became common the term “forest resources assessment” (Kuusela 1987: national report at the meeting of experts on forest resource assessment).

Anderson, Freimund and Pitt (1992) developed a recreation resource inventory model (RRIM) for forest planning and management and presented it at a meeting concerning “Nordic outdoor recreation”.

IUFRO international guidelines for forest monitoring intended to promote standardized or compatible collection and reporting of selected data on forest monitoring in such a way that the results offer a common database for research and management. The guidelines include sections on collection “of map data and remotely sensed data, and sampling design” (For. Abs. 1850/1995). This remarkable guide was edited by R. Päivinen (Finn), H. G. Lund (USA), S. Poso (Finn) and T. Zawila-Niedzwiecki.

Among the works on multi-source national forest inventory in Finland should be mentioned that completed by Tomppo in 1993 and 1996; Tomppo et al. in 1996.

Guangxing Wang was probably the first author in Finland who constructed an expert system for forest resource inventory and monitoring in the frame of multi-source data (173pp).

In 1997 Häme et al. developed a new methodology to estimate the biomass (organic matter) of conifer-dominated boreal forests using ground measurements and high resolution satellite images (Landsat TM), spectral models being applied directly to a calibrated AVHRR (Advanced Very High Resolution Radiometer). The results have been more than acceptable.

Cited authors:

Anderson et al. 1992, Hallikainen et al. 1988, Häme and Tomppo 1987, Häme et al. 1997, Hyyppä and Hallikainen 1993, 1996; Ilvessalo 1927, 1932, 1949a, 1949b, 1950, 1953; Kangas 1996, Korhonen and Päivinen 1990, Kuusela 1956, 1978a, 1978b, 1981, 1987; Kuusela and Salminen 1983, 1991; Kuusela et al. 1986, Lindeberg 1924, 1926; Mottila 1985, 1986; Mikkola 1997, Nyyssönen 1956, 1963, 1993; Paavilainen and Tiihonen 1984, 1988; Päivinen et al. 1994, Poso 1972, 1978, 1988, 1991; Poso et al. 1987, Särkkä 1996, Tokola and Heikkilä 1997, Tomppo 1990, 1993, 1996; Tomppo and Siitonen 1991, Tomppo et al. 1996, 1997; Varjo 1996, Wang 1996.

1.11. Chronology of selected events

1909: Site classification and evaluation of productive land based on ground vegetation (Aimo Kaarlo Cajander).

1912: Early groundwork for forest inventory.

1914: First successful study on repartition of trees by diameter categories in even-aged stands using the statistical method: Charlier distribution (Verner

Cajanus).

1920: First Finnish yield tables for Scots pine, spruce and birch (in southern Finland) based on Cajander's site type classification (Yrjö Ilvessalo).

1920, 1927: Early tree-ring studies (E. Laitakari – 1920, A. Boman – 1927).

1921-1924: The first national forest inventory in Finland.

1924, 1926: Theory on the determination of mean error in the case of inventory based on systematic strips (J. W. Lindeberg).

1927: A detalied report on the results of the first national forest inventory (Yrjö Ilvessalo).

1932: The establishment and mensurement of permanent sample plots (Y. Ilvessalo).

1933: An alternative to Cajander's evaluation of site productivity: Two Way Indicator Species Analysis (TWINSPAN) based on some soil characteristics as texture, stoniness and humus layer depth (J. Nieppola).

1936: Early works on stem form of Scots Pine and birch (J. Lappi and Seppälä).

1944: The use for the first time of the simple correlation technique to establish the relationship between ring width and climate (I. Hustich and G. Elfving).

1947/1948: Extensive volume and increment tables of standing trees (Yrjö Ilvessalo).

1949: Description of sampling techniques in forest inventories completed in Finland (Y. Ilvessalo).

1950s: The early use of the aerial photographs as maps in the field (Aarne Nyyssönen).

1955: The estimation of growing stock became possible from aerial photographs (A. Nyyssönen).

1955: Estimation of the growing stock from aerial photographs (A. Nyyssönen).

1956: The methods used in Finland for determination of increment (Yrjö Ilvessalo).

1956: A review of tree-ring researches in Finland (Peista Mikola).

1957: Early application of the principles of sampling with partial replacement (A. Nyyssönen 1993)

1960: A new generation of growth and yield tables also based on Cajander's site classes (P. Koivisto).

1964: A cluster sampling pattern was adopted in forest inventories (A. Nyyssönen 1993)

1965: Functions for variable density yield tables of pine (Y. Vuokila).

Since 1970 was applied a two-step sampling design based on sampling design with photo-interpretation and field sample plots (Simo Poso 1972, Mattila E. 1985).

1971: One of the earliest works in the world concerning dendrochronological interpretation of geomorphic processes (J. Alestalo).

1975: A long-term timber production-model (P. Kilkki and R. Pökälä).

1977: Finnish volume increment function (H. G. Gustavsen).

Late 1970s: MELA-System – a forest management planning system containing stand growth models.

1978: A simultaneous equation model to determine taper curve (P. Kilkki).

1979: Wood density and dry weight tables for scots pine (*Pinus sylvestris*), Norway spruce and birch stems valid for the whole Finland (P. Hakkila).

1980: Growth and yield models for conifer cultures in Finland, age and dominant height as entries (Y. Vuokila and H. Väliaho).

1981: A turning point in forest inventory: From timber surveys to monitoring of forest ecosystems. The beginning of the development of multi-resource forest inventories (K.Kuusela 1981, Risto Päivinen et al. 1993, Tompa E. 1993 and 1996).

1982: Taper curves and volume functions for pine, spruce and birch (Jouko Laasasenato).

1982: A general taper curve polynomial model used in Finland (Jouko Laasasenato).

1982: A core monograph on growth disturbances of forest trees (Kimmo K. Kolari ed).

1983: Variation and size of artificial form factor of pine, spruce and birch stands (H. G. Gustavsen and H. Fagerström).

1986: Mixed linear models for analyzing and predicting stem form variation of Scots pine (J. Lappi).

1986/1987: An early Finnish process-oriented growth model based on carbon uptake and allocation in individual trees in order to determine stand growth. Tested and calibrated in 1987. (Annikki Mäkela and P. Hari).

1987: Forest inventory by compartments using satellite imagery in Sauthern Finland (S.Poso et al.).

1987: First experiments on stand based forestry inventory from SPOT and Landsat Tematic Mapper (MT) satellite imagery (T. Häme and E. Tomppo).

1987/1988: Optimization of species composition in mixed even-aged spruce-birch stands based on optimum thinning and rotation management regimes (Louri T. Valsta).

1988: A process-oriented growth model utilizing photosynthesis and respiration relationships in individual trees (R. Sievänen, T. E. Burk and A. R. Ek).

1988: An original way to determine stem growth using polar coordinates (Risto Ojansuu).

Since the end of 1980s there was a strong movement towards the use of satellite imagery for the development of forest inventories.

1990: Satellite image-based national forest inventory of Finland (E. Tomppo).

1991: A two-phase sampling approach to gather data for GIS was developed (S. Poso).

1990s: The use of modelling in forest inventories: a model forest for evaluating forest inventories (K.T. Korhonen and Risto Päivinen).

1992: Multi-source national forest inventory of Finland (Tomppo E).

1993: Determination of spruce growth in relation to stem cross-sectional area at the crown base (Jyrki Koivuniemi).

1994: A IUFRO Project on guidelines for forest monitoring (R. Päivien-Finn, H.G. Lund-USA, S. Poso-Finn, T. Zawila-Niedzweki).

1993: A review of process-oriented forest growth and yield models (A. Mäkelä).

1993: The use of helicopter-borne radar which can measure a radar canopy profile with a range resolution of 65cm (J. Hyyppa and M. Hallikainen).

1993: Registration, storage and processing of data were almost entirely computerized (A. Nyyssönen).

1995: A scheme to derive growth models which is based on primary growth factors and measurable tree and stand variables (Jouko Laasasenaho and Mark-Leo Waite).

1995: Growth trends of forests in Finland (K. Mielikäinen).

1995: Growth models for predicting the development of Finnish forests within the Finnish MELA System (Jari Hynynen).

1995: Relationship between distance independent and distance dependent growth models (Risto Sievänen).

1995, 1996: A 7000 and 7500 years pine master chronology in northern Fennoscandia (Pentti Zetterberg and Matti Eronen).

1996: Construction of an expert system for forest resource inventory and monitoring in the frame of multi-source data (Guanaxing Wang, Univ. of Helsinki).

1997: A new methodology was developed to estimate the biomass (organic matter of conifer boreal forest) using satellite images (T. Häme, A. Salli, K. Anderson, A. Lahi).

1997: A remote sensing analysis of vegetation damage performed in Russian Kola Peninsula by The Finnish Forest Research Institute (Mikkola, K.).

1.12. Selected contributors

In chronological order:

Author	Printing years	Field
A. K. Cajander	1900s-1930s	2
Y. Ilvessalo	1920s-1950s	7, 4, 2, 1, 3
E. Lönnroth	1920s-1930s	1, 3, 4
I. Hustich	1940s-1950s	6, 4
P. Mikola	1950s	6, 4
A. Nyyssönen	1950s-1990s	4, 1, 3, 7
G. Sirén	1950s-1970s	6, 4
K. Kuusela	1950s-1990s	7
Y. Vuokila	1960s-1980s	4, 1
P. Hakkila	1960s-1970s	5
H. G. Gustavsen	1970s-1990s	1, 2, 3
S. Poso	1970s-1980s	7
P. Kilkki	1970s	1, 4
J. Laasasenaho	1980s-1990s	1, 4, 3
J. Lappi	1980s	1, 2, 3
A. Mäkela	1980s-1990s	4
E. Tomppo	1980s-1990s	7
K. Mielikäinen	1980s-1990s	4
T. Pukkala	1980s-1990s	3
R. Sievanen	1980s-1990s	4
R. Päivinen	1990s	7

1 = tree, 2 = site evaluation, 3 = stand structure and development, 4 = stand growth and yield, yield tables, modelling (process-oriented growth and yield models included), 5 = weight and biomass, 6 = tree-ring studies, 7 = forest inventory.

1.13. Comments

(1) The particularities of Finnish land (small altitude variation), climate (prevailing boreal, except for the southern part of the country), and reduced number of forest species (3-4 main species) determined the features of forest mensuration which is ecologically oriented more than in other countries. The investigations of stand structure, growth and yield studies are based on Cajander's site type classification which is using ground vegetation as main indicator of site productivity.

(2) Analysis of the available and investigated literature by author indicate an increasing interest during the last 15-20 years in the problems of forest inventory (especially MRI) and monitoring, site evaluation, and modelling in stand structure, growth and yield. The interest for tree measurement, weight and biomass, and tree-ring studies seems to decrease.

The following table presents the repartition (%) of the analyzed papers and refers to the 1903-1997 period:

(1.1.)	Tree measurement and volume determination	4 %
(1.2.)	Tree form	5 %
(1.3.)	Tree growth	8 %
	Total tree	17 %
(1.4.)	Forest site evaluation	9 %
(1.5.)	Structure and development of stands	13 %
(1.6.)	Stand volume, growth and yield	15 %
(1.7.)	Process-oriented growth and yield models	6 %
(1.8.)	Weight and biomass	5 %
(1.9.)	Tree-ring studies	11 %
(1.10.)	Forest inventory	24 %
	TOTAL	100.0 %

The major interest was given to the problems of forest inventory tree mensurement (especially tree growth), and stand volume, growth and yield.

The interest for a field sometimes differs from one period to another:

Period	Major interest
1901-1920	Site evaluation and stand structure.
1920-1940	Stand growth and yield and forest inventory.
1941-1960	Tree and stand studies, tree-ring studies, forest inventory.
1961-1980	Tree studies, stand growth and yield modelling, forest inventory.
1981-1997	Forest inventory, stand structure growth and yield modelling, process-oriented models

(3) Finnish forest mensuration is one of the most advanced in the world and during its development the following periods could be distinguished:

(i) Early dendrometrical investigation of the Cajander's forest types and the first ground forest inventories (1910-cca. 1940).

(ii) Determination of tree and stand characteristics based on mathematical statistics methods (cca. 1940-cca. 1970). Early use of photography in forest inventory.

(iii) Since 1970 the development of computerized models and the increased interest for construction of process oriented growth models.

(iv) After 1980 forest inventory (especially multi-resource inventory-MRI) and monitoring of forest ecosystems using remote sensing and GIS, and use of permanent sample plots on ground become of major interest. High attention is paid also to the development of process oriented models. These subjects are characteristic for the last 15-20 years of the 20th century in Finnish forest mensuration.

References

AALTONEN, V. T. 1937. Die bodenkundliche Bonitierung der Waldstandsorte. (Evaluation of forest site using soil characteristics). Comm. Inst. For. Fenn. 25 (1): 1-90.

ALESTALO, J. 1971. Dendrochronological interpretation of geomorphic processes. Soc. Geogr. Fenn. 105: 1-140.

ANDERSON, DOROTHY H.; FREIMUND, WAYNE A.; PITT, DAVID G. 1992. Developing a recreation resourse inventory model (RRIM) for forest planning and management. In: Sievanen, Thuija, ed. Nordic outdoor recreation: international comparative studies; 9-10 september 1992, Siuntio, Finland. Research Paper 439. Helsinki, Finland: Finnish Forest Research Inst., pp 72-88.

ASSMANN, E. 1970. The Principles of Forest Yield. Study. Pergamon Press, Oxford, England, 506 pp. Translation by S. H. Gardiner of the "Waldertragskunde – 1961".

BOMAN, A. 1927. Tutkimuksia männyn paksuuskasvun monivuitisista vaihteluista. (Studies on the variations of the radial growth of pine). Acta Forest. Fenn. 32 (4), 177 pp.

BOTKIN, D. B.; J. F. JANAK; J. R. WALIS. 1972. Some ecological consequences of a computer model of forest growth. Journal of Ecology 60: 849 (Refers to JABOWA model, U.S.A.).

CAJANDER, A. K. 1903-1909. Beiträge zur Kenntnis der Vegetation der Alluvionen des nördlichen Eurasien I-III. (Researches on alluvial vegetation of northern Eurasia I-III). Acta Soc. Scient. Fenn. 32, 33, 37; 1903, 1905, 1909.

CAJANDER, A. K. 1909. Über Waldtypen. (About forest types). Acta For. Fenn. 1 (4): 1-176.

CAJANDER, A. K. 1913. Studien über die Moore Finlands. (Study on moor [swampy areas] in Finland. Acta For. Fenn. 213: 1-208.

CAJANDER, A. K. 1926. The theory of forest types. Acta For. Fenn. 29 (3): 1-108.

CAJANDER, A. K. 1930. Wesen und Deutung der Waldtypen. (Existence and importance of forest types). Silva Fennica 15, Helsinki.

CAJANDER, A. K. 1949. Forest types and their significance. Acta For. Fenn. 56 (5): 1-71.

CAJANUS, VERNER. 1914. Über die Entwicklung gleichaltriger Waldbestände. (Concerning the development of even-aged forest stands). Acta Forestalia Fennica 3, 142 pp.

EHRENBERG, C. 1970. Breeding for stem quality. Unasylva 24 (2-3): 23-31.

EKLUND, B. 1944. Ett försök att numeriskt fastaställa klimates inflytande på tallens och granes radietillväxt vid de båda finska riksskogstaxeringarna. (An experiment to estimate numerically the effect of climate on the radial growth of pine and spruce in the two Finnish national forest surveys - in Swedish). Norvl. Skogsvardsf. Tidskr., III, pp. 193-225.

GUSTAVSEN, H. G. 1977. Valtakunnalliset Kuutiokasvuyhtälöt. (Finnish volume increment functions). Folia Forestalia 331, 37 pp.

GUSTAVSEN, H. G. 1996. Site index model approach for drained peatland forest stands. Suo (1996) 47 (2): 37-46.

GUSTAVSEN, H. G.; H. FAGERSTRÖM. 1983. Brösthöjdsformtalets variation i tall-, gran- och björkbestånd. (The variation of the breast height form factor for pine, spruce and birch stands in Finland). Folia Forestalia, Institutum Forestale Fenniae no. 576, 32 pp., Helsinki, Finland.

HAKKILA, P. 1969. Weight and composition of the branches of large Scots pine and Norway spruce trees. Com. Institute Forestalia Fenniae 67, 6, 37 pp.

HAKKILA, P. 1970. Basic density, bark percentage and dry matter content of grey alder (*Alnus incana*). Com. Inst. Forestalia Fenniae 71, 5, 33 pp.

HAKKILA, PENTTI. 1991 a. Whole-tree chipping in thinning operations. Thinning and mechanization. IUFRO, Stockholm.

HAKKILA, PENTTI. 1991 b. Branches, stumps and roots as a future raw material source in Finland. IUFRO Section 25, Forest Biomass Studies, pp. 51-62, Experiment Station, University of Maine at Orono.

HAKKILA, P. 1979. Wood density and dry weight tables for pine, spruce and birch stems in Finland. Commun. Inst. For. Fenn. 96.3: 1-59.

HAKKILA, P.; M. MAKELA. 1973. Harvesting of stump and root wood by the Palleri stumpharvester. Com. Inst. For. Fenniae 77, 5, 57 pp.

HALLIKAINEN, M. T.; JOLMA, P. A.; HYYPPÄ, J. M. 1988. Satellite microwave radiometry of forest and surface types in Finland. IEEE Transactions on Geoscience and Remote Sensing (1988) 26 (5) : 622-628.

HÄME, T. ; TOMPO, E. 1987. Stand based forestry inventory from Spot image. First experiments. In Spot I : premiers résultats en vol. Toulouse, France Cepadues-Editions (1987), pp. 253-258, 326.

HÄME, T.; SALLI, A.; ANDERSSON, K. ; LOHI, A. 1997. A new methodology for the estimation of biomass of conifer-dominated boreal forest using NOAA AVHRR data. International Journal of Remote Sensing 18 (15): 3211-3243.

HARI, P.; M. LEIKOLA; P. RÄSÄNEN. 1970. A dynamic model of the daily height increment of plants. Ann. Bot. Fenn. 7: 375-378.

HARI, P.; S. KELLOMÄKI; A. MÄKELÄ; P. ILONEN; M. KANNINEN; E. KORPILAHTI; M. NYGREN. 1982. Metsikön varhaiskehityksen dynamiikka. (Summary: Dynamics of early development of tree stand). Acta Forestalia Fennica 177, 1.

HEIKINHEIMO, O. 1915. Kaskiviviljelyn vaikutus Suomen metsiin. (The influence of shifting cultivation on forests of Finland). Acta For. Fenn. 4, pp. 1-262.

HEIKURAINEN, L. 1958. Sekamtsikoiden juuristoista ojitetulla suolla. (The root structure in mixed forests or drained bogs). Acta For. Fenn. 67 (2): 1-32.

HEIKURAINEN, L. 1971. Virgin peatland forests in Finland. Acta Agr. Fenn. 123: 11-26.

HEIKURAINEN, L.; K. KUUSELA. 1962. Revival of the tree growth after drainage and its dependence on the tree size and age. Commun. Inst. For. Fenn. 55 (8): 1-15.

HESSELMAN, H. 1904 a. Om tallens höjdtillväxt och skotbildning somrarne 1900-1903. (On height growth and sprout building of pine at the beginning of summer in 1903-1903). Medd. Statens Skogsförsöksanst., 1.

HESSELMAN, H. 1904 b. Om tallens diametertillväxt under de sista tio åren. (On diameter growth of Scots pine in the last ten years). Medd. Statens Skogsförsöksanst., 1: 25-63.

HÖKKÄ, H. 1997. Height-diameter curves with random intercepts and slopes for trees growing on drained peatlands. Forest Ecology and Management 97 (1): 63-72.

HUIKARI, O. 1974. Site quality estimation on forest land. In: Proc. of the Int. Symp. on Forest Drainage, Sept. 2-6, 1974, Jyväskylä-Öulu, Finland, pp. 15-24.

HUSTICH, I. 1943. De årliga variationerna i tillväxtföreteelser och skördevärden i Lappland. (The annual variations in the growth and crop values in Lapland). Geogr. Annaler no. 1/2: 104-115.

HUSTICH, I. 1945. The radial growth of the pine at the forest limit and its dependence on the climate. Sc. Scient. Fenn., Comm. Biol. 9 (11), 30 pp.

HUSTICH, I. 1947. On variations in climate, in crop of cereals and in growth of pine in northern Finland 1890-1939. Fennia 70 (2), 24 pp.

HUSTICH, I. 1948. The Scots pine in northernmost Finland and its dependence on the climate in the last decades. Acta Botanica Fennica vol. 42, pp. 4-75.

HUSTICH, I. 1949. On the correlation between growth and the recent climatic fluctuation. Geogr. Annaler, no. 1/2: 90-105.

HUSTICH, I. 1950. Notes on the forests on the east coast of Hudson Bay and James Bay. Acta Geogr. 11 (1), 83 pp.

HUSTICH, I. 1954. On forests and trees growth in the Knob Lake area, Quebec-Labrador Peninsula. Acta Geogr. 13 (1), 60 pp.

HUSTICH, I.; G. ELFVING. 1944. Die Radiozuwachsvariationen der Waldgrenzkiefer. (The radial growth variations of forest border pine) Soc. Sci. Fenn. Comment. Biol. 9 (8): 1-18.

HYNYNEN, JARI. 1995. Models for predicting the Development of Finnish Forests. Tampere IUFRO Congress, Inviting papers, p. 281-282.

HYYPPÄ, J.; HALLIKAINEN, M. 1993. A helicopter-borne eight-channel ranging scatterometer for remote sensing. Part II: forest inventory. IEEE Transactions on Geoscience and RemoteSensing 31(1): 170-179.

HYYPPA, J.; HALLIKAINEN, M. 1996. Applicability of airborne profiling radar to forest inventory. Remote Sensing of Environment 57(1): 39-57.

HYTÖNEN, J.; I. LUMME; T. TÖRMÄLÄ. 1987. Comparison of methods estimating willow biomass. Biomass (1987), 14 (1): 39-49.

ILVESSALO, Y. 1920 a. Untersuchungen über die taxatorische Bedeutung der Waldtypen, hauptsächlich auf den Arbeiten für die Aufstellung der neuen Ertragstafeln Finnlands fussend. Original title: Tutkimuksia metsätyyppien taksatoorisestä nojautuen etupäässä kotimaiseen kasvutaulujen laatimistyöhön. (Researches on forest mensurational importance of forest types for new yield tables of (standing) stands in Finland). AFF An. For. Fenn.

ILVESSALO, Y. 1920 b. Kasvu-ja touttotaulut Suomen eteläpuoliskon mäntykuusija koivumetsille. (Referat: Yield tables for pine, spruce and birch stands in southern Finland). Acta For. Fenn. 15: 1-9.

ILVESSALO, Y. 1923. Ein Beitrag zur Frage der Korrelation zwischen den Eigenschaften des Bodens und dem Zuwachs des Waldbestandes. (A paper on the problem of correlation between soil properties and growth of forest stands). AFF.

ILVESSALO, YRJÖ. 1927. Methods for preparing yield tables. Silva Fenn. 5: 1-30.

ILVESSALO, Y. 1927. [The forests of Suomi (Finland). Results of the general survey of the forests of the country carried out during the years. 1921-1924] (In Finnish, Engl. summary). Com. Inst. Forest Fenn. Helsinki, 421 pp and tables 192 pp.

ILVESSALO, Y. 1930. Possibilities of finding a uniform basis for the study of growth and yield in different countries. Proc. International Congr. Forestry Exp. Sta. 24 pp.

ILVESSALO, Y. 1932. The establishment and measurement of permanent sample plots. Acta For. Fenn.

ILVESSALO, Y. 1937. Perä-Pohjolan luonnon normaalien metsiköiden kasvu ja kchitys. (Growth of natural, normal stands in Central North Finland). Metsäntutkimus laitoksen julkaisuja, 24. Comm. Inst. Forest. Fenn. 24, 2: 1-168.

ILVESSALO, Y. 1943. Suomen metsävorat ja metsien tila, II valtakunnan metsien, arviointi. (The forest resources and the conditions of the forest of Finland. The second national forest survey). Comml. Inst. Forest. Fenn. 30.

ILVESSALO, YRJÖ. 1947. Pystpuiden Kuutioimistanlukot. (Volume tables for standing trees). Comm. Inst. Forestalis Fenniae 34 (4): 1-149.

ILVESSALO, Y. 1948. Pystpuiden Kuutioimis-ja kasvunlaskentataulukot. (Tables for calculation of volume and increment of standing trees). Helsinki.

ILVESSALO, YRJÖ. 1949a. Forest surveying by ground survey. Proc. III World Forestry Cong. Helsinki 1: 61-68.

ILVESSALO, YRJÖ. 1949b. Sampling techniques in forest inventory. Proceeding of the U. N. Scientific conference on the conservation and utilization of resources UNSCCUR. Lake Success, New York, Vol. V, Forest Resources. S. 2-5.

ILVESSALO, YRJÖ. 1950. On the correlation between the crown diameter and the stem of trees. Comm. Inst. Forestalis Fenniae 38 (2): 5-32.

ILVESSALO, Y. 1953. The third inventory of Finnish Forests, Finnish Paper and Timber. Helsinki 4, 8: 100-101.

ILVESSALO, Y. 1956. On the methods for determination of increment generally used in Finland. IUFRO Sect. 25, Oxford Congr., 1956.

KALELA, E. K. 1937. Tutkimuksia Itä-Suomen kuusi - harmaaleppä-sekametsiköiden-kehityksesta. (Researches on growth and development of spruce - *Alnus incana* mixed stands in eastern Finland). Acta Forest. Fenn. 44.2: 1-198.

KALLIO, K. 1957. Käenkaali-mustikkattypin kuusikoiden kehityksestä Suomen lounaisosassa. Taksatoris-liiketaloudellinen tutkimus. (On the development of spruce forests of the Oxalis-Myrtillus site type in the southwest of Finland. Forest mensuration and management research). Acta Forest. Fenn. 66, pp. 1-155.

KANGAS, A. 1996. Small-area estimates using model-based methods. Canadian Journal of Forest Research 26 (5): 758-766.

KÄRKKÄINEN, M. 1972. Kuusen ja männyn sydänpuuosuudesta. (On the proportion of heartwood in Norway spruce and Scots pine). Silva Fenn 6: 193-208.

KAUNISTO, S. 1983. Koripajun (Salix viminalis) biomass satuotos sekä ravinteiden ja veden käyttö eri tavvin lannoitetuilla turpeilla kasvihuoneessa. (Biomass production of Salix viminalis and its nutrient and water consumption on differently fertilized peats in the greenhouse). Folia Forestalia Institutum Forestale Fenniae no. 551, 34 pp.

KELLOMÄKI, S.; H. VAISÄNEN; H. STRANDMAN. 1993. Finn. For.: a model for calculating the response of the boreal forest ecosystem to climate changes. Research Note no. 6, Faculty of Forestry, University of Joensuu. Joenss, Finland, 120 pp.

KILKKI, P.; R. PÖKÄLÄ. 1975. A long-term timber production model and its application to a large forest area. Acta Forestalia Fennica, vol. 143.

KILKKI, P.; M. SARAMÉKI, M. VARMOLA. 1978. A simultaneous equation model to determine taper curve. Silva Fenn. 12 (2): 120-125.

KOIVISTO, P. 1960. Kasvu-ja tuottotaulukoita. (Growth and yield tables). Commun. Inst. Forest. Fenn. 51: 1-49.

KOIVUNIEMI, JYRKI. 1993. Growth of Norway spruce in relation to stem cross-sectional area at the crown base. In: Wood, G. B., and Wiant, Jr., H.v. (eds.), Modern Method of Estimating Tree and Log volume, West Virginia University. U.S.A., pp. 118-125.

KOLARI, KIMMO K. (ED.). 1983. Growth Disturbances of Forest Trees; Proceedings of an International Workshop, Jyvaskyla and Kivisuo, Finland, October 1982: Metsapuiden kasvuhairiot, Helsinki, Finland, Finnish Forest Research Institute, 208 pp.

KOLSTROM, T. 1992. Dynamics of uneven-aged stands of Norway spruce - a model approach. Dissertation Joensuu, Finland.

KORHONEN, K. T.; PÄIVINEN, R. 1991. A model forest for evaluating forest inventory designs. Proceedings, IUFRO, S4. 02 Symposium: "Forest inventory in Europe with special reference to statistical methods“. Switzerland, May 14-16, 1990. Published in 1991, p. 192-200, Köhl and Pelz eds.

KUJALA, V. 1945. Waldvegetationsuntersuchungen in Kanada mit besonderer Berücksichtigung der Anbaumöglichkeiten kanadischer Holzarten auf natürlichen Waldböden in Finland. (Researches on Canadian forest vegetation especially for possibility of growing Canadian species in Finnish forests). Ann. Acad. Scient. Fenn. A 4 (7): 1-434.

KUUSELA, K. 1953/1954. Zur Theorie der Forstlichen Zuwachsberechnung auf Grund der periodischen Messung. (On theory of growth determination using periodical measurements). Acta For. Fenn. no. 60, p. 136.

KUUSELA, K. 1956. Outline of cartographical and timber survey unit. Silva Fenn. 90. 11 pp.

KUUSELA, KULLERVO. 1978a. The need and purpose of the national inventory on the basis of forest resource statistics in Europe. IUFRO, Proceedings of a Bucharest meeting, pp. 364-367.

KUUSELA, KULLERVO. 1978b. The national forest inventory in Finland. IUFRO, Proceedings of a Bucharest meeting, pp. 368-377.

KUUSELA, K. 1981. From timber surveys to monitoring of the forest ecosystem. Proceedings, XVII IUFRO World Congres, S.4. 02, pp. 184-187.

KUUSELA, K. 1987. National report: Finland. Proceedings of ad hoc FAO/ECE/FINIDA meeting of experts on forest resource assessment. Bulletins of the Finnish Forest Resourch Institute 284, p. 187-197.

KUUSELA, K.; S. SALMINEN. 1983. Forest resources of the six Northernmost forestry board districts of South Finland, 1979-1982, and in the whole of South Finland, 1977-1982. (In Finnish, English summary). Folia Forestalia 568, 79 pp.

KUUSELA, K.; S. SALMINEN. 1991. Suomen metsävart 1977-1984 ja hiiden kehittyminen 1962-1980. (Finnish forest resources from 1977 to 1984 and their development from 1952 to 1980). Acta Forestalia Fennica No. 220, 84 pp.

KUUSELA, K.; E. MATTILA; S. SALMINEN. 1986. Forest resources in North Finland by forestry board districts, 1982 to 1984 (In Finnish, English summary). Folia Forestalia 655, 86 pp.

LAASASENAHO, J. 1982. Taper curve and volume functions for pine, spruce and birch. Communications Instituti Forestalis Fenniae 108: 1-74.

LAASASENAHO, JOUKO. 1988. Use of taper curve in determining tree branchiness and preparing instructions on stand densities. In: "Forest growth modelling and prediction", Ek, Alan R., Stephen Shifley; Thomas Burk (eds.), Forest Service North Central Forest Experimental Station, Technical Report NC-120, p. 1014-1020, St. Paul, Minnesota, U.S.A., Proceedings IUFRO Conference 1987, August 23-27, Minneapolis.

LAASASENAHO, JOUKO. 1993. Modelling taper curves and stem increment. In: Modern Methods of Estimating Tree and Log Volume, Wood and Wiant eds., West Virginia University, U.S.A., pp. 54-57.

LAASASENAHO, J.; J. KOIVUNIEMI. 1990. Dependence of some stand characteristics on stand density. Tree Physiology 7: 183-187.

LAASASENAHO, JOUKO.; MARK-LEO WAITE. 1995. Modelling of Tree and stand Growth. IUFRO Tampere Congress, Inviting Papers, p. 286.

LAHTI, T. 1953. The measurement of the contents of pulpwood bundles. Metsät. Aikak, 5: 148-152.

LAHTI, T. 1995. Understorey vegetation as an indicator of forest site potential in southern Finland. Suomen Metsötiettelinen Seura (Society of Forestry in Finland), Acta Forestalia Fennica 246, 68 pp.

LAINE, J.; M. R. STARR. 1979. An analysis of the post drainage stand increment in relation to the peatland site type classification in Finland. In: Proc. of the Inst. Symp. on Classification of Peat and Peatlands. Hyytiälä, Finland, Sept. 17-21, 1979. Int. Peat Society, pp. 147-159.

LAITAKARI, E. 1920. Tutkimuksia sääsuhteiden vaikutuksesta männyn pituus-ja paksu-uskasvuum. (Studies on the effect of weather conditions on the height and diameter growth of Scots pine). Acta Forestalia Fennica 17 (1), 53 pp.

LAPPI, J. 1986. Mixed linear models for analyzing and predicting stem form variation of Scots pine. Communicationes Instituti Forestalia Fenniae 134: 1-69.

LAPPI, JUHA; ROBERT L. BAILEY. 1988 a. Optimal prediction of dominant height curves based on an analysis of variance components and serial autocorrelation. In FGMP pp. 691-698 FGMP: "Forest growth modelling and prediction", Ek, Alan; Stephen R. Shifley and Thomas Burk, eds., Forest Service North Central Forest Experimental Station, General Technical Report NC-120, vol. 1 and 2, 1153 pp., St. Paul, Minnesota, USA, Proceedings, IUFRO Conference 1987, August 23-27, Minneapolis, MN.

LAPPI, J.; R. L. BAILEY. 1988 b. A height prediction model with random stand and tree parameters: an alternative to traditional site index methods. Forest Science 34 (4): 907-927.

LAPPI-SEPPÄLÄ. 1930. Untersuchungen über die Entwicklung gleichaltriger Mischbestände aus Kiefer und Birke. (Researches on growth and development of homogeneous and even-aged mixed stands of pine and birch). A.F.F.

LAPPI-SEPPÄLÄ. 1936. Untersuchungen über die Stammform der Kiefer u. Birke. (Researches on stem form of pine and birch). A.F.F.

LATHINEN, A. 1988. On the construction of monotony preserving taper curves. Seloste: Monotonisuuden säilyttävien runkokäyrien muodostamisesta. A.F.F. 203, 34 pp.

LATHINEN, A.; LAASASENAHO, J. 1979. On the construction of taper curves by using spline functions. Commun. Inst. For. Fenn. 95, 63 pp.

LEIKOCA, M. 1969. The influence of environmental factors on the diameter growth of forest trees. Auxometric study. A.F.F. (Acta Forest. Fenn.), 92: 1-144.

LINDEBERG, J. W. 1924. Űber die Berechnung des Mittel fehlers des Resultates einer Linientaxierung. (About the determintion of mean error of the results of an inventory strip). Acta Forest. Fenn. 25. 22pp.

LINDEBERG, J. W. 1926. Zur Theorie der Linientaxierung. Acta Forest. Fenn. 9pp.

LÖNNROTH, E. 1926. Ein Dendrometer. (A hypsometer). Helsinki.

LÖNNROTH, E. 1927. Über Stammkubierungsformeln. (On formulas for stem volume determination). Helsinki.

LÖNNROTH, E. 1930. Untersuchungen über die innere Struktur und Entwicklung gleichaltriger naturnormalen Kiefernbestände. (Investigation of the inner structure and development of even-aged naturally normal pine stands). Acta For. Fenn. 30: 1-269.

LÖNNROTH, E. 1934. Zur Frage der Volumengeraden des Waldbestandes. (On volume determination of stands). Helsinki.

MÄKELÄ, A. 1986. Implications of the pipe-model theory on dry matter partitioning and height growth in trees. Journal of Theoretical Biology 123: 103-120.

MÄKELÄ, ANNIKKI. 1988 a. Parameter estimation and testing of a process-based stand growth model using Monte Carlo techniques. In FGMP pp. 315-322. FGMP: Forest growth modelling and prediction. Forest Service, North Central Forest Experimental Station, General Technical Report NC-120, Ek, Alan; Stephen R. Shifley and Thomas Burk eds. vol. 1 and 2, 1153 pp., St. Paul, Minnesota, U.S.A., Proceedings IUFRO Conference 1987, Aug. 23-27, Minneapolis.

MÄKELÄ, A. 1988 b. Models of pine-stand development: an ecophysiological system analysis. Research Note 62, Department of Silviculture, University of Helsinki, Helsinki, Finland 267 pp.

MÄKELÄ, A. 1988 c. Performance analysis of a process-based stand growth model using Monte Carlo techniques. Scandinavian Journal of Forest Research 3: 315-331.

MÄKELÄ, A. 1990. Modelling structural-functional relationships in whole-tree growth: resource allocation. Chapter 7 (pp. 81-95). In: R. K. Dixon, R. S. Meldahl, G. A. Ruark and W. G. Warren (eds.). Process Modelling of Forest Growth Responses to Environmental Stress. Timber Press, Portland Oregon, 441 pp.

MÄKELÄ, A. 1992. Process-oriented growth and yield models: Recent advances and future prospects. In T. Preuhsler (ed.) Research on Growth and Yield with emphasis on Mixed Stands. Proc. S4.01 “Mensuration, Growth and Yield” sessions at IUFRO Centennial Meeting, Berlin, 31st of August-4th of September 1992. Bayerische Forstliche Versuchs- und Forschungsanstalt, Freising, Germany, pp. 85-96.

MÄKELÄ, A.; P. HARI. 1986. Stand growth model based on carbon uptake and allocation in individual trees. Ecological Modelling 33: 205-229.

MALKONEN, EINE. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Communicationes Instituti Forestalis Fenniae, vol. 85, 5: 1-87.

MALTAMO, M. 1997. Comparing basal area diameter distributions estimated by tree species and for the entire growing stock in a mixed stands. Silva Fennica 31 (1): 53-65.

MATTILA, E. 1985. The combined use of systematic field and photo samples in a large-scale forest inventory in North Finland. Comm. Inst. Forest. Fenn. 131. 97 pp.

MATTILA, E. 1986, Lapin metsävart osa-alueittain. Valtakunnan metsein, 7, inventointi vuosina 1978 ja 1982-84. (The forest resources of Finnish Lapland by sub-areas. The 7th National Forest Inventory in 1978 and 1982-84. Folia Forestalia Institutum Fenniae no. 661, 77 pp.

MIELIKÄINEN, K. 1980. Mänty-koivusekametsiköiden rakenne ja kehitys. (Summary: structure and development of mixed pine and birch stands). Comm. Inst. For. Fenn. 99.3: 1-82.

MIELIKÄINEN, K. 1985. Koivusekoituksen vaikutus-kuusikon rakenteeseen ja kehitykseen. (Summary: Effect of an admixture of birch on the structure and developement of Norway spruce stands. Comm. Inst. Forest. Fenn. 133: 1-79.

MIELIKÄINEN, K. 1995. Growth trends of forests in Finland and north-western Russia. Abstract, IUFRO XX World Congress 1995, Tampere, Finland, p. 274.

MIELIKÄINEN, K.; M. TIMONEN 1996. Growth trends of Scots pine (*Pinus sylvestris* L.) in unmanaged and regularly managed stands in southern and central Finland. In: Growth Trends in European Forests, H. Spieker et al. eds., Springer, pp. 41-60.

MIKKOLA, K. 1997 A remote sensing analysis of vegetation damage around metal smelters in the Kola Peninsula, Russia. International Journal of Remote sensing. 17 (18): 3675-3690.

MIKOLA, P. 1950. Puiden kasvun vaihteluista ja niiden merkityksesta kasvututkimuksissa. (On variations in tree growth and their significance to growth studies). Commun. Inst. Forst. Fenn. 38,5, 131 pp.

MIKOLA, P. 1952. The effect of recent climatic variations on forest growth in Finland. Fennia 75: 69-76.

MIKOLA, P. 1956. Tree-ring research in Finland. Tree-Ring Bull. 21, 16-20.

NIEPPOLA, J. 1993 a. Site classification in *Pinus sylvestris* L. forests in southern Finland. Silva Fennica 27 (1): 9-20.

NIEPPOLA, J. 1993 b. Understorey plants as indicators of site productivity in *Pinus sylvestris* L. stands. Scandinavian Journal of Forest Research 8 (1): 49-65.

NYYSSÖNEN, A. 1953. Hakkauksilla käsiteltyjen männikoiden rakenteesta ja kehityksesta. (On the structure and development of Finnish pine stands treated with different cuttings). Acta Forest. Fenn. 60 (4), 194 pp.

NYYSSÖNEN, A. 1955. Estimation of the cut from stumps. Comm. Inst. For. Fenn. vol. 45/5.

NYYSSÖNEN, A. 1955 a. On the estimation of the growing stock from aerial photographs. Comm. Inst. For. Fenn. vol. 46: 1-57, 57pp.

NYYSSÖNEN, A. 1955 b. Estimation of stand volume by means of the relascope. Comm. Inst. For. Fenn. vol. 44.

NYYSSÖNEN, A. 1963. Analysis of two alternative methods for national forest inventories in Northern Europe. Acta Forest. Fenn. 76, 19pp.

NYYSSÖNEN, A. 1967. Remeasured sample plots in forest inventory. Medd. fra det norske Skogforsökvesen, 84 B XXII: 187-220.

NYYSSÖNEN, AARNE 1993. National forest inventories in the Nordic, countries. Proceding of the 1992 meeting of the IUFRO Group S4. 02, IUFRO Centennial 1992, pp 28-35.

NYYSSÖNEN, A.; MIELIKÄINEN, K. 1978. Metsikön kasvun arviointi. (Estimation of stand increment). Acta Forest. Fenn. 163: 1-40.

NYYSSÖNEN, A.; R. OJANSUU. 1982. Metsikön puutavaralajirakenteen, arvon ja arvokasvun aviointi. (Assessment of timber assortments, value and value increment of tree stands). Acta For. Fenn. 179, 52 pp.

OIKARINEN, M. 1983. Etelä-Suomen viljeltyjen rauduskoivikoiden kasvatusmallit. (Growth and yield models for silver birch (*Betula pendula*) plantations in southern Finland). Comm. Instituti Forestalis Fenniae, no. 113, 75 pp.

OJANSUU, RISTO. 1988. Mixed linear models for stem size and form development. FGMP pp. 724-730. FGMP: Forest growth modelling and predictions. Forest Service, North Central Forest Experimental Station. General Technical Report NC-120 vol 1 and 2, 1153 pp, St. Paul, Minnesota, USA, Proceedings, IUFRO Conference 1987, Aug 23-27, Minneapolis, MN.

OJANSUU, RISTO. 1995. The ability of competition indices to describe stand dynamic. IUFRO XX World Congress, Tampere, Inviting Papers, summary, p. 287.

OKER-BLOM, P. 1986. Photosynthetic radiation regime and canopy structure in modelled forest stands. Acta Forestalia Fennica 197, 44 pp.

ORDING, A. 1941. Årringanalyser på gran og furu. (Annual ring analyses of spruce and pine). Medd. Norske Skogforsoksvesen 7 (25): 105-354.

PAAVILAINEN, E.; TIIHONNEN, P. 1984. Etelä-ja Keski-Suomem suometsät vuosina 1951-1981. (Peatland forests in southern and central Finland in 1951-1981). Folia Forestalia Institutum Forestale Fenniae No. 580, 20pp.

PAAVILAINEN, E.; TIIHONNEN, P. 1988. Suomen suometsät vuosina 1951-1984. (Peatland forests in Finland 1951-1984). Folia Forestalia No. 714, 29pp.

PÄIVINEN, R.; LUND, H. G.; POSO, S.; ZAWILA-NIEDZWIECKI, T. (eds.). 1994. IUFRO international guidelines for forest monitoring: project of IUFRO Working Party S4.02-05, IUFRO World Series No. 5, 102pp.

PARVIAINEN, J. 1994. The impact of fire on Finnish forest in the past and today. Symposium "Fire in Ecosystem of Boreal Eurasia and Fire Research Campain Asia-North (FIRE SCAN) Krasnoyarsk, Russian Federation, 26 June-12 July 1993. Edited by Goldammer, J., Freiburg, Germany.

POSO, S. 1972. A method of combining photo and field samples in forest inventory. Communicationes Instituti Forestalis Fenniae, 76-1, 133pp.

PASO, SIMO. 1978. National forest inventory in northern Finland. IUFRO Meeting in Bucharest, Romania, pp 378-386.

POSO, S. 1988. Seeking for an optimal path for using satellite imageries for forest inventory and monitoring. Proc. of the IUFRO S4.02-05, Department of forest mensuration and management, University of Helsinki. Research notes 21: 181-192.

POSO, S. 1991. A two-phase sampling approach to gather data for GIS. Proceedings of the international IUFRO S4.02 and S6.04 Symposium May 14-16 1990 Birmensdorf, Switzerland, Swiss Federal Institute for Forest, snow and Landscape Research 1991, 239pp., Köhl, Michael; Pelz, Dieter R (eds.), pp. 155-163.

POSO, S.; PAANANEN, R.; SIMILÄ, M. 1987. Forest inventory by compartments using satellite imagery. Silva Fennica 21 (1): 69-94.

PUKKALA, T. 1988. Effect of spatial distribution of trees on the volume increment of a young Scots pine stand. Silva Fennica 22: 1-17.

PUKKALA, T. 1989 a. Methods to describe the competition process in a tree stand. Scandinavian Journal of Forest Research 4: 187-202.

PUKKALA, T. 1989 b. Prediction of tree diameter and height in a Scots pine stand as a function of the spatial pattern of trees. Silva Fenn. 23: 83-99.

PUKKALA, T. 1989c. Pedicting diameter growth in even-ayed Scots pine stands with a spatial and non spatial model. Silva Fennica 23: 83-99.

PUKKALA, T.; T. KOLSTRÖM. 1987. Competition indices and the prediction of radial growth in Scots pine. Silva Fenn. 21: 55-76.

PUKKALA, T.; T. KOLSTRÖM 1988. Simulation on the development of Norway spruce using a transition matrix. Forest Ecology and Management 25: 255-267.

PUKKALA, T.; T. KOLSTRÖM. 1991. Effect of spatial pattern of trees on the growth of a Norway spruce stand. A simulation model. Silva Fennica 25: 117-131.

PUKKALA, T.; T. KOLSTRÖM; J. MIINA. 1994. A method for predicting tree dimensions in Scots pine and Norway spruce stands. Forest Ecology and Management 65: 123-124.

RAULO, J.; M. LEIKOLA. 1974. Studies on the annual height growth of trees. Commun. Inst. Forest. Fenn. 81, 2: 1-19.

SÄRKKÄ, A.; TOMPPO, E. 1996. Modelling interactions between trees by means of field observations. in: Päivinen, Vanclay-Miina (eds), 1996, pp. 161-170, see Tomppo 1996.

SAVAS, R. 1972. Investigations on the annual cycle of development of forest trees. Active period. Commun. Inst. Forest. Fenn. 76, 3.

SCHMIDT-VOGT, HELMUT. 1986. Die Fichte. (The spruce). Band II/1. Wachstum-Züchtung-Boden-Umwelt-Holz. Vol. II/1 (Growth-Silvicultural measures-Soil-Environment-Wood). Verlag Paul Parey. Hamburg und Berlin.

SCHMIDT-VOGT, HELMUT. 1991. Die Fichte (The spruce). II/3. Parey Verlag, Hamburg-Berlin, 804 pp.

SERVAS, J. 1977. Mathematical model for the physiological clock and growth. Acta Forestalia Fennica 156, 25 pp., Helsinki.

SIEVANEN, R. 1983. Growth model for mini-rotation plantations Communications Instituti Forestalis Fenniae 117: 1-41.

SIEVANEN, R. 1993. A process-based model for the dimensional growth of even-aged stands. Scandinavian Journal of Forest Research 8 (1): 28-48.

SIEVANEN, RISTO. 1995. Some relationships between distance independent and distance dependent growth models. IUFRO XX World Congress, Tampere, Finland, Summary p. 289-290.

SIEVANEN, R.; T. E. BURK. 1993. Adjusting a process-based growth model for varying site conditions through parameter estimation. Can. J. Res. 23: 1837-1851.

SIEVANEN, R.; T. E. BURK; A. R. EK. 1988. Construction of a stand growth model utilizing photosynthesis and respiration relationships in individual trees. Can. J. For. Res. 18: 1027-1035.

SIITONEN, MARKKU; TUULA NUUTINEN. 1995. Large-scale forestry modelling and analysis in Finland. IUFRO XX World Congress, Tampere, Finland, Poster, 242, p. 139.

SIRÉN, G. 1955. The development of spruce forest on raw humus sites in northern Finland and its ecology. Acta Forest. Fenn. 64, 4:1-363.

SIRÉN, G. 1963. Tree rings and climate forecasts. New Scientist 346: 18-20.

SIRÉN, G.; P. HARI. 1971. Coinciding periodicity in recent tree rings and glacial cley sediments. Rep. KEVO Suarctic Res. Sta. 8: 155-157.

STARR, MICHAEL R. 1986. Forest site classification and evaluation in Finland. FSC pp. 155-170.

TOKOLA, TIMO; HEIKKILÄ, JUHO. 1997. Improving satellite imaged based forest inventory by using a priori site quality information. Silva Fennica 31(1): 67-78.

TOMPPO, E. 1986. [Models and methods for analysing spatial patters of trees]. Seloste: malleja ja menetelmiä puiden tilajärjestyksen analysoimiseksi. Communicationes Instituti Forestalis Fenniae 138, 65 pp.

TOMPPO, E. 1990. Satellite image-based national forest inventory of Finland. ISPRS, Commission VII. Mid-Term Symp. Global and Envir. Monit. Tech. and Impacts, Victoria, Canada. pp. 419-424.

TOMPPO, E. 1993. Multi-source National Forest Inventory of Finland. Proceedings Ilvessalo Symp. on Nat. For. Inv. Finland. 17-21 August, 1992. p.52-60.

TOMPPO, E. 1996. Multi-source National Forest Inventory of Finland. In: Proceedings of the subject Group S4.02.00 Forest Resource Inventory and Monitoring, and Subject Group S4.12.00 Remote Sensing Technology, Volume I, IUFRO XX World Congress 6-12 August 1995, Tampere, Finland, eds.: Risto Päivinen, Jerry Vanclay and Sarja Miina. pp.27-42.

TOMPPO, ERKKI; et al. 1997. Country report for Finland. In: Study on European Forestry. Information and Communication System-Reports on forest inventory and survey systems. Volume I CH - 11 - 97- 001 -EN - C Luxembourg: European Commission; pp. 145-226.

TOMPPO, E.; SIITONEN, M. 1991. The national forest inventory of Finland. Paper and Timber 73: 2, 8 pp.

TOMPPO, E.; GOULDING, C.; KATILA, M. 1996. Applying Finnish multisource inventory with New Zealand preharvest inventory data. In: Päivinen-Vanclay-Miina eds. 1996, p. 185-204; see Tomppo 1996.

UNCED. 1992. Finland National Report to UNCED 1992, 17 pp.

VÄJSÄNEN, E.; S. KELLOMÄKI; P. HARI. 1977. Annual growth level of some plant species as a function of light available for photosynthesis. Silva Fennica 11: 269-275.

VALSTA, L. T. 1986. Månty-rauduskoivusekametsikön hakkuuohjelman optimointi. Summary: optimizing thinnings and rotation for mixed, even-aged pine birch stands. Folia Forestalia 666, 23 pp.

VALSTA, LAURI T. 1988. Optimizing species composition in mixed, even-aged stands. FGMP: pp. 913-920. FGMP: "Forest Growth Modelling and Prediction", Ek, Alan R.; Stephen R. Shifley; Thomas Burk (eds.) Forest Service North Central Forest Experimental Station, General Technical Report NC-120, vol. 1 and 2, 1153 pp., St. Paul, Minnesota, U.S.A. Proceedings, IUFRO Conference 1987, August 23-27, Minneapolis, U.S.A.

VARJO, J. 1996. Controlling continuously updated forest data by satellite remote sensing. International Journal of Remote Sensing 17 (1): 43-67.

VASANDER, H. 1982. Plant biomass and production in virgin, drained and fertilized sites in a raised bog in southern Finland. Annales Botanici Fennici, 19 (2): 103-125.

VUOKILA, Y. 1955. The Finnish curve calipers. J. For. 53 (5): 366-367.

VUOKILA, Y. 1965. Functions for variable density yield tables of pine based on temporary sample plots. Commun. Inst. For. Fenn. 60 (4): 1-86.

VUOKILA, Y. 1966. Growth and yield tables for pine stands treated with intermediate cuttings of varying degree for southern Central Finland. Comm. Inst. For. Fenn. 63.

VUOKILA, Y. 1968. Karsiminen ja kasvu. (Pruning and increment). Comm. Inst. Forest. Fenn. 66, 61 pp.

VUOKILA, Y. 1980. Kasvatustiheiden vaikutus istutuskuusikon kasvuun ja tuotokseen. (The dependence of growth and yield on the density of spruce plantations in Finland). Folia Forestalia 448, Helsinki.

VUOKILA, Y. 1983. Viljely metsiköiden harvennusmallit. Gallingsmallar för odlade bestand i Finland. (Thinning models for forest cultures in Finland). Folia Forestalia 556, Helsinki.

VUOKILA, Y.; H. VÄLLIAHO. 1980. Viljeltyjen havumetsiköiden kasvutusmallit. (Growth and yield models for conifer cultures in Finland). Comm. Inst. For. Fenn. 99.2 Helsinki.

WANG, GUANGXING. 1996. An expert system for forest resource inventory and monitoring in the frame of multi-source data. Dep. of Forest Resource Management Publications 10. Helsinki, Finland, University of Helsinki. 173 pp.

WESTMAN, C. J. 1981. Fertility of surface peat in relation to the site type and potential stand growth. Acta For. Fenn. 172: 1-72.

YLINEN, A. 1952. Über die mechanische Schaftformtheorie der Bäume. (On the mechanical theory of stem form). T. H. in Finland. Wiss. Forschungen, no. 7.

ZETTERBERG, PENTTI; MATTI ERONEN. 1995. Construction of a 7000-year tree-ring record for Scots pine in northern Fennoscandia and its application to paleoclimatic and growth variation studies IUFRO XX World Congress, Tampere, Finland, Poster 235, summary, pp. 135-136.

ZETTERBERG, P.; M. ERONEN, M. LINDHOLM. 1996. Construction of a 7500-year tree-ring record for Scots pine (*Pinus sylvestris* L.) in northern Fennoscandia and its application to growth variation and paleoclimatic studies. In: "Growth trends in European forests" H. Spiecker, K. Mielikäinen, M. Köhl and J. Skovsgaard (eds). pp. 7-18, Springer.

2. NORWAY

General information

Land area: 306,688 sq.km (118,491 sq.mi.), forest and other wooded land: 95,650 sq. km (36,932 sq. mi.) forest: 8,697,000 ha or 33,580 sq. mi. (28 % of land area), volume: 71 m^3/ha, biomass 36 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: industrial round wood: 9.6 million m^3, fuel and charcoal 0.9 million m^3, total round wood: 10.5 million m^3 (World Resources 1996-97, p. 220.

Forest vegetation: Boreal forest in the north and a reduced area of temperate mixed forest in the central and southern parts of the country. In the coastal region with a maritime climate (a result of the Gulf Stream influence) species like oak (*Quercus robur*), ash (*Fraxinus* spp.), alder (*Alnus* spp.), European beech (*Fagus sylvatica*) cover limited areas.

Repartition by species groups:

- Conifers: 70 %
- Broad-leaved: 30 %

Under the conditions of the predominant continental climate the main forest species are represented by spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), birch (*Betula* spp.), and tremble aspen (*Populus tremula*).

Acclimatized species: *Picea sitchensis, Pseudotsuga menziensii*.

Forestry education and research organizations involved in the areas of forest mensuration and forest management (date of establishment in brackets):

- Agricultural University of Norway, Department of Forestry. Ås-NLH (1898).
- Nord-Troendelag College, Section of Forestry, Steikjer (1880).
- Norwegian Forest Research Institute, Ås (1917): Norsk. Institut for Skogforskning.

Publications:

- Meddelelser frå Det Norsk Institutt for Skogsforskning;
- Meddelelser frå Norske Skogsførsksvesen;
- Norsk Skogbruk.

2. 1. Tree and log measurement

In the 1920s and 1930s, should be noted the works concerning the establishment of the amplitude of diameter class in the case of application of the stand table projection method used for volume determination (Langsaeter 1929), height, width of the annual ring and diameter distribution (Langsaeter 1929, 1932 a, 1934).

Relascopic height and cubic volume determination was in use in the 1950s (Strand 1957).

In 1959 Dahl and Mork tried to establish the relationship between temperature, respiration and growth in Norway spruce.

A textbook concerning forest mensuration was published by H.K. Seip in 1964.

In 1974 Braastad developed, in a detailed work the diameter increment functions for spruce.

In connection with bark thickness of saw-logs regression equations were developed by Okstad (1981) to correct top diameter measurements of unbarked spruce saw-logs with automatic optical devices (over bark) to those required for timber price tables (under bark); a linear regression equation gave almost the same fit as a second degree polynominal one. Linear regression equations were established for different regions of Norway for three classes of bark thickness (thin, average, thick). The same types of equations were developed by Okstad the next year (1982) for Scots pine also for three bark classes (but different from spruce): smooth, average and rough.

Blingsmo constructed in 1985 taper functions and tables for birch: *Betula verrucosa* (*B. pendula*) and *Betula pubescens* valid for the entire country. Taper and volume tables for aspen (*Populus tremula*) were developed for southern Norway by Opdhal in 1989.

In 1995 Bauger published tree volume functions and tables for Scots pine, Norway spruce and Sitka spruce in western Norway.

Cited authors:

Bauger 1995, Blingsmo 1985, Braastad 1974, Dahl and Mork 1959, Langsaeter 1929, 1932, 1934; Okstad 1981, 1982; Opdahl 1989, Seip 1964, Strand 1957.

2. 2. Site evaluation

Numerical construction of site index curves were detailed and presented by Strand (1964). Tweite (1969) developed a method for construction of site curves, and used it in the case of Norway spruce in 1977.

Cited authors:

Strand 1964, Tweite 1969, 1977.

2. 3. Stand structure

Determination of the number of trees per unit area (in forest strip survey) and their repartition by diameter categories was investigated by Langsaeter (1932a, 1932b) who determined later (1941, 1942) the distribution of total spruce stand yield by diameter categories.

A measure of the distribution of the individuals over a certain area was investigated by Strand in 1952 in connexion with the error in determination of average diameter and stand basal area. In the same year (1952) Braathe established the effect of different spacing upon stand development and yield in Norway spruce forests.

Tveite (1967) completed a detailed study on the relationship between mean height by Lorey's formula (HL) and some other stand heights in pine and spruce stands.

Another study on diameter distribution and height-curves for even-aged stands of Norway spruce growing on slopes was developed by Vestjordet in 1972.

Braastad studied the mortality in Norway spruce stands (1982) and Frivold published in the same year (1982) a detailed report on stand structure and yield of mixed stands of birch (*Betula verrucosa* Ehrh., *B. pubescens* Erhr.) and Norway spruce in South East Norway. In the same time Nilsen and Haveraaen (1982) analyzed tree size distribution and increment in different diameter classes in old Norway spruce stands.

Cited authors:

Braastad 1982, Braathe 1952, Frivald 1982, Langsaeter 1932 a, 1932 b, 1942; Nilsen and Haveraaen 1982, Strand 1952, Tveite 1967, Vestjordet 1972a, 1972b.

2. 4. Stand growth and yield

Early spruce yield studies and yield tables were developed by Eide and Langsaeter in 1940 - 1941 and Langsaeter in 1941.

In 1951 Brantseg carried out investigations on volume and yield in spruce plantations in western Norway.

Bauger (1970) compared height development of Sitka spruce and Norway spruce in northern and western Norway and Klem (1970) studied the influence of increased growth rate on some quality properties of Norway spruce and Scots pine.

Strand discussed in 1972 the problem of a model for stand growth having as starting point a map of the stand with coordinates for the individual trees, and each tree has a potential growing space. The model must be tested against real data.

In 1975 Braastad developed yield tables and growth models for spruce in a very well documented paper and analyzed later (1983) yield level in spruce stands with low initial density and irregular spacing.

Strand developed in 1983 increment functions for long-term yield forecasts.

Air pollution and forest damage in Norway was analyzed by Tveite in 1985.

Cited authors:

Bauger 1970, Braastad 1975, 1983: Brantseg 1951, Eide and Langsaeter 1940-1941, Klem 1970, Langsaeter 1941, Strand 1972, 1983; Tveite 1985.

2. 5. Weight and biomass

Wilhelmsen and Vestjordet (1973, 1974) constructed the first preliminary dry wood weight tables for merchantable stems and stands of Norway spruce, while Gislerud (1974) completed a report on biomass and biomass properties of trees from thinnings of spruce, pine, birch and alder.

Cited authors:

Gislerud 1974, Wilhelm and Vestjordet 1973, 1974.

2. 6. Tree-ring studies

Eide published in 1926 the first Norwegian paper on the correlation between growth rings and climatic factors using 1243 stems of spruce in eastern Norway. Eide's work is considered by Høeg (1956) "the first study of growth-ring variation in spruce in Scandinavia".

Some tree-ring works were performed at Oslo University by Aandstat: 1934 (diameter growth in Scots pine in Solör), 1938 a and 1938 b (annual growth of Scots pine and weather and the correction for the effect of age).

Annual ring analyses in spruce and pine were developed by Ording (1941a, 1941b, 1941c) who pointed out that it is better to measure a great number of stems with one radius or a few radii in each, than to measure many radii in few stems, and used also the correction - as Eidem in 1943 - of the effect of age on the development of tree-ring series.

Ording (1941) and Ruden (1945) introduced in tree-ring research the methods of mathematical statistics as correlation and its coefficients. Ording (1941a) tested the reliability of the ocular crossdating and concluded that with a very high correlation between the standard scale and the cross-identification curve it is possible to carry through an ocular dating of considerable signifiance.

A summary of dendrochronological methods was written by Høeg in 1944, and Ruden (1945) made a valuation of these methods. Ruden recommended the use of logarithmic scale which was first introduced by Huber in 1943, and Ruden presented also the mathematical justification of his proposal.

An earlier review of tree-ring studies in Scandinavia was completed by the American scholar Edmund Schulman (1944) who worked in the U.S.A. with Douglass, the founder of dendrochronology as it was practiced after 1919. Schulman mentioned that "Tree-ring chronologies in Scandinavia exceeded in volume those for any other region outside of the Southwestern United States. Two factors seem largely responsible: the major economic importance of forests and the work of De Geer (1938 Sweden) on the clay layers of varves; the field work of Douglass in Scandinavia in the winter of 1912-13 also seems to have directed much attention to dendrochronology" (Tree-Ring Studies, 1944, vol. 11, no. 1, p. 1). Schulman mentioned for Norway the works of Ording (1941) considering them "among the most competent and comprehensive studies which have yet appeared anywhere" (Op. cit. p. 1).

In a few cases material from Norway was investigated by non-Norwegians such as: Douglass 1919, De Geer 1938, 1939; Schowe 1954.

Since 1950 the Norwegian Research Council for Science and Humanities has supported dendrochronological researches paying the salaries of part time or whole time researchers (Høeg 1956).

In 1950 Strand investigated the effect of nitrogen loss, occurring under saltpetre production, on the diameter increment of Norway spruce (probably the first or at least one of the earliest studies on the influence of pollution on tree-ring growth).

Eidem (1953) analyzed variation of the annual ring widths in Norway spruce and Scots pine - a comprehensive work based on 182,000 measurements of nearly 62,500 different rings - and introduced the use of exponents in his tables of index-series to indicate the number of trees on which the series is based from a certain year onwards. Eidem also performed (1955) dendrochronological dating of a cast-house from Istad, Slidre Valdres.

Growth-ring studies in fruit trees were performed in 1954 by Ljones and Nesdal.

An excellent review of growth-ring research in Norway was completed by Ove Arbo Høeg in 1956 who refers to the methods (he stated: "The use of mathematical methods is a characteristic feature of Norwegian growth-ring research.

It involves a very great amount of work in order to give statistically reliable results". (Tree-Ring Bull. Vol. 21, no. 1-4, p. 8)). Factors influencing the width of growth-rings in Norway (specific differences, flowering, seeding, soil humidity, nutrition, insects, temperature), and missing rings, double rings, late wood-percentage, resin canals, and standard index series were analized in this review.

Various series have been published by Ording (1941) and refer to southern Norway. The largest series is from Flesberg near Kongsberg, for Pinus sylvestris, the oldest ring being measured, from 1383.

Høeg (1956) observed that "For the practical work it is important to know to what extent beams from one part of the country can be crossdated by means of a standard series from another district....Norwegian investigators have found it necessary to adopt a cautious attitude toward the idea of teleconnections ones (for a critical analysis of dating of a small Norvegian material by comparison with the growth curve of Sequoia gigantea; see Ording 1941 a, p. 293 and 338). However, recent experiences have given at least the same ideas of the validity and limitations of the various standard series and the correlation between those of the various parts of the country." (Tree-Ring Bull. 1956, vol. 21, no. 1-4, p. 13).

In 1957 Slastad published the results of tree-ring investigations supported by the Norwegian Research Council for Science and Humanities.

The annual ring formation in Norway spruce in mountain forest was analyzed in 1969 by Zumer. After 1969 we have no available information on tree ring studies in Norway.

Cited authors:

Aandstad 1934, 1938 a, 1938 b; De Geer 1938 a, 1938 b (Sweden), Douglass 1919 (U.S.A.), Eide 1926, Eidem, 1953, 1955; Høeg 1944, 1956; Ljones and Nesdal 1954, Ording 1941 a, 1941 b; Ruden 1945, Shove 1954, Schulman 1944 (USA), Slastad 1957, Strand 1950, Zumer 1969.

2. 7. Forest inventory: sampling, remote sensing and GIS

Forest inventories on national level began in Norway in 1919. The first inventories were based on systematic strip or line-plot surveys. National forest inventories (NFIs) were completed during the following periods: 1919-1932, 1937-1956, 1957-1964, 1964-1976, 1981-1986, 1986-1993 and another one at the end of the 20th century.

“In Norway, great emphasis has been put on results in single counties, which is why only the more important counties, have been inventoried during some cycles; there have also been interruptions of some years in the work” (Nyyssönen 1993, p. 29).

Between 1919 and 1972 forest inventories (NFI) were completed by National Forest Survey (Landsskogtaxeringen) on independent organizations subordinated to the Directorate of Forestry in the Ministry of Agriculture. According to Nyyssönen (1993) “In 1978-1987 the inventory was performed by a department of the Norvegian Forest Research Institute (NISK) and in 1988 it was transferred to the Norvegian Institute of Land Inventory (NIJOS)”.

The problems of accuracy in forest strip survey were analized by Langsaeter (1926 and 1932). The effect of the plot size on accuracy and some methods for estimating volume and increment were investigated in detail later by Strand (1955, 1957, 1959) and Nestern (1967). Transition from strip survey to line-plot sampling accured in 1954, the next step being the adoption of a cluster sampling patern. Should be underlined that forest inventory works were done county by county. Varying in size from 100 to 1000 sq. meters the circular concentric plots were the most common type of sample plot used in Norway and part of them were remeasured. On counties level the relative Standard errors represented 1-4 % for forest area and average volume, and 2-5 % in the case of total volume (Nyyssönen 1967, 1993). The permanent sample plots were adopted in 1980s due to the introduction of monitoring of forest health. New information on sampling design of forest inventories and data processing have been supplied by Tomter (1991, 1997).

In 1997 were completed questionnaires for multi-resource inventories and published by Dramstand (for agriculture) and Elgersma (for Norway landscapes).

A detailed national monitoring of forest vitality in Norway during 1989-1996 period was published in a report in 1997 authored by Støen, Nellemann and Eriksen.

Remote sensing was practiced in Norwegian forest inventory on a smaller scale than in Finland.

Aerial photographs (1:15000) were used to establish the effect of season on estimation of stand mean height, crown closure and tree species; the results did not show any notable effects of seasons (Naesset 1991). Among other papers of Naesset should be mentioned the use of forest aerial photographs for derivation of stumpage value and logging costs for individual forest stands and cartographic modelling (1996), and the estimation of timber volume of forest stands using airborne laser scanner data (1997).

Small-format photogrammetry for forest and wildlife surveys was evaluated by Warner and Fry using Euclidian versus fractal geometry (1990).

Cited authors:

Dramstad 1997, Elgersma 1997, Langsaeter 1926, 1932; Naesset 1991, 1996, 1997; Nestern 1967, Nyyssönen 1963, 1967, 1993; Stöen (Støen), Nellemann and Eriksen 1997, Strand 1955, 1957, 1959; Tomter 1991, 1997; Warner 1990.

2. 8. Chronology of selected events

1926: Early tree ring studies in Norway. The use for the first time of correlation between tree-ring width and climatic factors (E. Eide).

1926, 1932: Accuracy in strip survey of forest (A. Langsaeter).

1929: The use of a stand table method for volume determination in Norway (A. Langsaeter).

1940/1941: Early spruce yield tables (E. Eide, Alf Langsaeter).

1941: Early dendrochronological series (A. Ording).

1941, 1945: Introduction of statistical methods in tree ring research (A. Ording - 1941, T. Ruden 1945).

1942: Distribution by diameter categories of total spruce yield (Alf Langsaeter).

1944: An early review on tree-ring works in Scandinavia (Edmund Schulman - USA).

1944, 1945: A summary and valuation of dendrochronological methods (Ove Arbo Høeg - 1944, T. Ruden - 1945).

1950: The effect of nitrogen excess on diameter increment of Norway spruce (L. Strand).

1955-1959: The effect of plot size and the accuracy of some methods for estimating volume and increment on sample plots (L. Strand).

1956: A review of growth-ring researches in Norway (Ore Arbo Høeg).

1964: Numerical constructions of site index curves (L. Strand).

1964: A forest mensuration textbook (H.K. Seip).

1967: Optimal sampling schemes for systematic plot (S. Nestern).

1972: Diameter distribution in Norway spruce stands. (E. Vestjordet).

1973, 1974: Preliminary dry wood weight tables for merchantable stems and stands of Norway spruce (G. Wilhelmsen and E. Vestjordet).

1974: Diameter increment functions for Picea abies: spruce (H. Braastad).

1975: Yield tables and growth models for spruce (H. Braastad).

1981: Regression equations developed to convert top diameter measurements of unbarked spruce sawlogs with automatic optical devices (over bark) to those required for timber price tables under bark (T. Okstad).

1982: Structure and yield of mixed stands of birch and Norway spruce in

South East Norway (L. H. Frivold).

1985: Taper functions and tables for birch (Betula verrucosa and B. pubescens) valid for the whole country (K.R. Blingsmo).

1990: Euclidian versus fractal geometry in evaluation of small format photogrammetry for forest and wildlife surveys (W.S. Warner and G. Fry).

1993: A review of national forest inventories in the Nordic countries (A. Nyyssönen).

1995: Tree volume functions and tables for Scots pine, Norway spruce and Sitka spruce in western Norway (E. Bauger).

1996: A procedure for calculation of stumpage value and logging costs of individual mature stands using aerial photo-interpretation and a grid-based GIS: Geographical information system (E. Naesset).

1997: Country report for Norway on forest inventory and survey systems (S.M. Tomter).

1997: National monitoring of forest vitality in Norway 1989-1996 statistics (O.G.Støen, C. Nellemann, R. Eriksen).

1997: The use of airborne lasser scanner data for estimation of timber volume of forest stands (E. Naesset).

2.9. Selected contributors

Author	Printing years	Field
A. Langsaeter	1920s-1940s	1, 3, 4, 7
E. Eide	1920s-1940s	6, 4
S. Aandstad	1930s	6
P. Eidem	1940s-1950s	6
O. A. Høeg	1940s-1950s	6
A. Ording	1940s	6
L. Strand	1950s-1980s	6, 3, 1, 2, 4, 7
B. Tveite	1960s-1970s	2, 3
E. Bauger	1970s-1990s	1, 4
H. Braastad	1970s	1, 3, 4
E. Vestjordet	1970s	3
T. Okstad	1980s	1
E. Naesset	1990s	7

1 = tree, 2 = site evaluation, 3 = stand structure, 4 = stand growth and yield,
6 = tree-ring studies, 7 = forest inventory.

2.10. Comments

Around of 75 cited papers representing 28 % have been published after 1980 and 12 % after 1990. In spite of an unavoidable bias in selection of cited works their repartition indicates the following prevailing fields: stand structure growth and yield (25 %) and forest inventory (25 %) followed by tree and log measurement (16 %) and other subjects such as site evaluation (3%) and weight and biomass (4 %).

A special position belongs to tree ring studies (27 % of cited papers) and it is due to the advanced works during 1926-1956, and completed by Eide, Høed and especially Ording (1941) and Ruden (1945) who introduces in tree ring research the methods of mathematical statistics.

On the other hand, considering only forest inventory (including sampling methods, monitoring, the willingness to introduce multiresource inventories, and the use of remote sensing and GIS techniques) Norwegian forest mensuration can be considered as similar with that practiced in Sweden and Finland.

References

AANDSTAD, S. 1934. Untersuchungen über Dickenwachstum der Kiefer in Solör, Norwegen. (Researches on diameter growth of pine in Solör, Norway). Nytt. Mag. f. Naturvidenskaberne, 74.

AANDSTAD, S. 1938 a. Die Jahresbestimmung der Kiefer und die Zeitbestimmungen älterer Gebäude in Solö im östlichen Norwegen. (Age determination of pine wood in old buildings in Solör in eastern Norway). Nyt. Mag. f. Naturvidenskaberne, 78.

AANDSTAD, S. 1938 b. Die Jahresringbreiten einiger seltenen Kiefern in Steigen Nordland. (Tree-ring series in northern lands). Nyt. Mag. f. Naturvidenkaberne, 79: 127-140.

AUSTIN, T. 1958. Foresterie norvégiene. (Norwegian forestry). Bull. Soc. Roy. For. Belg. no. 4.

BAUGER, E. 1970. Stammenligning mellom sitkagranens og granens høydeutvikling på Vestlandet og i Nord-Norge. (Comparison between height development of Sitka spruce and Norway spruce in West Norway and North Norway). Medd. Vestl. Forstl. Forseksstasion Bergen 14, pp. 145-221.

BAUGER, E. 1995. Funksjoner og tabeller for kubering av staende tā-r. Furu gran og sitkagran på Vestlandet. (Tree volume functions and tables. Scots pine (*Pinus sylvestris*).

BLINGSMO, K.R. 1985. Ausmalningsfunksjoner og-tabeller for bjørk. (Taper functions and tables for birch [*Betula verucosa* (*B. pendula*)] and *B. pubescens* in Norway). Rapport, Norsk Institut for Skogsforskning no. 10, 35 pp.

BRAASTAD, H. 1974. Diametertilvekstfunksjoner for gran. (Diameter increment functions for *Picea abies*. Medd. Norsk. Inst. Skogsforskning 31: 1-74.

BRAASTAD, H. 1975. Poduksjontabeller og tilvekstmodeller for gran. (Yield tables and growth models for *Picea abies*). Medd. Norske Skogforsøksv 31: 357-537.

BRAASTAD, H. 1982. Naturling avgang i granbestand. (Natural mortality in *Picea abies* stands). Medd. Norsk Inst. Skogforskning 12.

BRAADSTAD, H. 1983. Produksjousvivået i glissen og ujamu granskog. (Yield level in *Picea abies* stands with low initial density and irregular spacing). Research paper from Norwegian Forest Research Institute 7183, 42 pp.

BRAATHE, P. 1952. Planteavstandens virkning på bestandsutvikling og masseproduksjon i granskog. (The effect of different spacing upon stand development and yield in forests of Norway spruce). Medd. Norske Skogsvorsøksv. 11: 425-469.

BRANTSEG, A. 1951. Kubikk-og producsjonsundersokelser i vest-norske granplantaninger. (Investigations on volume and yield in spruce plantations in West-Norway). Medd. Vestl. Forstl. Forsøksv. 9: 1-109.

DAHL, E.; MORK, E. 1959. Om sambandet mellom temperatur, ånding og vekst hos gran [*Picea abies* (L.) Karst]. (On the relationship between temperature, respiration and growth in Norway spruce [*Picea abies* (L.) Karst.]. Medd. Norske Skogsforsksv. 53: 81-93.

DE GEER, E. H. 1938. Raknehaugen. Universitetes Oldsaksami. Arbok 1937: 27-74 Oslo. (Cited in Norway in 1938).

DE GEER, E. H. 1939. Kubbestolen frar Sauland II. Biokronologisk datering. Fataburen 1939: 123-130.

DOUGLASS, A. E. 1919. Climatic Cycles and Tree-Growth. Carnegie Inst. Wash. Publ. 289, Washington.

DRAMSTAD, WENCHE E. 1997. MRI questionnaire for Norway agriculture. 30 June 1997. As, Norway; Norvegian Institute of land Inventory, 2p. On EFI file, Joensuu Finland.

EIDE, E. 1926. Om sommervarmesns inntlydelse på arringsbredden. (On summer temperatures and diameter growth of spruce. Medd. Norske Skogsforsoksvesen 2 (7): 87-104, Oslo.

EIDE, E.; A. LANGSSAETER. 1940-1941. Produksjonsunderkelser i granskog. (Researches on yield of spruce forests). Medd. Norske Skogsforsoksvesen 7: 355-500.

EIDEM, P. 1943. Über Schwankungen im Dickenwachstum der Fichte (*Picea abies* in Selbu, Norwegen. (On variation of diameter growth of spruce [*Picea abies*] in Selbu, Norway). Nytt. Mag. Naturvid. 83: 145-189 Oslo.

EIDEM, P. 1953. Om Svingninger i tykkelsestilveksten has gran (*Picea abies* og furu (*Pinus sylvestris*) i Trondelag. (On variations of the annual ring width in Norway spruce [*Picea abies*] and Scots pine [*Pinus sylvestris*] in Trondelag. Medd. Norske Skogsforsokwesen 12 (41): 1-155 Oslo.

EIDEM, P. 1955. Badstua fra Istad: Slidre. En. dendrokronologisk tidfesting. (Dendrochronological dating of an cast-house from Istad. Slidre, Valdres.) Blyttia 13: 65-70.

ELGERSMA, ANNE. 1997. MRI questionnaire for Norway, landscape, 30 June 1997. Ǻs, Norway; Norwegian Institute of Land Inventory. 1p. On EFI file, Joensuu, Finland.

FRIVOLD, L. H. 1982. Bestandsstruktur og produksjon i blandingsskog av bjork [*Betula verrucosa* Ehrh. 13, *B. pubescens* Ehrh. og gran (*Picea abies* (L.) Karst.) i Sydost-Norge. (Stand structure and yield of mixed stands of birch [*Betula verrucosa* Erhr. *B. pubescens* Erhr.] and spruce [*Picea abies* (L.) Karst.] in South East Norway. Scientific Reports of the Agricultural University of Norway, 61 (18), 108 pp.

GISLERUD, O. 1974. Whole tree utilization. II. Biomass and biomass properties of trees from thinnings of spruce, pine, birch and alder. Repport 6/74 Norsk Institutt for Skogsforskning 59 pp.

HØEG, O. A. 1944. Dendrokronologi. Viking 1944: 231-282, Pl. XUV-XLV, Oslo.

HØEG, OVE ARBO. 1956. Growth-ring research in Norway. Tree-Ring Bull. Vol. 21 no. 1-4: 2-15.

KLEM, G. S. 1970. Betydningen avøeket verksthastighet for en del virkesegenskaper hos gran [*Picea abies* (L.) Korst.] og furu (*Pinus sylvestris* L.) Norw. (The influence of increased growth rate on some quality properties of Norway spruce [*Picea abies* (L.) Karst. and Scots pine (*Pinus sylvestris* L.) Medd. Norske Skogsforsøksv. 27, H. 96: 63-90.

LANGSAETER, A. 1926. Űber die Berechnung des Mittelfehlers des Resultates einer regelmässigen Linientaxierung. In Norwegian, German summary. (About the determination of mean error of the results of an inventory strip) Medd fra det norske Skogforsöksvesen.

LANGSAETER, A. 1929. Die durchschnittlichen Durchmesser der Durchmesserklassen. (Normal mean of diameter classes). Mittlg. a.d. forstl. Versuchswesen Norwegens Nr. 11: 217-241.

LANGSAETER, ALF. 1932 a. Nølaktigheten Veldlinjetaksering av skog. (Accuracy in forest strip surveys). I. Bestemmlese av treantall og dimensjonsfordeling (I. Determination of the number of trees and diameter distribution). II Bestemmelse av Hoide og Arringbredde. (II. Determination of height and annual ring width). Medd. Norske Skogfor 4: 232-563, 5: 405-445. Translated in the U.S.A. by U.S.F.S. 354 A, 354 B, 355, 1938.

LANGSAETER, A. 1932 b. Über die Genauigkeit der Waldtaxierung mittels Probestreifen I. Bestimung von Baumzahl und Dimensionsverrteilung. (On the accuracy of forest volume estimation using sample strips. I Determination of the number of trees and their distribution by diameter categories. Mitt. a. d. forstl. Vers.-Wesen Norwegens, 15.

LANGSAETER, A. 1934. Über die Genauigkeit der Waldtaxierung mittels Probestreifen (On the accuracy of forest volume estimation using sample strips). II. Bestimmung der Höhe und der Jahresringbreite. (Determination of height and width of the annual tree-rings). Mitt. a.d. forstl. Vers.-Wesen, Norwegens, 18.

LANGSAETER, A. 1941. Im tynning i enaldret granog furuskog. (Researches on spruce yield). Medd. Norske Skogforsøeksv. 8: 131-216.

LANGSAETER, A. 1942. Die Verteilung der Gesamtproduktion im Fichtenwald auf Durchmesserklassen. (The distribution of total yield by diameter classes in spruce forest). Tidskr. f. Skogr. 50.

LJONES, B.; O. NESDAL. 1954. Arringstudier i frukttre. (Growth ring studies in fruit trees). Medd. Norges Landbrukshøegskale 33: 1-39.

NILSEN, P.; O. HAVERAAEN, O. 1982. Dimensjonsfordeling og diameterklassevis tilvekst i eldre granskog. (Tree size distribution and increment in different diameter classes in old Norway spruce Stands). Medd. Norsk. Inst. Skogsforskning 15.

NAESSET, E. 1991. Betydiningrn av arstid for registreringer av bestandshøyde kronedekining og treslag i flybilder. (The effect of season on estimation of stand mean height, crown closure and tree species from aerial photographs). Meddelelser fra Norsk Institut for skogsforskning (1991), 44(7) 28 pp.

NAESSET, E. 1996. Derivation of stumpage value and logging costs for individual forest stands using aerial photographs and cartographic modelling. Scandinavian Journal of Forest Research 11(4): 388-396.

NAESSET, E. 1997. Estimating timber volume of forest stands using airborne laser scanner data. Remote Sensing of Environment 61(2): 246-253.

NESTERN, S. 1967. (Some calculations on optimal sampling schemes for systematic plot surveys). Medd Norske Skogfors. ves. 22, 84: 367-429.

NYYSSONEN, A. 1963. Analysis of two alternative methods for national forest inventories in Northern Europe. Acta Forest. Fenn. 76, 19 pp.

NYYSSONEN, AARNE. 1967. Remeasured sample plots in forest inventory. Norwegian

Forest Research Inst., Vollebekk, Norway, 25 pp.

NYYSSONEN, A. 1993. National forest inventories in the Nordic countries. Proceedings of the 1992 meeting of the IUFRO Group S4.02, IUFRO Centennial 1992, pp. 28-35.

OKSTAD, T. 1981. Barktykkelse hos skurtømmer. I. Gran. (Bark thickness of sawlogs. I. Spruce). Rapport, Norsk Institut for Skogforstning, no. 3; 33 pp.

OKSTAD, T. 1982. Barltykkelse hos skurtømmer. II. Furm. (Bark thickness of sawlog. II. Scots pine). Repport Norsk Institutt for Skogforskning no. 112, 36 pp.

OPDAHL, H. 1989. Avsmaling og volume hos osp (*Populus tremula* L.) i Sør-Norge. [Taper and volume of aspen (*Populus tremula*) in south Norway]. Meddelelser fra Norsk Institutt for Skogforskning 43 (2), 42 pp.

ORDING, A. 1941 a. Annual ring analysis in spruce and pine. In Norwegian Engl. summ. pp. 324-345. Medd. Det. Norske Skogforsöksvesen 7: 105-354, Oslo.

ORDING, A. 1941 b. Skoghistoriske analyser fra Raknehaugen. (Forest historical analyses from Raknehaugen). Medd. Det. Norske Skogforsöksvesen 8: 91-130, Oslo.

RUDEN, T. 1945. En vurdering av anvendte arbeidsmetoder innen trekronologi og arring-analyse. (A variation of the methods employed in dendrochronology and annual ring analyses). Medd. Norske Skogforsøksvesen 9 (32): 181-267, Oslo.

SCHOVE, D. J. 1954. Summer temperatures and tree-rings in North Scandinavia A.D. 1461-1950. Geografiska Annaler 1954: 40-80.

SCHULMAN, EDMUND. 1944. Tree-ring work in Scandinavia. Tree-ring Bull. Vol. 11, no. 1, p. 1.

SEIP, H.K. 1964. Tremaling (Forest mensuration). Skogbruk og Skogindustri vol 3. Norway.

SLASTAD, T. 1957. Arringundersøkelser I gudbrandsdalen. (Tree-ring analyses in gud-brandsdalen). Results of the tree-ring investigation supported by the Norwegian Res. Council for Sci. and Humanities, 6, Meddelelser fra Det Norske Skogforsøksvesen 48, Oslo.

STØEN, OLE-GUNNAR; NELLEMANN, CHRISTIAN; ERIKSEN, RUNE. 1997. National monitoring of forest vitality in Norway 1989-96 statistics. NIJOS Repport 1/97. As, Norway, Norwegian Institute of Land Inventory. 82 pp.

STRAND, L. 1950. Undersøkelse angäende den innflytelse som kwelstofftapet ved salpeter fabrikasjonen har på granas diametertilvekst. (Investigations on the effect of loss accuring under salpetre production on the diameter increment of Norway spruce). Medd. Norske Skogforsøksvesen 11 (38): 79-127, Oslo.

STRAND, L. 1952. A measure of the distribution of individuals over a certain area. Moddel. fra Det Norke Skogforsøkswesen, nr. 42.

STRAND, L. 1955. Plot size in field trials. Zeitfchrift fur Forst genetik: 157-162.

STRAND, L. 1957. "Relaskopisk" hoyde-og kubikkmassebestemmelse. (Relascopic height and cubic volume determination). Norsk Skogbruk 3: 535-538.

STRAND, L. 1957a. The effect of plot size on the accuracy of forest surveys. Moddel. fra Det Norske Skogsforsøkswessen, Nr. 48.

STRAND, L. 1959. The accuracy of some methods for estimating volume and increment on sample plots. Meddel fra Det Norske Skogsforsfswesen, Ne. 52.

STRAND, L. 1964. Numerical constructions of site index curves. Forest Science, X, 4.

STRAND, L. 1972. A model for stand growth. IUFRO 3rd Conference Advisory Group of Forest Statisticians. Jouy-es-Josas, Sept. 7-11, 1970. Institut National de la Recherche Agronomique Publ. 72-3: 207-216.

STRAND, L. 1983. Tilvekstfunksjoner for prognoseformål. (Increment functions for long-term yield forecasts). Medd. Norsk. Inst. Skogforskning 15/83.

TOMTER, S. M. 1991. The national forest survey of Norway-Some notes about sampling design and data processing. In Köhl and Pelz (eds.) 1991 pp. 66-69; see Poso, S. 1991, Finland.

TOMTER, STEIN M. 1997. Country report for Norway. In: Study on European Forestry Information and Communication System-Reports on forest inventory survey systems. Volume 2, CH-11-97-002-EN-C. Luxembourg: European Commission; 799-860.

TVEITE, B. 1967. Sambandet mellom grunnflateveid middelhøyde (HL) og noen andre bestandshaøyder i gran-og furuskog. (The relationship between mean height by Lorey's formula (HL) and some other stand heights in pine and spruce stands). Medd. Norske Skogforsoeksv, 22: 483-538.

TWEITE, B. 1969. A method for construction of site index curves. Meddelelser frå Norsk Institutt for Skogsforskning 27.

TWEITE, B. 1977. Bonitetskurve for gran. (Site curves for spruce). Medd. Norsk. Inst. Skogforskning 33.

TWEITE, B. 1985. Air pollution and forest damage in Norway. pp. 59-68. In: Nutchinson, T.C.; Meema, K. M. (eds.): “Effects of Atmospheric Pollutants on Forests Wetlands and Agricultural Ecosystems", Springer Verlag".

VESTJORDET, E. 1972a. Diameterfordelinger og hoydekurver for esaldrede granbestand. (Diameter distributions and height curves for even-aged stands of Norway spruce). Medd. Norske Skogforsøksv 29: 469-557.

VESTJORDET, E. 1972b. Diameterspredning hos gran i helinger. En orienterende undersøkelse. (Diameter distribution of Norway spruce on slopes. A pilot study). Medd. Norske Skogforsøksv. 32, 485-502.

WARNER, W. S. ; FRY, G. 1990. Evaluating small-format and wildlife surveys: Euclidean vs. fractal geometry. Forest Ecology and Management 3(1-2) 101-108.

WILHELMSEN, G. ; E. VESTJORDET. 1973. Preliminary dry wood weight tables for merchantable stems and stands of Norway spruce [*Picea abies* (L.) Karst.] in Norway. In: Young, H. E. (ed.) IUFRO biomass studies, Univ. of Maine, Orono, pp. 519-531. Published also by Norsk Institutt for Skogførskning 31.5: 183-240.

ZUMER, M. 1969. Annual ring formation on Norway spruce in mountain forest. Meddelelser fra Det Norske Skogforsøksvesen 27: 165-164.

3. SWEDEN

General information

Land area: 408,230 sq. km (157,624 sq. mi.), forest and other wooded land: 280,150 sq. km. (108,170 sq. mi.), forest: 24,437,000 ha or 94,355 sq. mi. (60 % of land area), volume: 107 m^3/ha, biomass: 57 tons/ha (FAO 1955/1924: Forest resources assessment).

Round wood production: industrial round wood 55.5 million m^3, fuel and charcoal 4.4 million m^3, total round wood 59.9 million m^3 (World Resources 1996-97, p. 220).

Forest vegetation: Boreal and temperate mixed forests.

• Conifers: 65 %

• Broad-leaved: 35 %

• Main species: Scots pine (*Pinus sylvestris*), spruce (*Picea abies*), birch *(Betula* spp.), tremble aspen (*Populus tremula*) European beech (*Fagus sylvatica*).

In Sweden there are four distinct regions from the north to the south of the country: (1) Birch region (in Lapland), (2) Region of the northern resinous forests (up to 60^0 northern latitude) with predominance of Scots pine and spruce pure or mixed stands, (3) Southern region of coniferous forests which cover the southern part of the country except the south-western subregion; the dominant forests types of the third region are: Scots pine and spruce mixed stands of previous two species and birch, and on small areas, islands of European oak (*Quercus robur*) and European beech (*Fagus sylvatica*): (4) Beech region, in the south-western part of the country, is covered by pure or mixed stands of oak (*Q. robur*), European ash, hornbeam (*Carpinus betulus*), and acclimatized American red oak (*Quercus rubra*).

Before the 9th century, according to "Uppsala öd" (bill.), products of Swedish land were the propriety of the King and the Uppsala pagan temple. In 1542 the King Gustav Vasa decided that all lands unused by private persons "belong to God, to Us and Swedish Crown and nobody else" (Milescu and Alexe 1969, p. 106).

Forestry education institutions and research organizations involved in the areas of forest mensuration and forest management (date of establishment in brackets):

• Swedish University of Agricultural Sciences (SUAS). Faculty of Forestry, Uppsala (1915).

• Forestry Research Institute "SKOGFORSK", Uppsala (1991).

Publications:

• Meddelanden från statens Skogsförsöksanstalt (since 1946 Statens Skogsforskningsinstitut (Reports of the forest Research Institute of Sweden).

• Studia Forestalia Suecica.

• Ambio Vol. 1 (1972+.) Stockholm: Royal Swedish Academy of Science. Bimonthly.

• Scandinavian Journal of Forest Research. Vol. 1 (1986+.) Stockholm, Sweden Alimqvist and Wiksell. Periodical Co. Quarterly.

• Svenska Skogsvårdsföreningens Tidskrift (från, 1966), Sveriges Skogsvårdsförbunds Tidskrift (Journal of the Swedish Forestry Society).

3.1. Tree and log measurement

Hanlik presented in 1924 the tree classification in Sweden. Measurement and errors in determination of tree basal area were analyzed by Tiren in 1929, two years later than Tischendorf.

The instruments used in Sweden for the measurement of tree height were described in 1953 by Skansheim.

Standardized measurement of saw timber is shown in Skogen 1953, 40, 10, p. 220 and of pulpwood in Skogen 1953, 40, p. 240.

Data on bark for the main species, for different site and age classes, and for sawlogs and pulpwood were summarized by Ölstlin (1963).

In 1985 Nasberg developed mathematical models for optimal log bucking.

In 1987 a one-hand calliper for thinnings was produced by Arne Jonsson and Pellbo Krylbo. This caliper works like a tong: it can be opened with one hand and automatically springs back; its scale goes up to 32 cm.

Modern equipment for electronic recording of field data (calipers, hypsometers and tachometers) enables readings to be recorded automatically and transferred without error and was presented shortly by Hörpsten and Hellström (1996). Computing power in the field makes possible the processing of data on the spot and compare the results and check their rightfulness.

Oja (1997) compared three different methods of measuring knot parameters in *Picea abies* (knot structure of trees is important for foresters and sawmillers). For research purposes he applied a non-destructive method using X-ray computer tomography (CT) and image analysis well comparable with the destructive methods, but a large number of smaller knots cannot be found by the CT method, and in conclusion it must be improved.

Among the instruments of the last generation will be mentioned Mantax Computer caliper constructed by the Swedish firm Haglöf. This caliper is very precise (error ±1 mm), its computer is programmable and has a memory of 512 KB and data can be transferred in a modern personal computer (PC) (Prodan et al. 1997, p. 29).

A new Swedish device for measuring distances heights and angles is the Forester Vertex (1990s) based on ultrasonic determination of distances; it calculates the object height from both measured values. The device has two components: the actual measuring device and DME 201 the ultrasonic transponder.

Cited authors:

Anonymous 1987, Hanzlik 1924, Hörnten and Hellström 1996, Nasberg 1985, Oja 1997, Östlin 1963, Prodan et al. 1997, Skadsheim 1953, Skogen 1953, Tiren 1929.

3.2. Tree form

The first attempt to express the form of an average stem by an equation (relationship) belongs to Hojer (1903):

$$k_i = \frac{d_i}{D} = c \log \frac{c+l}{c}$$ where:

C and c are constants;

d_i= stem diameter at height l meters from the top toward the ground;

D = dbh (diameter and breast height).

In 1910 Jonson proposed the function:

$$y_i = b_1 \frac{\log(b_2 + x_i + 2.5)}{b_2}$$ where:

y_i = diameter of the i-th percentage distance from the top of the tree;

x_i = percentage distance of the point of measurement from the top of the tree.

Tree height was defined as the height above the 1,3 m reference point. Behre (1923-USA) discussed the validity of this formula for the establishment of stem taper and proposed an improved function:

$$y_i = x_i/(b_0+b_1x_i)$$

Later, in 1928, Jonson modified Hojer's formula proposing:

$$k_i = \frac{d_i}{D} = C \log \frac{c + l - 2.5}{c}$$ where:

k_i = quotient of superior diameter/dbh;
l = relative height in percentage of h-1,3;
h = stem height up to superior end.

Jonson replaced the constants C and c with different form quotients within the range 0,55 < k1/2 < 0,80. This formula is not suitable for the lower part of stem.

Maas (1908) determined the cubic contents and form of pine and spruce in certain districts in Dalarma and established the connection between the artificial form factor and other tree biometrical characteristics.

Sylvén (1909) studied spruce morphology, especially types of branching and their forest importance.

In 1910 Jonson began his forest mensurational investigations on stem form: spruce stem form in 1910, pine stem form in 1911 and a synthesis in 1912: "Forest mensurational investigations concerning forest tree form. Form determination of standing tree form". In 1915 Jonson used taper curves as a basis of volume tables. Form variability of larch was investigated by Mattson (1916/1917a, b). New contributions on stem form characteristics were provided by Tiren who constructed stem curve (1922, 1928, 1929), Petrini (1921), Jonson (1926/1927), Jonson 1926 ("summary on method and aids in tree form investigations and in the calculation of volume yield of various products and growth"), Pettersen 1925 (influence of crown on stem form), 1927 (studies on stem form).

In 1928 Heijbel published a system of equations for determining stem form in pine and in another paper (1928b) analyzed form factor from mathematical and statistical point of view. In the field of stem form investigations should be mentioned also the works of Petterson (1936), Maass 1939 (who proposed determination of stem-form of pine using the diameter at 2.3 meters above ground).

Hagberg (1942) studied the change in the form of pine and spruce during the development of the stand and after thinnings. In 1944 Hagberg connected yield calculation and stem form based on comparisons of calculated and measured log yield form fellings, and investigations on the importance of calculations of individual stem form and root swelling.

Fries and Matérn (1965) discussed the use of multivariate methods for the construction of tree taper curves and proposed a regression equation of taper curve represented by a polynom of 58 degree (!).

One of the frequent subjects in Matérn's researches was the geometry of the cross-section of a stem (1956). He developed a detailed analysis (1990) on the shape of the cross-section of Scots pine and Norway spruce stems which is an interesting empirical study of the geometry of mensurational methods.

According to Matérn, if a tape is used tightly wrapped around a stem with irregular form it encloses an area which reflect its convex closure and the measured circumference is always smaller then the true circumference that means that the cross-sectional area is smaller than estimated area. This problem was largely commented by Laar and Akça 1997, p. 85 (Germany).

Cited authors:

Behre 1923 (U.S.A.) Fires and Matérn 1965, Hagberg 1942. 1944: Heijbel 1928, Hojer 1903, Jonson 1910, 1911, 1912, 1915, 1926, 1926/1927, 1928a, 1928b, Laar and Akça 1997 - Germany, Maass 1908, 1939: Matern 1956, 1990: Mattson 1916-1917 , 1916-1917b, Niemistö 1995, Petrini 1921, Pettersen 1925, Petterson 1927, 1936: Sylvén 1909, Tirén 1928, 1929.

3.3. Tree volume tables and equations

An early work on "cubic contents" of pine and spruce was completed by Maass in 1908 for these species in certain districts in Dalama. In 1911 Maass constructed volume tables for pine growing in normal stands.

In 1915 and 1918 Jonson developed volume tables for many species growing in Sweden using taper curves as a basis for these tables, and presented later (1926) the methods and aids for the calculation of volume and yield of various products, and in 1928 new techniques for volume and increment calculation of standing trees.

Stem volume determination based on "Formpunktsmethoden" was practiced by Petrini (1918, 1919) and Jonson (1928).

Heijbel (1929) developed "mathematical" investigations on pine bark while Östlin (1930) studied it "from a forest mensurational" point of view.

In 1940, 1947 and 1957 Näslund developed volume tables based on functions for standing trees of pine, spruce and birch for different regions (north, south). Näslund's volume tables are based on formulas obtained by the method of multiple correlations, but in practice the volume functions are presented in tabular form. For example, in 1947 Näslund developed the tree volume equation of the following type:

$$v=b_1d^2+b_2d^2h+b_3dh^2+b_4d^2h_c+b_5dhBT$$

where h_c = height above ground at the base of the live crown, BT = bark thickness and d = dbh (diameter at breast height).

For the stem volume of *Pinus sylvestris* in southern Sweden the following equation was determined:

$$v=0.1193d^2+0.2574d^2h+0.004054dh^2+0.007262d^2k-0.003112dbh$$

where: d = dbh over bark in cm, h = total height in metres, k = length of stem from the ground to the base of crown in meters, b = double thickness of bark in mm.

This type of formulas was used in Swedish forest inventories (1940s, 1950s) and data processed by computer (IBM type using punched cards as shown in Figure 3.3.-1:

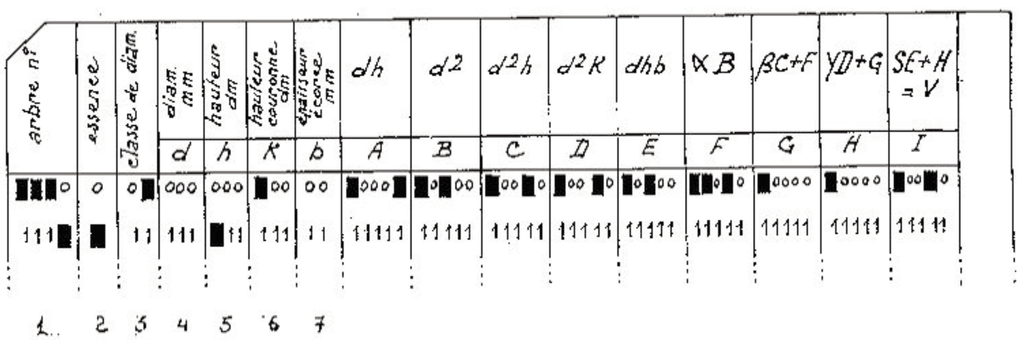


Fig. 3.3.-1. Model of Swedish punched card (type IBM) for mechanographic calculus of tree volume. 1 = tree number, 2 = species, 3 = diameter class, 4 = diameter mm, 5 = height dm, 6 = crown length dm, 7 = bark thickness.
SOURCE: Pardé 1961, Dendrometrie p. 169, fig. 79.

The error of Näslund's functions for a lot of 19,000 trees (real volume determined later) was 0,05 % and for 40000 trees 0,10 % (after Pardé - 1961, p. 168).

The functions and tables for volume determination of small trees were developed by Andersson in 1954.

In 1973 Eriksson established tree volume functions for ash, alder and lodgepole pine in Sweden.

A remarkable paper concerning functions for forecasting of timber yields-increment and form height for individual trees of native species in Sweden was published in 1986 by Söderberg as a report of Section of Forest Mensuration and Management, Swedish University of Agricultural Sciences, Umea.

Cited authors:

Andersson 1954, Eriksson 1973, Heijbel 1929, Jonson 1915, 1918, 1926, 1928: Maass 1908, 1911 a, 1911 b; Näslund 1940, 1947, 1957; Östlin 1930, Pard, 1961, Petrini 1918, 1919; Söderberg 1986.

3.4. Tree growth

Hojer (1903) entitled his work "Pine and spruce growth" but in fact tried to represent mathematically (see 3.2.) the stem taper curve.

Early investigations on tree growth were carried out by Hesselman and refer to Scots pine height and shoots growth during summer (1904 a) and diameter growth in the last previous years (1904 b).

In 1926 and 1928 Jonson presented the methods and aids for calculation of tree form and growth. The stem analysis was known and practiced in Sweden before 1927 (Petrini 1927).

New informations on the date of completion of annual diameter growth in pine and spruce were supplied by Andersson (1953). Holmsgaard (1958) underlined basic growth concepts and Matérn (1961) determined the precision of estimates of diameter growth from increment borings.

Odin and Openshaw used in 1971 electrical methods for measuring changes in shoot length and stem diameter.

Odin (1972) studied also the increment rhythm of Scots pine and Norway spruce plants, and Perssons (1978) determined root dynamics in a young Scots pine stand in central Sweden.

In 1979 special workshop was held at Jädraäs in Sweden on "Understanding and Predicting Tree Growth", proceedings being published in 1981 (Linder, S.).

In an extensive book Sönderberg (1986) presented functions for forecasting of timber yields: increment and form height for individual trees of native species in Sweden.

In 1990 Santantonio (a guest scientist at the Department of Ecology and Environmental Research, Swedish Univ. Uppsala) discussed growth and production of trees roots describing several approaches to modelling root growth: (i) allometric relations, (ii) allocation or partitioning fractions, (iii), utilization of substrates (iv), specific activity, (v) functional balance between shoot and roots, (vi). Thomley's mechanistic approach and (vii) indirect approaches based on carbon balance or root decomposition and concluded that "allometric and pipe model (a relation between conducting area and foliage mass) approaches seem best for coarse roots. For fine roots, the best approach may be a functional balance between the size and activity of fine-root and foliage systems" (p. 124).

Cited authors:

Andersson 1953, Hesselman 1904 a, 1904 b; Hojer 1903, Holmsgaard 1958, Jonson 1926,1928; Linder 1981, Matérn 1961, Odin 1972, Odin and Openshaw 1971, Persson 1978, Petrini 1927, Santantonio 1990, Söderberg 1986.

3.5. Evaluation of forest site productivity

Without any mathematical definition since 1867 assessment of stocking (volume per ha) had been a part of management inventories of the Swedish State forests and considered the main indicator of site productivity. Stocking remains an important variable in the Swedish National Forest Inventory (NFI) since the first inventory started in 1923. Tor Jonson constructed in 1914 a measure of stocking which has been used for sixty years in NFI. Jonson's measure was used also for planning for cutting calculations to define so-called "better health" of forest, a concept used as a measure of future yield capacity of the forest used later by Nilson (1961) for construction of yield tables based on NFI data. Jonson's (1914) measure of stocking is based on the idea that volume in fully stocked stands could be described by the mean height of the trees and this could be done independently of stand age and site. Jonson used data from natural unthinned stands. Jonson used the Eichhorn rule (1904, Germany), which some years earlier has been found applicable to pine volume tables by Mass (1911) and obtained also a support in Schwappach's (1908) studies developed in Germany. It should be remembered that according to Eichhorn's rule in its original form (from studies in silver fir stands) "a given mean height of a stand is matched by the same volume in all site classes". Gerhard (1904, Germany) extended this rule to spruce and pine but later, according to Assmann (1970 p. 161, see Germany) "corrected his statement in favour of a differentiation by yield classes". Jonson (1914) calculated the ratio of volume to height in fully stocked stands and called it "intensity". From ratios (one from each investigated stand) Jonson proposed the following formulas in which the "intensity" is expressed as a function of stand mean height (h):

$$\text{for spruce stand intensity} = 4.2 \cdot \sqrt{h}$$

$$\text{pine stands intensity} = 6.0\ \sqrt[3]{h}$$

From these formulas and volume and height of a given stand a relative volume index can be calculated:

$$\text{relative volume index} = \text{volume}/(\text{height} * \text{intensity})$$

The site index (SI) was introduced later in Sweden and represents the dominant height of a stand in meters at a pre-fixed age. In the NFI the mean height of the two trees with the largest diameter at breast height on a plot with a radius of 10 m was considered to be the dominant height. Site index H100 is the dominant height (H) at the age of 100 years.

In Sweden a special procedure for determination of dominant height is also practiced: a curve of trees repartition by diameter categories is constructed (in even-aged stands) and M is an average interval, than in the interval M±3s (s = standard deviation), and the dominant height is defined as the height of trees whose diameter is M+3s (Petterson 1955).

The forest area of the world and its potential productivity was estimated by Paterson (1956) by the means of an index which bears his name (see the formula of the index in "France" chapter).

The problem of site evaluation in northern Sweden was examined by Stridsberg (1956).

Site index curves for Norway spruce in northern Sweden were developed by Hägglund (1972) and in southern Sweden in 1973. In 1974 general considerations on site index were presented by the same author mentioned before.

Lundmark (1974) used site properties for assessing site in stands of Scots pine and Norway spruce.

In 1975 Hägglund established the relationship between the dominant height site index and Jonson's site classes. In the same year Hägglund estimated the accuracy of site index curves by means of simulation. A new study on site index estimation by means of site properties was completed in 1977 by Hägglund and Lundmark.

Hägglund (1978) presented information on evaluation of site quality in connection with a model for large scale forecasting of timber yields. Since 1978 in Sweden a site quality evaluation system was under development and was based on dominant height at a fixed reference age, as in the USA). Those parts of this system (which are auxiliary for assessing site index) have been incorporated in a model for long term forecasting of forest yield, which was called the HUGIN model. In this model two methods are used for estimating site index: 1) Site index curves, showing the relationships between age and dominant height for different levels of site productivity are used for estimating site index on plots in the areas where there are even-aged undisturbed not too young and preferable pure (one species). These stands are supposed to reflect site productivity in an unbiased way. 2) On the rest of the plots where stands do not fulfill the above-mentioned restrictions site index is estimated by means of a set of functions derived from NFI. In the Swedish site quality system the site curves have the following properties: most of them show the development of dominant height over age of dbh of the 100 (by diameter) largest trees per hectare. The most common definition of site index is dominant height at total age of 100 years. In 1978 have been developed curves for *Pinus sylvestris, Pinus contorta* var. *latifolia*, *Picea abies, Betula verrucosa, Quercus robur* and *Fagus sylvatica*; the principles used for the construction of the Swedish site index curves were reported before by Hägglund (1972).

Hägglund considered in 1981 that the evaluation of forest site productivity may be expressed in terms of mean annual increment (MAI) at the age of its maximum.

Ecological significance of forest fire for the northern boreal, Swedish forests and their influence on site productivity was investigated by Zackrisson (1980).

Site conditions on forest land and wetlands in Sweden were described in 1982 by Hägglund and Svenson who used data from the National Forest Survey.

In 1985 Strömberg and Tegnhammar used site variables as indicators of site index in beech stands. This was a pilot study carried out in southern Sweden in 100 circular plots. The relationship between site index and different combinations of site variables was analyzed by multiple regression analysis and site index tables based on the selected combinations of variables that have been presented. On the other hand, Attebring (1985) discovered that there is a frequent gap between increment and site productivity. A site index classification was developed in Uppland for Norway spruce (Jacobson 1986).

Landsberg's (1986) "Physiological Ecology of Forest Production" contains useful information on site productivity.

Short-term and long-term effects on site productivity by soil treatments in forestry were analyzed by Lundmark (1986).

In 1994 in a study on topographic and geochemical influence on the forest site quality, with respect to *Pinus sylvestris* and *Picea abies* Holmgren noted that the quality of most forest sites in Sweden is now classified by means of site properties according to a system developed in the 1970s (HUGIN) but although its regression functions are accurate on a country-wide sample scale, the local precision of the system is low. Holmgren suggested an alternative model that is based on digital map information and presented results from a study in the central Sweden for *Pinus sylvestris* for which the results were more accurate than that of the existing system but in the case of spruce the degree of determination was equally low for both methods. In 1996 Johansson constructed site index curves for European aspen (*Populus tremula* L). growing on forest land of different soils in Sweden. In 1996 Elfring and Nystrom investigated the stability of site index in Scots pine plantations over year of planting in the period 1960-1977. Long-term changes in site index were confirmed by Eriksson and Karlsson (1996) in the case of Norway spruce and Scots pine in Sweden. In 1996 Elfving and Nystrom investigated the stability of site index in Scots pine plantations over year of planting in the period 1900-1977. Long-term changes in site index were confirmed by Eriksson and Karlsson (1996) in the case of Norway spruce and Scots pine in Sweden. Elfving and Kiviste (1997) developed site index equations for *Pinus sylvestris* L. using permanent plot data. They used three general methods for construction of site index equations (the guide curve model, the parameter prediction method and the difference equations method) testing three growth functions on data from 156 permanent plots. Functions and construction methods were compared with respect to residual variation (root mean square error, RMSE) from original data and the following results were obtained: the guide curve method: RMSE-0,56, difference equation method with the anamorphic formulation: RMSE-0,46, the difference equation method gave a higher RMSE: with polymorphic than anamorphic formulation. They also used Hossfeld function, the Tveite method and Mitscherlich function. In the same year (1997) Karlsson et al. determined site index and productivity of artificially regenerated *Betula pendula* and *Betula pubescens*. The average age of stands was 28.5 yr. (5-57) in 1992, average 51 was nearly 28 m and the site quality ranged from 5 to 11.4 m^3 ha-1yr-1.

Cited authors:

Attebring 1985, Elfving and Kiviste 1997, Elfving and Nyström, k. 1996, Ericsson and Karlsson 1996, Hägglund 1972, 1973, 1974, 1975a, 1975b, 1978, 1981: Hägglund and Lundmark 1977, Hägglund and Swensson 1982, Holmgren 1994, Jacobson 1986, Johansson 1996, Jonson 1914, Karlsson et al. 1997, Landsberg 1986, Lundmark 1974, 1986: Paterson 1956, Petterson 1955, Stridsberg 1956, Strömberg and Tegnhammar 1985, Zackrisson 1980.

3.6. Stand structure

Mattson published an early paper (1920) on stand density and density factors.

In 1929 Näslund established an useful relationship between height and d = dbh in a stand based on a parabola of second degree:

$$h-1.3=\frac{d^2}{(a+bd)^2} \quad \text{and} \quad \frac{d^2}{h-1.3}=z^2=(a+bd)^2 \qquad z=\frac{d}{\sqrt{h-1.3}}=a+bd$$

In 1935, in Sweden was proposed (Näslund 1935) the definition of top height or maximum height as the regression height of the tree with dbh equal to the arithmetic mean plus three times the standard deviation.

Distribution of trees by diameter categories was analyzed by Näslund (1936, 1937 - bimodal distribution) and later by Tham (1987/1988). The distribution of stems in diameter classes is influenced by the thinning method. In mixed spruce and birch stands the suitable distribution proved to be Johnson SB probability function (Tham 1987/1988).

Structure of mixed stands in central Sweden was investigated by Hagberg (1938) and spatial variation in stands was analyzed by Matérn (1960) who proposed a stochastic model to solve some problems of forest inventory. Johannsson (1961) described the natural establishment and development of some mixed conifer stands in Central Värmland.

Jakobsons (1970) established the correlation between the diameter of tree crown and other tree factors, especially the breast height diameter (dbh). In 1973 and 1976 Eriksson presented a competition models for trees after clearing (a volume equation for alder with three variables).

Björn Elfving developed in 1974 one of the earliest models for the description of the structure in unthinned stands of Scots pine.

An excellent monography of structure and function of northern coniferous forest with many references on Swedish forest ecosystems was published in 1980 (Persson, T. ed.).

Attebring proposed in 1987 the relative volume increment as a measure of stocking in forest stands. The relative volume increment is defined as the actual volume increment of a stand in percent of the reference increment" while "the reference increment is the 95th percentile of current annual volume increment in today's spruce [*Picea abies* L. (Karst.)] forest in southern Sweden". The percentiles are estimated with a non-parametric method from the National Forest Inventory (NFI) sample plots. Attebring determined functions for predicting relative increment, and independent variables in these functions are basal area, number of stems, age, yield capacity, stand history, stand structure and broadleaf percentage. The variable used to express stand structure is by definition the basal area of dominant and co-dominant trees in percent of total basal area of the plot.

The structure and thinning in the mixed spruce and birch stands in South and Middle Sweden were investigated by Tham (1987a, 1987b).

Comparisons and implications for forest succession modelling were completed by Prentice and Helmisaari (1991) who considered that "Forest succession models will gain reliability by eliminating unreliable descriptors such as maximum tree diameter, dealing appropriately with ontogenetic changes in key attributes such as shade tolerance and incorporating climate-response functions based on explicit physiological constraints" (p. 79). The imposition of a maximum tree size is not very realistic because heartwood has no respiratory cost. In Levin’s opinion (U.S.A., 1966) the biological models cannot be general, realistic, and precise, there can be only two of these things and not all of them together.

The structure of mixed stands determined also their quality from economical point of view. Analyzing the quality in mixed stands of Norway spruce and birch in Sweden Dahlgren and Thamm (1992) noted that: "the number of broad-leaved plants per hectare has increased dramatically in young forests during the last 20-30 years”. At the same time the number of conifers per hectare has decreased substantially and it should be taken into account that "The price ratio for pulp-wood is 1 for Norway spruce towards 0.75 for birch. The price ratio for timber is 1 for Norway spruce towards 1.5 for birch" (p. 462). To establish the more convenient proposition between spruce and birch remains a task for forest management.

An interesting investigation on the structure of boreal forests was completed by Linder and Ösland (1992). They discovered that during the last 150 years the standing volume of trees decreased as a result of large-scale exploitation of virgin forests. Forest structure has also changed. For instance, the proportion of forests older than 150 years decreased from 43.5 % in 1915 to 7 % in 1990. Stands are usually cut in Sweden at the age of 100-150 years but the natural lifespan of Norway spruce (*Picea abies*) is 250-400 years and that of Scots pine (*Pinus sylvestris*) 300-600 years. The number of trees with diameter at breast height more than 30 cm decreased more than 80 % during the last 100 years.

In a paper published in 1992 Bertie Matérn examined spatial statistics in forestry. He reviewed the methods which have been used or a quantitative description of the spatial pattern mentioning same mathematical models that have been used to simulate spatial patterns. Matérn concluded that: “Several early models were of an ad hoc type. Later modelling has been based on concepts and formulas taken from the theory of stochastic processes (in time and place). The French geostatistical school has developed a rich set of concepts and methods for spatial models" (Matérn 1992, p. 495).

Some other works of the 1990s will be mentioned shortly at the end of this text. Simulation and future projection of succession in a Swedish broad-leaved forest was completed by Leemans (1992). For modelling diameter distribution in Scots pine and spruce stands Maltama et al. (1995) used beta and Weibull functions. Influence of initial spacing on growth and yield of silver birch was investigated by Niemistö (1995).

Cited authors:

Attebring 1987, Dahlgren and Tham 1992, Erikson 1973, 1976, Hagberg 1938, Jakobsons 1970, Johannsson 1961, Levins-USA 1966, Leemans 1992, Maltano et al. 1995, Matérn 1960, 1992; Mattson 1920, Näslund 1929, 1936, 1935, Niemisto 1995, Persson 1980, Prentice and Helmisaari 1991, Tham 1987 a, 1987 b, 1987/1988.

3.7. Stand volume, growth and yield-conventional methods

Stand form factors and stand tables were in use in Sweden in 1916/1917 (Mattson 1916-1917).

According to Söderberg (1987/1988, p. 151), the regression analysis was first used by Petterson in 1932 and Näslund in 1935 to develop increment functions.

During the same investigations on thinnings Näslund (1935, 1936/1937) established a relation between heights (h) and dbh (d) in a stand which is similar to that mentioned before (1929-5.3.6.):

$$h-1.3=\frac{d^2}{b_0+b_1d+b_2d_2^2} \quad \text{or by transformation} \quad \frac{d^2}{h-1.3}=z=b_0+b_1d+b_2d_2^2$$

Matérn (1949/1951) advocated for the adoption of modern statistical methods in estimating forest areas, timber, volumes, growth and drain.

Petterson (1951) constructed yield tables for certain types of Swedish conifers. In the case of spruce his tables have four H100 classes, refer to stands of 18-106 years of age and at the age of 80-83 the dominant height ranges from 18.3 to 29.6 m and mean growth 5.5-11.3 m^3/year/ha. Other yield tables were constructed by Nilsson (1961) using the data of the National Forest Survey and Eriksson's (1976) yield tables for Norway spruce within an extensive study on this species in Sweden with six H100 classes for stands having 20-142 years and at the age of 81 years 13.3-29.3 mhdom and mean growth 1.2-11.7 m^3/year/ha.

Stridsberg (1953) mentioned the use of compound interest in the calculation increment percentage for periods of several years.

A valuable book on stand volume production (yield) was published by Petterson as a synthesis in 1955. In this book to fit height (h) curves he introduced the equation:

$$1/\sqrt{(h-1.3)}=b_0+b_1 \cdot \frac{1}{d},$$

where:

d = dbh which was frequently used by German mensurationists.

Yield studies in planted spruce in southern Sweden were carried out by Carbonnier (1954) and that on yield of mixed coniferous forests (the height and diameter growth of Scots pine and Norway spruce mixed in various proportions) by Jonsson B. (1962). In 1955 were published the instructions for the third Swedish National Forest Inventory (NFI). In connection with NFI, Stand (1957) pointed out the effect of the plot size on the accuracy of forest surveys and in

1959 he determined the accuracy of some methods for estimating volume and increment on sample plots.

In 1960 Matérn discussed some recent developments of forest surveys and the statistical theory of sampling.

Forest yield for different intensity of stand treatment was mentioned by Carbonnier in 1966, and in 1974 he presented preliminary results from a thinning experiment in a Norway spruce plantation, in 1969 a detailed comparison between the volume and value of the yield from beech and Norway spruce. Jonsson (1974) proposed a method for yield prognosis.

New data for forest yield research on pine, spruce and birch became available in 1971 (Näslund).

In "Analyses of growth and yield" (Erriksson et al. 1984) edited by K. L. Perth and dedicated to professor Gustaf Sirén for his contributions in the field of biomass research, some papers refer to yield and growth such as: Yield of aspen and poplars in Sweden.

A method for predicting forest yield after drainage and fertilizer application was presented by Hänell (1984). Axelsson (1986) analyzed differences in yield at different sites within an irrigation-fertilization study of nutrient flux during fast growth.

Predicting individual tree growth in managed stands of mixed: *Picea abies, Betula pendula*, and *B. pubescens*, in connection with competition indices (APA procedure) Tham (1989) considered that mixed stands may require weight adjustment for each species.

Ranneby and Rovainen (1994) in a theoretical study in Nordic forests considered that not too long intervals (5 years) offer more reliable estimates of volume increment and it is advisable to measure once every five years because an extension from 5 to 10 years increases variance by 5-13 %.

Since the start of the first National Forest Inventory (NFI) in 1923 Elfving et al. (1955), and Elfving and Tegnhammar (1996) noticed a steady increase in estimated productivity of Swedish forests. "Young stands generally indicate higher site indices than old stands at equal site conditions. For spruce this rise of site index has been estimated to 0,05-0,11 m year^{-1} and they considered that there are two alternative explanations for this phenomenon: (1) change of forest structure due to altered silviculture, by “altered silviculture” it is altered the way of cutting from selective cutting to clear felling on thinning from below, genetic improvement, different site treatments and (2) “A long-term rise of natural site productivity is taking place as a result of increasing atmospheric nitrogen deposition (which) is suspected to have the biggest influence" (Elfving et al. p. 274).

In 1997 Bergh analyzed climatic and nutritional constrains to productivity in Norway spruce in boreal Swedish forests based on four papers including an appendix in which he refers to effects of global warning on net primary production at different nutrient levels (BIOMASS model for simulation was used): (1) climatic factors, (2) seasonal variation of maximum photochemical efficiency, (3) effects of soil warming, (4) effect of water and nutrient availability.

Cited authors:

Axelsson 1986, Bergh 1997, Carbonnier 1954, 1966, 1969, 1974; Elfving and Tegnhammar 1996, Elfving et al. 1995, Eriksson 1976, Eriksson et al. 1984, Hånell 1984, Jonsson 1962, 1974; Matérn 1949/1951, Mattson 1916/1917, Näslund 1935, 1936/37, 1971, Nilsson 1961, Perttu ed. 1984, Petterson 1951, 1955; Ranneby and Ravainen 1994, Strand 1957, 1959; Stridsberg 1953, Sweden 1955, Tham 1989.

3.8. Growth and yield: modelling, simulation, forecasting. Computerized models

In 1973 the International Union of Forest Research Organizations (IUFRO) held a Working Group Meeting S4-01-4, in Stockholm, on "Growth models for tree and stand simulation; the proceedings of the meeting were published next year (J. Fries ed.). This meeting stimulated the development of modelling in Swedish forest mensuration.

In 1976 Bergstrand and Nilsson developed a long range forest models (unpublished) and Jonsson (1977) developed a growth model as a basis for long-term forecasting of timber yields (also unpublished).

In 1978 Bengtson presented the main features of HUGIN - a Swedish research project developing methods for long-term forecasting of timber yields. This model was a 65-mean-year research project developed within the College of Forestry in Sweden with the purpose to develop and evaluate methods for long-term forecasting of timber yield. The main goal was to develop a computerized simulation system for forecast at national or regional level, using the data from the National Forest Inventory and it was emphasizing that it was necessary to use data from inventory experimental plots as a basis for growth functions. On the other hand, it should be remembered that Hugin was the name of a wise bird (raven) in the Old Swedish mythology. The Hugin project started in 1975 and was finished in 1980. The main output of the Hugin project was proposed to be: (1) annual yield (increment and mortality) in each decade, (2) size and composition of the cut in each decade (areas and volumes), and (3) the actual forest resources of ten years intervals (area distribution, volume and structure of the growing stock).

Eriksson (1978) proposed single-tree competition models for predicting stand development after cleaning.

Jonsson (1978, 1980) developed functions for long-term forecasting of the size and structure of timber yields.

Hägglund (1981) examined forecasting growth and yield in established forests, an outline and analysis of the outcome of a subprogram within the HUGIN project. Hägglund averaging yields from individual plots observed that “for uniform even-aged stands projections of the stand mean provided the same estimate as averaged projections of each individual plot. However, these results apply only to homogenous, well-managed stands inventoried using objective and accurate methods and cannot apply under other circumstances" (Vanclay's opinion, 1994, p. 235).

Landsberg (1981) discussed the problem of the "Number and Quality Growth", whereas Hart and Kellomäki (1981) presented modelling of the functioning of a tree in a stand. Gardner et al. (1983) developed the PRISM: a systematic method for determining the effect of parameter uncertainties on model predictions.

In "Analyses of growth and yields" (Perttu 1984, ed.) are presented models like the following: "Mathematical modelling of energy for forest growth: an outline”; "Modelling potential energy forest production", "Simulation model for photosynthesis and growth in short-rotation plantations".

Agestam (1985) developed a growth simulator for mixed stands in Sweden presenting two examples of yield in birch-pine and birch-spruce stands.

A growth simulator based on data from Swedish National Forests Survey was developed by Ekö (1985) and Eriksson constructed a model for predicting log yield from stand characteristics (1987).

Söderberg (1987/1988) described a method of constructing functions for long-term forecasting of timber yields and as in other cases his functions are based on sample trees from National Forest Inventory. Söderberg estimated individual tree growth from five-year "normal" basal area increment over bark. Volume and volume increment was estimated using form height functions and a study of tree mortality, based on unthinned permanent plots was employed; he also constructed a growth simulator. This model determined growth satisfactorily (standard deviation between observed and estimated growth is about 10 %).

Tham (1988) developed stand volume functions for young mixed stands of Norway spruce, silver birch (*Betula pendula* Roth) and European birch (*B. pubescens* Ehrh).

In 1997 Nyström and Kexi constructed individual tree basal area growth modules for young stands of Norway spruce, models forming part of the

HUGIN young stand survey. The authors observed that models based on a distance-dependent competition index and tree age explained about 79 % of the variance in basal area increment and models without distance-dependent competition index and tree age explained 74 %. It is interesting the fact that the inclusion of tree age in the models accounted only for about 3 % of the explained variation whereas the competition index accounted only about 2 % of the explained variation in basal area growth.

Cited authors:

Agestam 1985, Bengtsson 1978, Bergstrand and Nilssan 1976, Ekö 1985, Eriksson 1978, Eriksson and Sallnas 1987, Fries (ed.) 1974, Gardner et al. 1983, Hägglund 1981, Hari and Kellomäki 1981, Jonsson 1977, 1978, 1980; Landsberg 1981, Nyström and Kexi 1997, Perttu (ed.).1984, Söderberg 1987/1988, Tham 1988, Vanclay (Denmark) 1994.

3.9. Weight and biomass studies

The 1950s studies refer especially to weight measurement of pulpwood (Nylinder 1958, 1967).

In the frame of ecological studies in a Scanian woodland and meadow area in southern Sweden, Andersson (1969, 1970) determined plant biomass, primary production and turnover of organic matter. In the next year (1971) Tamm estimated primary production and turnover in a spruce forest ecosystem with controlled nutrient status. The methodological aspects concerning collecting data for biomass equation development were discussed in a short paper by Marklund (1983). In the same time Nilson (1983) derived allometric equations for determination of current leaf area of leaves from coppice willow stand (*Salix viminalis*).

In "Distribution of biomass and species" Elowson et al. (1984) determined distribution of biomass within willow plants (*Salix viminalis*) growing on a peat bog. Albrektson (1984) determined the relationship between foliage mass and sapwood basal area in the case of Scots pine.

Biomass functions for Norway spruce (1987), Scots pine and birch (*Betula verrucosa* and *B. pubescens*) were developed in 1987 and 1988 by Marklund. Parikka (1997) proposed BIOSIM - a method for the estimation of woody biomass for fuel in Sweden. This method uses stand data or sample plot data from National Forest Survey (NFS) and applies ecological restrictions based on variables like soil and vegetation classes calculating woody biomass from biomass functions established for the main species, or the ratio method.

Cited authors:

Albrektson 1984, Andersson 1970, Elowson et al. 1984 (Perttu K. L. ed.), Marklund 1983, 1987, 1988; Nylinder 1958, 1967; Nilsson 1983, Parikka 1997, Tamm 1971.

3.10. Tree-ring studies

Amilon's (1910) and Wallen's (1917) papers on radial growth could be considered as the earliest Swedish studies connected with tree rings.

On the other hand, De Geer's studies (1931, 1939, 1940) in the fields of geochronology and biochronology stimulated the appearance of the first dendrochronological investigations such as Erlandsson's (1936) studies presented in his Ph. D thesis, at the University of Uppsala. A few information on tree-ring work in Scandinavia were provided by Edmund Schulman (1944) from the U.S.A. and close Douglass associate - the founder of American school of dendrochronology.

In 1942 Näslund proposed an original method for the elimination of the influence of age-decrease for annual ring series using regressive analytical means. This method "consists in reproducing the declining tendency of the age-decrease by a function ... the constants of which are obtained by numerical adjustment of the annual ring series according to the method of least squares, after which the observed mean annual ring widths for each of the calendar years included in the investigation are placed in relation with that calculated according to the function, whereupon a so-called annual ring index is obtained. This is independent of the absolute size of the annual ring-widths and constitutes an approximate expression for the calendar year's property as a good or bad growing year with respect to the increase in diameter. An index value of 100 years represents a normal year, whereas an index figure of 120, for example indicates that the annual ring width is 20 % greater than the normal" (Eklung 1954, summary in Tree-Ring Bulletin vol. 21, 1956, p. 21).

In 1949 Bo Eklund presented the development, construction and use of the Forest Research Institute machine for measuring annual rings, which represented a great contribution to the improvement of tree-ring studies in the world.

In 1954 Eklund published a detailed work on variations in the widths of the annual rings in pine and spruce due to climatic conditions in northern Sweden during the 1900-1944 period. The paper refers to annual ring index series for pine and spruce for different geographical areas, provinces, latitude groups, altitudes, degrees of stand density and degrees of moisture, statistical methods being used on large scale.

Schove (1954) tried to connect summer temperatures and tree-rings in North-Scandinavia A.D. 1461-1950, and the similar work concerning the annual ring variations in spruce in the centre of northern Sweden and their relation to climatic conditions was completed by Eklund in 1957.

A comprehensive work was carried out by Jonsson (1969) who studied variations in the widths of annual rings in Scots pine and Norway spruce due to weather conditions in Sweden.

Hari and Sirén (1972) established influence of same ecological factors and the seasonal stage of development upon the annual ring width and radial growth index. The total annual ring indices for Norway spruce and Scots pine in different region of Sweden during the period 1911-1968 were determined by Jonsson (1972). The methodological aspects of the competition of annual ring indices were developed later (1978) by Jonsson and Matérn using a stochastic model.

Barthholin's (1975) work on dendrochronology of oak in southern Sweden was probably the first in the country for *Quercus* sp. and the chronology of this area is similar to that for southern Denmark.

The problem of xylem modelling was analyzed in 1981 by Ford.

Among the more recent works in the field of tree-rings will be mentioned Weslien's (1995), a paper on missing growth rings in branches of Scots pine, useful for self-pruning studies.

Cited authors:

Amilon 1910, Bartholin 1975, De Geer 1931, 1939, 1940; Eklund 1949, 1954, 1957; Erlander 1936, Ford 1981, Hari and Sirén 1972, Jonsson 1969, 1972; Jonsson and Matérn 1978, Näslund 1942, Schulman 1944 - U.S.A., Shove 1954, Wallén 1917, Weslien 1995.

3.11. Forest inventory: sampling, remote sensing and GIS

The early local groundwork for pilot forest inventories was performed in Sweden in 1911.

Forest inventories on national scale (NFI) began in 1923 and the annual NFI work covers all the country for every year since 1953. The following cycles of years have been completed up till 1953: 1923-1929, 1938-1952, 1953-1962, 1963-1972, 1973-1982, 1983-1992, and the last inventory began in 1993. Information on these inventories (with reference to different periods) have been published by Ostlin (1929), Thorell and Ostlin (1931), Tersmeden (1954), Hagberg (1967), Bumbu and R. Dissescu (1966), Hägglund (1983), Eriksson (1985), Hägglund (1985), Bengtsson (1987), Svensson (1989) and Söderberg (1997).

The works of NFI were carried by National Forest Survey Board and transferred in 1943 to the Forest Research Institute - later merged with the Institute of Forestry Training. This complex has been the core of a separate faculty of the Swedish University of Agricultural Sciences since 1977. The inventory unit is called the” Department of Forest Survey” (Nyyssönen 1993, p. 29).

The most important data produced by NFI are summarized by Bengtsson (1987) and Nyyssönen (1993) as follows:

- land use and forest site classes;
- growing stock (area and volume) by tree species diameter and quality class, and age and development class;
- annual increment of the growing stock;
- silvicultural condition and treatment needs.

In most cases, like in Finland and Norway, the basic method was systematic sampling from the ground. Strip surveys (parallel lines across the predominant configuration of the ground) were used in the earliest surveys in Sweden. In 1945 line strip survey was replaced by line plot sampling, and in 1953 a cluster sampling system was adopted.

Nyyssönen (1963) considered that the Swedish system of inventory on “the whole country to be covered every year” has more advantages than the inventory”county by county” applied in Finland and Norway” but its cost is higher.

Swedish forest inventories were exclusively based on mathematic statistical methods.

In the 1930s the standard error in strip surveys was investigated by Näslund (1930) and Ostlind (1932), while in 1939 Näslund computed the standard error in strips and plot surveying, and the methods of estimating the accuracy of line and sample plot surveying were presented by Matérn (1947) in a more detailed work which was summarized in 1949.

Lisdaniel (1947) analyzed in detail the size and spacing of sample plots in strip surveys.

In NFI, for forest area and mean volume estimated, the accuracy was 0.5 % and 0.7 % for total volume (Eriksson 1985).

Matérn (1947, 1960) underlined that accuracy of forest inventory is influenced by the stand structure.

Spatial variation, stochastic models and their application to some problems in forest surveys and other sampling investigation was analyzed and published by Matérn in 1960.

Since 1950 a few opinion were expressed on other type of forest inventory methods. In 1950 Patterson presented sampling on successive occasion with partial units, in 1952 Hagberg referred on a new model for FNI and Perssons described distance methods. Sampling at the forest edge was examined by Schmid P. (1982). Hägglund and Bengtsson developed plans for “a new national forest survey in Sweden”.

Permanent sample plots were adopted in Swesen on national scale since 1983 due to the interest in monitoring forest health indicators (Nyyssönen 1993, p. 32).

The methodology of the sixth national forest inventory (1983-1992) was improved taking into account “theoretical and practical aspects such as permanent plots, variables recorded, the system of data acquisition, results from field tests and statistical background of the new design” (Ranneby, Cruse, Hägglund, Jonasson and Swärd (1987. For. Abs. 3080/1987).

In 1991 Ranneby and Svensson were speaking “of sample tree data to images of tree populations”, and in 1995 Ranneby and Rovainen discussed the determination of time intervals between remeasurements of permanent plots within the framework of sampling with partial replacement (SPR) concluding that it is possible to extend this interval from five to ten years but in this case the variance will increase by 5-13 %; if the clear-cut plots are included in a separate stratum a considerable gain in precision may be obtained (15-20 %).

Remote sensing as aerial photographs was used in Sweden, by the Service of Forestry, at least since the 1950s (Kommitén för Skoglig Fotogrammetri published in 1951 a detailed textbook (196 pp) in this field.). Haider (1952) and Hagberg (1953) presented the use of “aerial photogrametry in forest surveys and mapping. In 1952 it was possible to estimate the mixture of species, tree height, stand density and volume with the help of air photographs. The Swedish Committe for Photogrametry published in 1955 a textbook on the interpretation of aerial photograps. In 1950s the use of aerial photographs was of large concern in the field of forestry: Alexon (1956), Hagberg (1956), Francis (1956), Sädertröm (1958).

The results of an early investigation on the diffuse reflection capacity of leaves and needles of different species were published in 1953 by Bäckström and Welander. Later (1986) Kelman measured the special reflectance of stands of Norway spruce and Scotch pine, measured from a helicopter.

In 1997 Holmgreen, Thuresson and Holm estimated forest characteristics in scanned aerial photographs with respect to requirements for economic forest management planning. They used digital high-altitude aerial photographs (stereo pairs of panchromatic and near infrared photographs) and circular plot data from a forest of about 100 ha located in northern Sweden. “Volumes, species mixture and harvest priorities were estimated using regression analysis based on textural and spectral information from aerial photographs” (For. Abs. 265/1998).

The situation of remote sensing (RS) in Swedish forestry was summarized in 1986 by Lepoutre, Leprieur and Peyron, with comments on RS use in France.

Satellite imagery (especially of Spot satellite) was used since 1987 on a larger scale for forest, inventory, updating of forest inventory, mapping and change monitoring (Jaakkola, Johansson, Hagner-1987; Johanson 1987; Jaakkola, Poso, Skråmo 1988).

Linder and Öslund (1992) established changes in the boreal forests during 1987-1991 period and discovered that the standing volume was less than 120 years ago.

A new airborne technology revealed that helicopters equipped with the GPS (global positioning system) are an efficient aid for forest surveys and the updating of forest data (Johansson and Eriksson 1995- For. Abs.4458/1996). According to Johansson (1995) Sweden is the first country that established a national service for real time correction of GPS data considering (among other reasons) the bright prospects of its use in forestry. With the help of GPS is possible to: "(a) provide guidance to harvesters in a logging tract; (b) locate sample plots, (c) identify positions quickly; and (d) produce sketch maps for planning (For. Abs. 1142/1997).

In 1996 volume and forest cover was estimated over southern Sweden using AVHRR data calibrated with Landsat Thematic Maper.

Nilsson (1997) estimated forest variables in the Swedish NFI using satellite image data and airborne lidar. The purpose of the study was the investigation of different sensors and methods, and the possibilities of their use in National Forest Inventory. In this paper are reported five studies on airborne lidar, NOAA AVHRR data and Landsat data. The conclusion of researches confirmed that remote sensing data can be integrated in the Swedish national forest inventories for estimation of stand volume (also in local and regional inventories), and tree heights when airborn lidar system is used. Volume and forest cover was reasonably estimated over southern Sweden when AVHRR data were calibrated with TM data.

In 1999 Brandtberg presented an automatic individual tree based analysis of high spatial resolution (pixel size 10 cm) and discussed the use of modern computer technology.

Walter (1999) described extraction of forest stand parameters from CARABAS VHF SAR images. Walter's text summarized "the result of height studies in which methods were developed and evaluated for extracting standwise forest parameters from images of five forest sites in Sweden. CARABAS is a unique airborne synthetic aperture radar (SAR) developed by the Swedish Defence Research Establishment; for forest stands and near horizontal ground the results for estimating stem volume, stem diameter, and tree height from CARABAS image data are very satisfactory. The root mean square errors for the estimates are comparable to those of subjective ground-based inventories for dense forest stands “(For. abs. 2786/2000).

Ekstrand (1996) used the Landsat TM for assessment of forest damage in a Norway spruce forest located in southwestern Sweden.

Since the middle 1990s Swedish forestry has been oriented toward multi resource inventories - MRI (Söderberg 1997) and during 1997 MRI questionnaires were completed (Merkell 1997, Noren 1997- for woodland habitats; Persson 1997 - for reinder/forest survey; Rudqvist 1997- for wetlands). A general MRI questionnaire for Sweden was prepared by Tomter from the Norwegian Institute of Land Inventory.

Cited authors:

Axelson 1956, Bäckström and Welander 1953, Bengtsson 1987, Brandtberg, T. 1999, Bumbu and R. Dissescu 1966, Ekstrand 1996, Eriksson 1985, Fazakas and Nilsson 1996, Francis 1957, Hagberg E. 1952, 1957; Hagberg and Tersmeden 1954, Hagberg N. 1953, 1956; Hägglund 1983, 1985; Hagglund and Bengtsson 1980, Haider 1952, Halmgren, Thuresson, Holm 1997, Jaakkola, Johasson and Hagner 1987, Jaakkola, Poso and Skråmo 1988, Johasson 1987, Johansson and Eriksson 1995a, 1995b; Kommitén för Skoglig Fotogrammetri 1951, 1955; Kleman 1986, Lepoutre, Leprieur and Peyron 1986, Linder and Östlund 1992, Lisdaniel 1947, Matern 1960, 1947.1949; Merkell 1997, Näslund 1930, 1939; Nielsson 1997, Noren 1997, Nyyssönen 1963, 1993; Östlin 1929, Ostlind 1932, Patterson 1950, Persson 1997, Perssons 1965, Ranneby and Rovainen 1995, Ranneby and Svensson 1991, Ranneby, Cruise, Hägglund, Jonasson and Swärd 1987, Rudquist 1997, Schmid P. 1982, Söderberg 1997, Söderström 1958; Svensson, Toet and Kempe 1989, Thorell and Östlin 1931, Tomter 1997, Walter 1999, Welander 1952.

3.12. Chronology of the selected events

1903: First attempt to express the stem form by an equation (A. G. Hojer).

1904: Early Swedish investigations on tree growth (H. Hesselman).

1910 - 1912: Tor Jonsson's investigations on tree stem form.

1911: First Swedish volume tables for pine growing in normal stands (A. Maass).

1911: The early ground works for pilot forest inventories (A. Nyyssönen 1993)

1914: "Intensity" and relative volume index = volume/(height*intensity), intensity = ratio of volume to height in fully stocked stands, as measure of stand stocking (Tor Jonson).

1915, 1926, 1928: Volume tables for many Swedish trees constructed on the basis of taper curves (Tor Jonson).

1916/1917: The use of stand form factors and stand tables in Sweden (L. Mattson).

1920: Stand density and density factors (L. A. Mattson).

1923-1929: The first national forest inventory based on strip survey method (A. Nyyssönen).

1929: Relationship between height and dbh based on a parabola of second degree (Manfred Näslund).

1930: An early work on computing the standard error in strip survey (M. Naslund).

1931: Information on the first and second national forest surveys in Sweden (K.E. Thorell and E.O. Östlin).

1932: The necessary survey percentage when line-surveying a forest (J. Ostlind).

1935, 1938: The first use of regression analysis to develop increment functions (M. Näslund (1935) and H. Petterson (1938).

1939: Determination of stem form of pine using the diameter at 2, 3 meters above ground (A. Maass).

1940-1941, 1947, 1957: Volume tables based on functions with coefficients determined using multiple correlation method (M. Näslund).

1940s, 1950s: Use of punched cards and IBM computers for tree and stand volume determination in Swedish Forest Inventories.

1942: A method for elimination of influence of the age decrease for annual ring series (M. Näslund).

1945, 1953: Transition from strip survey in forest inventories (1945) to line-plot sampling and adoption of a cluster sampling pattern in 1953 (A. Nyyssönen).

1947: Determination of the size and spacing of sample plots in strip surveys (O.M. Lisdaniel).

1947: Methods of estimating the accuracy of line and sample plot surveying (B. Matérn).

1949: A machine for measuring annual rings (Bo Eklund).

Since the 1950s: The development of site index curves for Swedish forest species [H. Petterson - 1951. (yield tables), B. Hägglund 1972, Björn Nilson - 1961 (yield tables), H. Eriksson - 1976 (yield tables)].

1951: Yield tables for certain types of Swedish conifer (N. Petterson).

1951: A textbook on the use of aerial photographs in forestry (Kommitén för Skogling Fotogrammetri).

1952: A detailed work on variations in the width of the annual rings in pine and spruce due to climatic conditions in northern Sweden during 1900-1944 period (Bo Eklund).

1953: An early investigation on the diffuse reflection capacity of leaves and needles of different species (H. Bäckström and E. Welander).

1953: The annual work in NFI was adopted on the level of the whole country (A. Nyyssönen).

1955: A textbook on the interpretation of aerial photographs (Kommitén för Skogling Fotogrammetri.

1960: Investigation on spatial variation, and stochastic models and their application to some problem in forest surveys and other sampling investigations (B. Matérn).

1965: The use of multivariate methods for the construction of tree taper curves (J. Fries and B. Matérn).

1969: Variations in the width of annual rings in Scots pine and Norway spruce of annual rings conditions in Sweden (B. Jonsson).

1971: Electrical methods for measuring changes in shoot length and stem diameter (H. Odin and Openshaw).

1972: Total annual ring indices for Norway spruce and Scots pine in different regions of Sweden during the 1911-1968 period. (B. Jonsson).

1975, 1978: The main features of HUGIN - a Swedish research project developing methods for a long-term forecasting of timber yields. The project was started in 1975 (presented by Göte Bengtsson).

1975: Use of simulation for estimation of accuracy of site index curves (B. Hägglund).

1975: A relationship established between dominant height, site index and Jonson's site classes. (B. Hägglund).

1976, 1977: Early models for long-term forecasting of timber yields (Bergstrand and N. E. Nilsson - 1976, B. Jonsson - 1977).

1978: A site quality evaluation system-under development – based on dominant height at a fixed reference age (as in the U.S.A.), called HUGIN model (B. Hägglund).

1978, 1980: Functions for long term forecasting of the size and structure of timber yields (B. Jonsson).

1978: Methods for computation of annual ring indices using a stochastic model (Bengt Jonsson and Bertie Matérn).

1983: Permanent sample plots in NFI were adopted in Sweden on a national scale (A. Nyyssönen).

1984, 1986: Methods for predicting forest yield after drainage and fertilizer application (B. Hänell - 1984; B. O. Axelsson - 1986).

1985: A growth simulator for mixed stands in Sweden: birch+pine and birch+spruce (E. Agestam).

1985: Site variables as indicators of site index in beech stands. A pilot study (L. Strömberg and L. Tagenhammar).

1986: The spectral reflectance of stands of Norway spruce and Scotch pine was measured from a helicopter (J. Kleman).

1986: A remarkable textbook on functions for forecasting of timber yields, increment and form height for individual trees of native Swedish species (Ulf Söderberg).

1987: Relative volume increment as a measure of stocking in forest stands (Jan Attebring).

1987: A one-hand calliper for thinnings (Arne Jansson and Pellbo Krylbo).

1987, 1988: Biomass functions for Norway spruce, Scots pine and birch (L. G. Marklund).

1987: Applicability of Spot for forest inventory, mapping and change monitoring (S. Jaakkola, L. Johansson and O. Hagner).

1987: Classification of land-use classes and forest land using satellite data. A procedural study for Swedish national forest inventories (H. Jonasson).

1987: A design for a new national forest survey: a summary of work on methodology that preceded the introduction of the Sixth National Forest Survey of Sweden (B. Ranneby, T. Cruse, B. Hägglund, H. Jonasson, J. Swärd).

1989: Presentation of the Swedish national forest inventory 1978-82: condition of forest, increment and logging (S. A. Svensson, H. Toet, G. Kempe).

1990s: Mantax Computer calliper, instrument of last generation constructed by Swedish firm Haglöf.

1992: Spatial statistics in forestry (B. Matérn).

1992: Structure changes in the boreal forests of Sweden (P. Linder, L. Östlund).

1995: 1996: Trends in the productivity of Swedish forests (B. Elfving, L. Tegnhammer and Björn Tweite - 1995, B. Elfving and L. Tegnhammar - 1996).

1995: Bright prospects for global positioning system-GPS in Sweden the first country to have established a nation wide service for real time correction of GPS (S. Johansson and I. Eriksson).

1996: An inventory of modern equipment for electronic recording and transfer of field data (L. Hömsten and C. Hellström).

1996:Assessment of forest damage using Landsat TM imagery (S. Ekstrand).

1997: Site index equations for Pinus sylvestris (B. Elfving and A. Kiviste).

1997: Different methods of measuring knot parameters - X-ray included (J. Oja).

1997: Multiresource inventory (MRI) questionnaire for Sweden (Björn Merkell).

1997: Estimation of forest variables using satellite image data and airborne lidar (M. Nilsson).

1999: Extraction of forest stand parameters from CARABAS VHF SAR images. CARABAS is a unique airborne synthetic aperture radar (SAR) developed by the Swedish Defence Research Establishment. (F. Walter).

3.13. Selected contributors

In chronological order:

Author	Printing years	Field(s)
A. G. Hojer	1900s (1903)	1
H. Hesselman	1904	1
Tor Jonson	1910s-1920s	1, 2
A. Maass	1900s-1930s	1
L. Mattson	1910s-1920s	1, 3
S. Petrini	1910s-1920s	1
H. Petterson	1920s-1950s	1, 4
Manfred Näslund	1920s-1990s	1, 4, 2, 3, 6, 7
Lars Tirén	1920	1, 2
N. Hagberg	1930s-1950s	1, 3, 4, 7
Bo Eklung	1940s-1950s	6
E. Hagberg	1950s	7
C. Carbonnier	1950s-1970s	4
Bertie Matérn	1950s-1990s	1, 3, 4, 7
L. Strand	1950s	4
Aarne Nyyssönen	1960s, 1990s	7
Bengt Jonsson	1960s-1970s	4, 6
Björn Hägglund	1970s-1980s	2, 4, 7
L. G. Marklund	1980s	5
Bo Ranneby	1980s-1990s	7
Ulf Söderberg	1980s-1990s	1, 4, 7
Åsa Tham	1980s	3, 4
Björn Elfving	1990s	4, 2

1 = tree and primary products; 2 = forest site evaluation; 3 = stand structure; 4 = growth and yield, 5 = weight and biomass; 6 = tree-ring studies; 7 = forest inventory.

3.14. Comments

Since the beginning of the 20th century Swedish forest mensuration has had a strong mathematical statistics orientation exemplified by the first mathematical expression of stem form (Hojer 1903). Works on statistical methods, a lot of them published in Sweden, influenced this methodological orientation: Charlier (1920), Eklund (1941), Weibull (1951), Jeffres 1953, 1960.

Tree form studies, growth and yield, and forecasting on long-term of country forest yield-based on national forest inventories represented the major fields of Swedish forest mensuration and this can be seen in the subject of the "Four lectures on forest biometry" given by Bertie Matén in April 1983 (published in 1984) in Beijing at the Forest Research Institute of Chinese Academy of Forestry: (1) Statistical methods of forest research, (2) Geometrical probability and forest mensuration, (3) On mathematical models in forestry, and (4) The development of sampling methods in forestry.

A high attention was paid in Sweden to modelling, especially to complex models such as HUGIN and other models for long term forecasting.

For a long time volume per hectare, and later Thor's "intensity" index, were used together with dominant height as criteria for forest site productivity evaluation. One of the earliest European tree-ring studies had been completed in Sweden (Erlansson 1936) - before German studies were carried out by Hustich.

Since 1923 forest inventory on national scale became of a major concern and Sweden can be considered as one of the most advanced European countries in this field. Swedish contributions to NFI are notable and include the use of aerial photography and satellite imagery, GIS and especially GPS (global positioning system). Sweden was the first country that established a national service for real time correction of GPS. A special mention deserves the CARABAS - a unique airborne synthetic aperture radar (SAR) developed by the Swedish Defence Research Establishment used for extraction of forest stand parameters (1999).

The trends in the last two twenty years periods (1960-1980/1981-1999) are increasing in the fields of tree mensuration, forest inventory, stand structure, growth and yield, weight and biomass, and decreasing in the fields of tree-ring studies and remain at the same level in the field of stand structure.

The period(s) of maximum selected works:

Tree	1901-1940
Site evaluation	1961-1980 and 1981-1999
Stand structure	1981-1999
Stand growth and yield	1981-1999

Weight and biomass	1981-1999
Tree-ring studies	1941-1980
Forest inventory	1960 -1999

The following is the repartition by subjects of the cited papers (252) which refer to the 1903-1999 period:

(3.1) Tree and log measurement……………………………………4 %
(3.2) Tree form……………………………………………………11 %
(3.3) Tree volume tables and equations…………………………......7 %
(3.4) Tree growth……………………………………………………6 %
(3.5) Evaluation of forest site productivity…………………………..10 %
(3.6) Stand structure…………………………………………………..9 %
(3.7 and 3.8) Stand volume, growth and yield including modelling…19 %
(3.9) Weight and biomass studies ……………………………………4 %
(3.10) Tree ring studies ………………………………………………7 %
(3.11) Forest inventory: sampling, remote sensing GIS and GPS……23 %

Out of 252 references 34 % refer after 1980 and 16 % after 1990; 46.5 % of references cover 1981-1999 period.

Tree mensuration subjects prevailed during 1903-1950 period. After 1950 more attention has been paid to stand growth-yield and forest inventory problems.

The American system of site index based on dominant height at a fixed reference age was generalized in Sweden in the 1970s.

References

ALBREKTSON, A. 1984. Sapwood basal area and needle mass of Scots pine (*Pinus sylvestris*) trees in central Sweden. Forestry 57: 35-47.

AGESTAM, E. 1985. A growth simulator for mixed stands in Sweden and two examples of yield in birch-pine and birch-spruce mixed stands. Rapporter, Institutionen för skogsskötsel, Sveriges Lontbruksuniversitet 14: 235-252.

AGESTAM, E. 1985. En productiosmodelle för blandbest ånd av Zall, gran och björk i Sverige. (A growth model for mixed stands of Scots pine. Norway spruce and birch (*Betula pendula* and *B. pubescens*). Rapporter Instructionen för Skogsproduktion, Sveriges Lantbruksuniversitet, no. 15, 150 pp.

AMILON, J. A. 1910. Om Ziden för diametertillvaxtens borjan has barrtraden och orsakerna härtill (Spruce diameter growth). Skogsvåardsföreningens Tidskrift, 8, Stockholm.

ANDERSSON, F. 1969. Methods and preliminary results of estimation of biomass and primary production in a south Swedish mixed deciduous woodland. pp. 281-287. In: Productivity of forest ecosystems UNESCO Brussels Symposium, October 1969, ed. D. Duvigneaud, 1971.

ANDERSSON, F. 1970. Ecological studies in a Scanian woodland and meadow area, southern Sweden II. Plant biomass, primary production and turnover of organic matter. Botaniska Notiser 123: 5-51.

ANDERSSON, S. O. 1953. Om ridpunkten den årliga diametertillväxtens avslutande hos tall och gran. (On the date of completion of annual diameter growth in pine and spruce). Medd. Statens Skogsforskningsinst, 43, S: 1-27.

ANDERSSON, S. O. 1954. Funktioner och tabeller för kubering av småträd (Functions and tables for volume of small wood). M. S. S. 44: 12-29 pp.

ANONYMOUS. 1987. Enhandsklave för gallering (A one-hand calliper for thinnings). Skogen no. 1, 43.

ATTEBRING, J. 1985. Varför är gapet mellan tillväxt och bonitet så stort? En orienterande studie av skogarna i småland. (Why is the gap between increment and site productivity so large? An introductory study of the forests in Småland). SLU, Department of Forest Survey, Report 38, 49 pp.

ATTEBRING, JAN. 1987. Relativ volymtillväxt som mått på slutenhet i skogsbestand. (Relative volume increment as a measure of stocking in forest stands). Sveriges Lanthbruksuniversitet Repporter - Skog Repport 41, Institutionen för skogstaxiering, Umeå, 128 pp.

AXELSON, HANS. 1956. Effect of photo scale on the use of aerial photographs in Swedish forestry. Norrlands Skogsvårdsförbunds Tidskrift 3: 255-292.

AXELSSON, B. O. 1986. Differences in yield at different sites an irrigation-fertilization study of nutrient flux during fast growth. In: Gessel S. P. (ed.) "Forest site productivity". Martinus Nijhoff Publishers, Dordrecht, The Netherlands, pp. 171-183.

BÄCKSTRÖM, H. E. WELANDER. 1953. En undersökning av remissionsförmagan hos blad ach barr av olika trädslag. (An investigation on the diffuse reflection capacity of leaves and needles of different species). Norrlands SkogsFörb. Tidskr. 1953 (1): 141-169; For. Abs. 14: 3637.

BARTHOLIN, THOMAS S. 1975. Dendrochronology of oak in southern Sweden. Tree-Ring Bulletin. Vol. 35: 25-30.

BEHRE, G. H. 1923. Preliminary notes on studies of stem form. J. Forestry (U.S.A.): 507-511.

BENGTSSON, GÖTE 1978. HUGIN -A Swedish research project developing methods for long-term forecasting of timber yields. In : "Growth models for long-term forecasting of timber yields". Fries et al. eds., U.S.A. pp. 25-29. Publication FWS - 1-78 School of For. and Wildlife Resources, Virginia Polytech. Inst. and State Univ., Blacksburg, VA, 249 pp.

BENGTSSON, G. 1987. National report: Sweden. Proceedings of ad hoc FAO/ECE/FINNIDA meeting of experts on forest resource assessment. Bulletins of the Finnish Forest Research Institute 284, p. 259-266.

BERGH, J. 1997. Climatic and nutritional constraints to productivity in Norway spruce. Uppsala, Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae – Silvestria no. 37, 34 + 68 pp.

BERGSTRAND, K. G.; N. E. NILLSON. 1976. Long-range forest development models. (Stencil). College of Forestry, Stockholm.

BRANDTBERG, T. 1999. Automatic individual tree based analysis of high spatial resolution. Can. Jour. of Forest Research (1999) 29 (16): 1464-1478.

BUMBU, GH.; DISSESCU, R. 1966. Inventarierea de stat a pădurilor din Suedia (State forest inventory in Sweden). Rev. Pădurilor 2: 96-105.

CARBONNIER, C. 1954. Några exempel på produktionen i planterad granskog i södra Sverige. (Yield studies in planted spruce in southern Sweden). Medd. Stat. Skogsforskningsinst, 44, 1-59 pp.

CARBONNIER, C. 1966. Forest yield for different intensity of stand treatment. Sexto congreso forestall mundial, Madrid, Junio, 1966.

CARBONNIER, CHARLES, 1969 En jämförelse mellan bokenş och granens volym - och värdeproduktion (A comparison between the volume and value of the yield from beech and Norway, spruce). Av Charles Carbonnier och Björn Hägglund. Rapporter och uppsatser, Skogshögskolan, Stockholm, Sweden. Institutionen för Skogsproduktion, nr. 17, 95 pp.

CARBONNIER, C. 1974. Preliminära resultat fran ett gallringsförsök i planterad granskog (Preliminary results from a thinning experiment in a Norway spruce plantation). Rapp. Uppsatser Inst. Skogsprod. 29.

CHARLIER, C. V. L. 1920. Grundzüge der mathem. Statistik. (Fundamentals of mathematical statistics). Lund, Sweden.

DAHLGREN, TORBJÖRN; THAM ÅSA. 1992. Quality in mixed stands of Norway spruce and birch in Sweden. IUFRO XX World Congress (IUFRO Centennial), Proceed. Inv. Papers. p. 462.

DE GEER, E. H. 1931. Geokronologi och biokronologi. (Geochronology and biochronology). Ymer, 51: 249-312 Stockholm.

DE GEER, E. H. 1939. Kubbestolen frän Sauland II. Biokronologic datering. Fataburen pp. 123-130, Stockholm.

DE GEER, E. H. 1940. Geochronologia Suecica. Principles. Kungl. Swenska Vet. Akad. Handl. 18, no. 6, 367 p.

EKLUND, B. O. 1941. Om nomogratiska framställnigsmetoder och deras tillamping po nägra shogligt bettydelse fula functioner. (Nomographical methods....) Stockholm 1941.

EKLUND, B. 1949. Skogsforskningsinstitutes arsringsmatningsmaskiner: deras tillkomst, konstouktion och anvandring. (The development, construction and use of the Forest Research Institute's machines for measuring annual rings). Medd. Skogsforskn. Inst., 38 (5): 1-77, Stockholm, Sweden.

EKLUND, B. O. 1954. Arsringsbreddens klimatiskt betingade variation has tall och gran inom norra Sverige åren 1900-1944. (Variations in the width of the annual rings in pine and spruce due to climatic conditions in northern Sweden during the years 1900-1944). Medd. Statens Skogsforskninginstitut 44 (8): 1-150.

EKLUND, B. 1957. The annual ring variations in spruce in the centre of northern Sweden and their relation to the climatic conditions. Statens Skogsforskningsinstitut 47 (1): 2-63.

EKÖ, P. M. 1985. En produktionsmodell för skog i Sverige, baserad på bestånd från riksskogstaxeringens provytor. (A growth simulator for Swedish forests, based on data form from the national forest survey). SLU Department of Silviculture, Report 16, 293 pp.

ELFVING, BJÖRN. 1974. A model for the description of the structure in unthinned stands of Scots pine. C M 161-180 GM = "Growth Models for Tree and Stand Simulation IUFRO working party S4.01-4 Proceedings of meetings in 1973. Edited by Jöran Fries Institutionen för Skogsproduction, Department of Forest Yield Research. Repporter och Uppsatser/Research Notes no. 30. 1974. Skogshögskolan Royal College of Forestry S-10405 Stockholm, Sweden, 379 pp.

EKSTRAND, S. 1996. Landsat TM-based forest damage assessment: correction for topographic effects. PE&RS, Photogrammetric Engineering and Remote Sensing 62(2): 151-161.

ELFVING, B.; A. KIVISTE. 1997. Construction of site index equations for *Pinus sylvestris* L. using permanent plot data in Sweden. Forest Ecology and Management. 98 (2): 125-134.

ELFVING, B.; K. NYSTROM. 1996. Stability of site index in Scots pine (*Pinus sylvestris* L.) plantations over year of planting in the period 1900-1977 in Sweden. In: "Growth Trends in European Forests". H. Spiecker et al. eds., pp. 71-78, Springer.

ELFVING, B.; L. TEGNHAMMAR. L. 1996. Trends of tree growth in Swedish forests 1953-1991: an analysis based on sample trees from the National Forest Inventory. Scandinavian Journal of Forest Research 11 (1): 26-37.

ELFVING, BJÖRN; LARS TEGNHAMMER; BJÖRN TVEITE. 1995. Growth trends of forests in Sweden and Norway. IUFRO XX World Congress, Tampere - Finland, Inviting Papers, p. 273.

ELOWSON, S; L. RYTTER; T. ERICSSON; H. KORSMO. 1984. Distribution of biomass and species. In: Ecology and management of forest biomass production systems. Papers dedicated to Professor Gustaf Sirén for his contributions in the field of biomass research (edited by Perttu, K. L. Repport Institutionen för Ekologi och Miljövård, Sveriges Lanntbruksuniversitet (1984), no. 15: 325-360.

ERIKSSON, B. 1985. The Swedish national forest inventory. In: National Forest inventory in Europe edited by P. R. Pelz and T. Cunia. Mitteilungen der Abteilung für forestliche Biometrie 85-3, Univ. Freiburg. p. 36-70.

ERIKSSON, H. 1937 a. Tree volume functions for ash, alder, and lodgepole pine in Sweden, Dep. of For. Yield Res. Note 26.

ERIKSSON, H. 1973 b. Competition models for individual trees after cleaning, Inst. f. Skogsteknik, no. 99.

ERIKSSON, H. 1976. Granens production i Sverige (Yield of Norway spruce in Sweden). Inst. f. Skogsproduktion Rapp. och Upps. 41: 1-293.

ERIKSSON, H.; P. HARI; H. AROVAARA; P. J. KOVALIK; L. O. NILSSON; K. PERTUU; H. ECKERSTEN; L. SENNERBY-FORSE; B. BERGGREN; L. BRUNKENER; I. FIELL; R. SIEVÄNEN. - K. PERTUU editor 1984. Analyses of growth and yields. In: Ecology and management of forest biomass production systems. Papers dedicated to Profesor Gustaf Sirén for his contributions in the field of biomass research. Rapport, Institutionen för Ekologi och Miljovard, Sveriges Lantbruksuniversitet (1984) No. 15: 393-510 (seven papers).

ERIKSSON, H.; A. KARLSSON. 1996. Long-term changes in site index in growth yield experiments with Norway spruce [*Picea abies* (L.) Karst] and Scots pine (*Pinus sylvestris* L.) in Sweden In: "Growth Trends in European Forests". H. Spiecker et al. pp. 79-88, Springer.

ERIKSSON, LENNART. 1978. Single-tree competition models, predicting stand development after cleaning. In: Growth models for long term forecasting of timber yields, Fries et al. eds. 1978, U.S.A., pp. 71-82.

ERIKSSON, L. O.; O. SALLNÄS. 1987. A model for predicting log yield form stand characteristics. Scand. J. For. Res. 2: 253-261.

ERLANDSSON, S. 1936. Dendrochronological studies. Stockholms Högsk. Geokron. Inst. Data 23, 119 p, Uppsala 1936. (Ph. D. Thesis, Univ. of Uppsala) and published in Geografiska Annaler 1936, no. 8, Stockholm.

FAZAKAS, Z.; NILSON, M. 1996. Volume and forest cover estimation over southern Sweden using AVHRR data calibrated with TM data. International Journal of Remote Sensing 17 (9): 1701-1709.

FORD, E. D. 1981. Can we model xylem production by conifers? Studia Forestalia Suecica., nr. 160: 19-29.

FRANCIS, D. A. 1957. The use of aerial survey methods in Scandinavian forestry. Empire Forestry Rev. 36: 266-276

FRIES, J. (ed.) 1974. Growth models for tree and stand simulation. Research Notes 30, Royal College of Forestry, Stockholm, Sweden, 379 pp. (Proceedings of IUFRO Working Party S4-01-4 in 1973).

FRIES, J.; B. MATERN. 1965. On the use of multivariate methods for the construction of the taper curves. IUFRO, Section 25, Conf. Stockholm Roy. Coll. For. Res. Notes 9.

GARDNER, R. H.; B. ROJDER; U. BERGSTROM. 1983 PRISM: A Systematic Method for determining the Effect of Parameter Uncertainties on Model Predictions. Technical Report, Studsvik Energiteknik AB report/NW - 83/555, Nykoping Sweden.

HAGBERG, E. 1952. Rksskogstaxering efter ny model (A new model for a forest inventory on national scale). Skogen 39: 19.

HAGBERG, E. 1957. The new Swedish national forest survey. Unasylva 11: 3-8 and 28.

HAGBERG, E.; TERSMEDEN, C. 1954. The national forest survey of western Sweden carried out in 1949-1951. Medd. f. St. Skogsforsk. Inst.

HAGBERG, N. 1938. Taxatoriska analyser av Mellansvenska blandskogarna. (Biometrical analysis of mixed stand in the middle Sweden). SST 36 (4): 385-511.

HAGBERG, N. 1942. Stamformes färändringar has tall och gran under bestandsutvecklingen och efter friställning. (Change in the form of pine and spruce during the development of the stand and after heavy thinnings). Sevnsk. Skogsv-Fören. Tidskr. 40: 1-46.

HAGBERG, N. 1944. Utbykalkylerna och stamformen Jämforelser mforelser mellan beräknat och uppmätt timmerutbyte ur stamplingsposter jämte undersökning över den individuella stamformens samt rotansvällningens betydelse för kalkylerna. (Yield calculations and stem form. Comparisons of calculated and measured log yield from fellings and investigations on the importance of calculations of individual stem form and root swelling.). Svensk. SkogsvFören. Tidskr. 42.

HAGBERG, N. 1953. Skovsavfattning på flygbilder. (Mapping forests from air photographs). Norrlands SkogsFörb. Tidskr 1953: 369-410.

HAGBERG, N. 1956. Storskogsbrukets med begagnande av figbilder. (Mapping methods, using aerial photographs, of large forestry concerns). Svenska SkogsFören. Tidskr 54: 223-264.

HÄGGLUND B. 1972. Om övre höjdens utveckling for gran i norra Sverige. (Site index curves for Norway spruce in northern Sweden). SHS, Department of Forest Yield Research Research Notes 21, 298 p.

HÄGGLUND. B., 1973. Om övre hojdens utveckling för gran i södra Sverige. (Site index curves for Norway spruce in southern Sweden). SHS, Department of Forest Yield Research, Research Notes 24, 49 pp.

HÄGGLUND, B. 1974 a. Höjdutvecklingskurvor för bonitering. (Curves for site productivity evaluation). Skogafakta no. 6.

HÄGGLUND. BJÖRN. 1974 b. Övre hojdens utveckling i tallbestand. (Site index curves for Scots pine in Sweden), 54 pp., Stockholm. Skogshögskolan. Institutioner för skogsproduction. Rapporter och uppsatser. Research notes no. 31.

HÄGGLUND, B. 1975 a. Estimating the accuracy of site index curves by means of simulation. Studia Forestalia Suedica, no. 129.

HÄGGLUND, B. 1975 b. Sambandet mellan överhöjdsbonitet och Janson bonitet-en orienterande studie. (The relationship between the dominant height site index and Jonson's site classes). SST 73 (4): 383-394.

HÄGGLUND, BJÖRN. 1978. Evaluation of site quality in connection with a model for large scale forecasting of timber yields. In: Growth models for long-term forecasting of timber yields. Fries. et al. eds. pp. 95-118.

HÄGGLUND, B. 1981. Prognoser över productionnen i etablerad skog. En sammanfattning och analys av arbetet inom ett av HUGIN - projektets problemområden. (Forecasting growth and yield in established forests. An outline and analysis of the outcome of a subprogram within the HUGIN project). Department of Forest Survey of the Swedish University of Agricultural Sciences.

HÄGGLUND, B. 1981a. Forecasting growth and yield in established forests: an outline and analysis of the outcome of a subprogram within the HUGIN project. Swedish Univ. of. Ag. Sc., Dep. For. Survey, Rep. 31, 145 pp.

HÄGGLUND, BJÖRN. 1981b. Evaluation of forest site productivity. For. Abstract Comm. For. Bureau Vol. 42 (11): 515-527.

HÄGGLUND, B. 1983. The new Swedish national forest survey. Paper presented at the conference on renewable resource inventories. Corvallis, Oregon, USA, August 1983.

HÄGGLUND, B. 1985. En ny svensk riksskogstaxering. (A new Swedish national forest survey). Sveriges Lantbruksuniversitet No. 37, 90 pp.

HÄGGLUND, B.; BENGTSON, G. 1980. Plans for a new national forest survey in Sweden. IUFRO Meeting of September 9-14, 1979, in Vienna, Austria, 10 pp.

HÄGGLUND, BJÖRN; J. E. LUNDMARK. 1977. Site index estimation by means of site properties. Stud. Forest. Suecica 138.

HÄGGLUND, B.; L. G. SVENSON. 1982. Standortsförhållanden på skogsmark och myr i Sverige. En. beskrivning och analys grundad på data fran riksskogstaxeringen. (Site conditions on forest land and wetlands in Sweden. A description and analysis based on data from the National Forest Survey, Report 35, 122 pp.

HAIDER, ARNE. 1952. Luftfotogrammetiens brukbarhet ved taxering og kartlegging av skog (The use of aerial photogrammetry in forest surveys and mapping). Tidskr. Skogbr 60: 41-67.

HANELL, B. 1984. Skogsdikningsboniteten has sveriges torvmarker. (Post-drainage site index of peatlands in Sweden). Repporter i Skogsekologi och Skoglig Marklära Instititutionen för Skoglig Markläa, Sveriges Lantbruksuniversitet (1984), no. 50, 121 pp.

HALZLIK, E. J. 1924. Tree classification in Sweden Jour. Forestry 22 (2): 175-177.

HARI, P.; S. KELLOMÄKI. 1981. Modelling of the functioning of a tree in a stand. Studia Forestalia Suecica 160: 39-42.

HARI, P.; G. SIRÉN. 1972. Influence of some ecological factors and the seasonal stage of development upon the annual ring width and radial growth index. Royal College of Forestry. Res. Notes 40, Stockholm.

HEIJBEL, IVOR. 1928. Ett. ekvationssystem för bestamning av tallens stamform. (A system of equations for determining stem form in pine). Svensk. SkogsFören, Tidskr. 3-4: 393-422. U.S. Forest Service Translation, 261, 1930.

HEIJBEL, I. 1929. Mathematische Untersuchungen über die Barke der Kiefer. Skogsv. Tiddkr. 27. (Mathematical researches on Scots pine bark).

HESSELMAN. H., 1904a. Om tallens hödtillväxt och skottbildring somrarne 1900-1903. (On height growth and development of shoots at the beginning of the 1900-1903 summers). Modd. Statens Skogsförsöksanst 1.

HASSELMAN, H. 1904b. Om tallens diametertillväxt under de sista tio åren. (The growth of Scots pine diameter in the last ten years). Medd. Statens Skogsförsöksant 1: 25-53.

HOJER, A. G. 1903. Tallens och granens tillväxt. (Pine and spruce growth). Bihana till Fr. Lovén Om råra barrskogar, Stockholm, Sweden.

HOLMGREN, P. 1994. Topographic and geochemical influence on the forest site quality, with respect to *Pinus sylvestris* and *Picea abies* in Sweden. Scandinavian Journal of Forest Research 9 (1): 75-82.

HOLMGREN, P.; THURESSON, T.; HOLM, S. 1997. Estimating forest characteristics in scanned aerial photographs with respect to requirements for economic forest management planning. Scandinavian Jurnal of Forest Research 12 (2): 189-199.

HOLMSGAARD, E. 1958. Basic growth concepts. Univ. Coll. of For. Bull. 42.

HÖRNSTEN, L.; C. HELLSTRÖM. 1996. Teknik för fältdatainsamling. (Equipment for recording field data). Uppsala, Sweden. SkogsForsk. (Forestry Research Institute of Sweden). Resultat - SkogsForsk no. 21, 4 pp.

JAAKKOLA, S.; JOHANSSON, L.; HAGNER, O. 1987. Applicability of Spot for forest inventory, mapping and change monitoring. In Spot 1: premier resultants en vol. Toulouse, France; Cepadues-Editions (1987) pp. 259-264, 327-328.

JAAKKOLA, S.; POSO, S.; SKRÅMO, G. 1988. Satellite remote sensing for forest inventory-Experiences in the Nordic Countries. Scand. J. For. Research 3: 545-567.

JACOBSON, S. 1986. Ständortsbonitering i Uppland. En kontrollstudie för trädslaget gran. (Site index classification in Uppland, Sweden. A control study on Norway spruce). Rapporter: Skogsekologi och Skoglig Marklära, Institutionen för Skogling Marklära, Sveriges Lantbruksuniversitet, no. 54, 50 pp.

JAKOBSSON, A. 1970. Sambandet mellan trädkronans diameter och andra trädfactorer, trämst brösthoidsdiametern. Analyser grundata på riksskogs taxeringens provträdsmaterial. (The correlation between the diameter of tree crown and other tree factors - mainly the breast height diameter. Analyses based on sample trees from the National Forest Survey). Department of Forest Survey of the Swedish University of Agricultural Sciences.

JEFFRES, J. N. R. 1953. Statistical methods in Forest Research. 11th Congr. Rome.

JEFFERS, J. N. R. 1960. Experimental design and analysis in forest research. Stockholm.

JOHANNSSON, D. 1961. The natural establishment and development of some mixed conifer stands in Central Värmland Svenska Skogsvårdsfören T.1: 23-40.

JOHANNSSON, T. 1996. Site index curves for European aspen (*Populus tremula* L.) growing on forest land of different soils in Sweden. Silva Fennica 30 (4): 437-458.

JOHANSSON, S.; ERIKSSON, I. 1995. Ny teknik i helikoptern underlattar inventering och ajourhållning. (New airborne technology facilitates forest surveys and updates). Uppsala Sweden; SkogsForsk (Forestry Research Institute of Sweden: Resultat- SkogForsk No 10, 4 pp.

JOHANSSON, S.; ERIKSSONI. 1995. Det ljusnar för GPS i skogen (Bright prospects for GPS in forestry). Uppsala, Sweden-SkogsForsk (Forestry Research Institute of Sweden) Resultat-SkogForsk No 11, 4 pp.

JONASSON, H. 1987. Klassificering av ägoslag och skogsmark med satellitbildsteknik. En metodstudie för riksskogstaxeringar (Classification of land-use classes and forest land using satellite data. A procedural study for Swedish national forest inventories. Rapport Institutionen för Skogstaxering Sveriges Lantbruksuniversitet No 42, 87 pp.

JONSON, T. 1910. Taxatoriska undersökningar om skogsträdens form. I. Granens stamform. (Forest mensurational investigations on forest tree form. Spruce stem form). Skogsvardsf. Tidskr. 8: 285-328.

JONSON, T. 1911. Taxatoriska undersökninger om skogsträdens form II. Tallens stamform. (Forest mensurational investigations on forest tree form. Pine stem form). Skogsvärdsf. Tidskr. 9: 285-329.

JONSON, T. 1912. Taxoriska undersökningal öfrer skogsträdens form III. Form-bestämning a stående träd. (Forest mensurational investigations concerning forest tree form. Form determination of standing trees). Svenska Skogsvardsf. Tidskr. 10: 235-75.

JONSON, TOR. 1914. Om bonitering av skogsmark. (Stocking as measure of site productivity). SST 12 (5): 369-392.

JONSON, TOR. 1915, 1918. Massatabeller för Träduppskattning. (Volume tables for tree estimation Stockholm, 94 pp, Zetterlund and Thelanders Boktryckeri Aktiebolag, Tredje Större Upplagan, (1915).

JONSON, TOR. 1926. Methods and aids in tree form investigations and in the calculation of volume, yield of various products and growth". Internatl. Cong. Plant. Sci. Proc. 1: 729-739.

JONSON, TOR, 1926-1927. Stamformsproblemet. (The problem of stem form). Medd. f. Statens Skogsför. 23: 495-586.

JONSON, T. 1928. Einige neue Methoden zur Berechnung des Volumens und des Zuwachses bei stehenden Bäumen. (New methods for determination of volumes and increment of standing trees). Original title: Några nya metoder för beräkning av stamvolym och tillväxt hos stående träd). Svensk. SkogsvFören Tidskr. 26: 423-527. U. S. Forest Serv. Trans. 262, 1930.

JONSSON, B. 1962. Om barrblandskogens volymproduktion. (Yield of mixed coniferous forests MSS 50 (8), 143 pp.

JONSSON, B. 1969. Studier över den av väerleken orsakade variationen i åsringsbredderna has tall roch gran i Sverige. (Studies of variations in the width of annual rings in Scots pine and Norway spruce due to weather conditions in Sweden). Royal College of Forestry Res. Notes 16, 297 pp.

JONSSON, B. 1972. Totala årsringsindex fö tall och gran i olika delar av Sverige aren 1911-1968. (Total annual ring indices for Scots pine and Norway spruce in different regions of Sweden during the period 1911 to 1968). S. H. S., Department of Forest. Yield Research, Research Notes 22, 45 pp.

JONSSON, B. 1974. En metod för produktionsprognoser och dess tillämpning för regionala avverkningsberakningar. (A method for yield forecast on regional level). Department of Forest Yield Research, Royal College of Forestry, Research Notes no. 33. A detailed work, only in Swedish.

JONSSON, B. 1977. A growth model as a basis for long-term forecasting of timber yields. Stencil. College of Forestry, Stockholm.

JONSSON, BENGT. 1978. A growth model as a basis for long-term forecasting of timber yields. (A preliminary version). In: Growth models for long-term forecasting of timber yields, Fries et al. eds. U.S.A., pp. 119-137.

JONSSON, B. 1980. Funktioner för längsiktiga prognoser beträffande, virkesförrådets sterlek och sammansättning. (Functions for long-term forecasting of the size and structure of timber yields). S. L. U. Section of Forest mensuration and Management, Report 7, 121 pp.

JONSSON, BENGT; BERTIL MATERN. 1978. On the computation of annual ring indices. In: Growth models for long term forecasting of timber yields. Fries et al. eds. 1998, U.S.A., pp. 138-142.

KARLSSON, A.; A. ALBREKTSON; J. SONESSON. 1997. Site index and productivity of artificially regenerated *Betula pendula* and *Betula pubescens* stands on former farmland in southern and central Sweden. Scandinavian Journal of Forest Research 12 (3): 256-263.

KLEMAN, J. 1986. The spectral reflectance of stands of Norway spruce and Scotch pine, measured from a helicopter. Remote Sensing of Environment 20 (3): 253-265.

KOMMITÉN FÖR SKOGLIG FOTOGRAMMETRI. 1951. Flygbilden i skogsbrukets tjänst (Aerial photographs in the service of Forestry) Staten Reproduktionsanstalt, Stokholm, 196 pp.

KOMMITÉN FÖR SKOGLIG FOTOGRAMMETRI. 1955. Tolking av Flygbilder. (Interpretation of Aerial Photographs.) Eselte Aktiebolag, Stockholm. 157 pp.

LAAR, ANTHONIE van; ALPARSLAN AKÇA. 1997. Forest Mensuration. 1. Aufl. (edn.) Cuvillier Verlag, Göttingen, 418 pp.

LANDSBERG, J. J. 1981. The number and quality of driving variables needed to model tree growth. Studia Forestalia Suecica 160: 43-50.

LANDSBERG, J. J. 1986. Physiological Ecology of Forest Production. Academic Press, London, England, U.K.

LEEMANS, R. 1992. Simulation and future projection of succession in a Swedish broad-leaved forest. Forest Ecology and Management 48: 305-319.

LEPOUTRE, D.; LEPRIEUR, C.; PEYRON, J. L. 1986. Télédetection et forêts: situation actuelle en Suède et perspectives pour la France. Revue Forests. Française. 38 (4): 385-393.

LEVINS, R. 1966. The strategy of model building in population biology. American Scientist. 54: 421-431.

LINDER, P.; ÖSTLUND, L. 1992. Forandringer i norra Svering skogar 1870-1991. (Changes in the boreal forests of Sweden 1870-1991) Svensk Botanic Tidskrift 86 (3): 199-215.

LINDER, S. 1981. Understanding and predicting tree growth. Proceedings of the SWECON workshop at Jädräs. Sweden. September. 1979. Studia Forestalia Suecica 160, 86 pp.

LISDANIEL, O. M. 1947. The size and spacing of sample plots in strip surveys. Swenska. Skogsw-Foren. Tidskr, 45: 217-245.

LUNDMARK, J. E. 1974. Ståndortsegenskaperna som bonitetsindikatorer i bestånd med tall och gran. (Use of site properties for assessing site index in stands of Scots pine and Norway spruce). S.H.S., Department of Forest Ecology and Forest Soils, Research Soils, Research Notes 16, 298 pp.

LUNDMARK, J. E. 1986. Skogen som Natur och Resurs. Förskarnas slutsatser om skoglig markvard. (Short-term and long-term effects on site productivity by soil treatments in forestry). Swedish. Univ. Agric. Sci. Skogsfakta Konferens 9.

MAASS, A. 1908. Kubikinnehållet och formen hos tallen och granen inom Särna socken I Dalarna. (Cubic contents and form of pine and spruce in certain districts in Dalarna). Moddel Statens Skogsförsöksanst 5: 227-286.

MAASS, A. 1911 a. Kubikinnehållet och formen hos taller i Sverige. (Cubic content and form of trees in Sweden). Medd. Statens Skogsför 8: 109-147.

MAASS, A. 1911 b. Erfarenhetstabeller för tallen. Ett bidrag till kännedamen on normala tallbestånd. (Tables for stem volume in normal stands). SST fockafdeln, häfte II: 375-422

MAASS, A. 1939. Tallens form bedömd av diametern 2,3 meter från marken. (Stem and pine as determined by diameter 2.3 meters above ground), Svensk. Skogsv. Fören, Tidsk. 37: 120-140.

MALTAMO, M.; J. PUUMALAINEN; R. PÄIVINEN. 1995. Comparison of Beta and Weibull functions for modelling the basal area diameter distribution in stands of *Pinus sylvestris* and *Picea abies*. Scand. Jour. For. Res. 10: 284-295.

MARKLUND, L. G. 1983. Collecting data for biomass equation development: some methodological aspects. INRA-B pp. 37-44 In: Mesures des biomasses et des accroissement forestiers Orleans 3-7 Octobre 1983, ed. Auclair D., INRA Publ. 1983, 365 pp., France.

MARKLUND, L. G. 1987. Biomass functions for Norway spruce [*Picea abies* (L.) Karst.] in Sweden Repport, Institutionen för Skogstaxering, Sveriges Lantbruksunversitet nr. 43, 127 pp.

MARKLUND, L. G. 1988. Biomassfunktioner för tall, gran och björk i Sverige. (Biomass functions for Scots pine, Norway spruce and birch [*Betula verrucosa* (*B. pendula*)] and *B. pubescens* in Sweden. Rapport, Institutionen för Skogstaxering, Sveriges Lantbruksuniversitet, No. 45, 73 pp.

MATÉRN, B. 1947. Methods of estimating the accuracy of line and sample plot surveying. (In Swedish, English summary), Medd. Staténs Skogsforskninginstitut, 36:1, 137pp.

MATÉRN, B. 1949/1951. Adaptation of modern statistical methods to the estimation of forest areas, timber volumes, growth and drain. U.N. Sci. Conf. Conserv. Util. Resources. 7pp.

MATÉRN, B. 1956. On the geometry of the cross-section of a stem. Medd. Statens Skogsforskningsinst, Swed. 46 (11), 28 pp.

MATÉRN, B. 1960. Spatial variation-stochastic models and their application to some problems in forest survey and other sampling investigations. Meddelanden fran statens Skogsforskninginstitut, vol. 49, no. 5, 1-44 pp. Stockholm.

MATÉRN, B. 1961. On the precision of estimates of diameter growth from increment borings. Repports du 13e congrès IUFRO, Vol. 2, Vienne, 8 pp.

MATÉRN, B. 1984. Four lectures on forest biometry. Repport Avdelningen för Skogling Biometri, Sveriges Lantbruksuniversitet no. 23, 139 pp.

MATÉRN, B. 1990. On the shape of the cross-section of a tree stem. An empirical study of the geometry of mensurational methods. Swedish Univ. of Agr. Sci. Report 28, 46 pp.

MATÉRN, BERTIE. 1992. On spatial statistics in forestry. IUFRO XX World Congress, Centennial, Tampere Finland, Inviting Papers, p. 495.

MATTSON, L. 1916-1917 a. Form och formvariationer hös Lärken. (Form and lach form variation). Medd. Statens Skogsför. 13-14: 841-992.

MATTSON, L. 1916-1917 b. Formklasstudier i fullslutna tallbestand. Medd.Statens Skogsför 13-14: 261-296. (Studies on form classes...).

MATTSON, L. 1920. Slutenhet och slutenhetsfaktorer. (Density and density factors). Svensk. SkogsvFören. Tidsk. 18: 168-193.

MERKELL, BJÖRN. 1997. MRI questionnaire for Sweden. 17 June 1997. Jönkoping, Sweden. Skogsstyrelsen National Board of Forestry. 3pp. On EFI file, Joensuu, Finland.

NASBERG, MIKAEL. 1985. Mathematical programming models for optimal log bucking. Linkoping Studies in Science and Technology. Dissertation 132. Kinkoping, Sweden: Department of Mathematics, Linkoping University, 200 pp.

NÄSLUND, M. 1929. Antalet provträ och hojdkurvans noggranhet. Mitt. d. Schwed forstl. Vers-Anst., Stockholm.

NÄSLUND, M. 1930. Om medelfelets beränkning vid linjetaxering. (On computing the standard error in strip survey) Svensk. SkogsvFören Tidskr 28, p 309 ss.

NÄSLUND, M. 1935. Ett gallringsförsök i stavagranskog. (An experimental research on thinnings in spruce stand). Medd. Stat. Skogsförsöksanst 28, 651-730.

NÄSLUND, M. 1936. Die Durchforstungsversuche der forstlichen Versuchsanstalt Schwedens im Kieferrnwald. (Researches on thinnings in Swedish pine forests). Meddelanden fran Statens Skogsforsknins Inst., Stockholm.

NÄSLUND, M. 1939. Om modelfelets härledning vid linje-och proyytetaxering. (On computing the standard error in strip and plot surveying). Medd Statens Skogsför. 31: 301-344.

NÄSLUND, M. 1940-41. Funktioner och tabeller för kubering av stående träd: tall, gran och björk i norrd Sverige. (Formulae and tables for use in determining the volume of standing timber. Pine, spruce, and birch in northern Sweden). Medd. Statens Skogsför., 32: 87-142.

NÄSLUND, MANFRED. 1942. Den gamla norrländska granskogens reaktions förmåga efter genomhugging. Medd. Stat. Skogsförsöksanst. 33 (1).

NÄSLUND, M. 1947 a. Functions and tables for computing the cubic volume of standing trees. Medd. Stat. Forsk. Inst. 36: 41-53.

NÄSLUND, M. 1947 b, 1957. Funktioner och tabeller för kubering av staende träd: Tall, gran och bjök i sodra Sverige samt i hela landet. (Formulae and tables for use in determining the volume of standing timber: pine, spruce and birch in southern Sweden and in the entire country). Medd. Statens Skogsför, 36, 81 pp.

NÄSLUND, M. 1971. Nytt material för skogling produktionsforskning. Tall, gran och björk. (New material for forest yield research. Pine, spruce and birch). SFS 89, 124 pp.

NIEMISTÖ, P. 1995 a. Influence of initial sparing and row-to-row distance on the crown and branch properties and taper of silver birch (Betula pendula). Scand.-J. For. Res. 10: 235-244.

NIEMISTÖ, P. 1995 b. Influence of initial spacing and row-to-row distance on the growth and yield of silver birch (Betula pendula). Scand. J. For. Res. 10: 245-255.

NILSSON, M. 1997. Estimation of forest variables using satellite image data and airborne lidar. Umeå, Sweden; Swedish Univ. of Agric. Sciences. Acta Universitatis Agriculturae Sueciae Silvestria No 17, 31 pp. + papers i-v.

NILSSON, L. O. 1983. Leaf development of willow. Methods and applications. INRA: pp. 21-30. INRA 1983: Measures des biomass et des accroissement forestiers. Orleans 3-7 Octobre 1983, Ed. INRA Publ., Auclair D. ed., 365 pp.

NILSSON, N. E. 1961. Riksskogstaxeringens produktionsöversikter. (Yield tables from the National Forest Survey). MSS 50 (1), 152 pp., Sweden.

NOREN, MIKAEL. 1997. MRI questionaire for Sweden woodland habitats. 25 June 1997. Jönköping, Sweden; Skoggsstyrelsen National Board of Forestry. 3 pp. On EFI file, Joensuu, Finland.

NYLINDER, P. 1958. Weight measurement of pulpwood. Stockholm: Rapp. Inst. Virkeslära K. Skogshögsh no. R 57.

NYSTRÖM. K.; M. KEXI. 1997. Individual tree basal area growth models for young stands of Norway spruce in Sweden. In Special Issue: Regeneration success and early growth of forest stands. Selected and edited papers from the IUFRO Conference on modelling regeneration success and early growth of forest stands, held in Copenhagen, Denmark, 10-13 June 1996 (edited by Skovsgaard, J. R. ; Vanclay, J. K.). Forest Ecology and Management 97 (2): 173-185.

NYYSSÖNEN, A. 1963. Analysis of two alternative methods for national forest inventories in Northern Europe. Acta Forest Fenn. 76, 19 pp.

NYYSSÖNEN, AARNE. 1993. National forest inventories in the Nordic countries. Proceedings of the 1992 meeting of the IUFRO Group S4.02, IUFRO Centennial 1992, pp. 28-35.

ODIN, H. 1972. Studies of the increment rhythms of Scots pine and Norway spruce plants. Stud. Forest. Suec. 97.

ODIN, H.; OPENSHAW. 1971. Electrical methods for measuring changes in shoot length and stem diameter. Royal College of Forestry Res. Notes 29, Stockholm.

OJA, J. 1997. A comparison between three different methods of measuring knot parameters in Picea abies. Scandinavian Journal of Forest Research 12 (3): 311-315.

ÖSTLIN, ERIK. 1929. Forest surveys in Sweden. Jour. Forestry 25: 723-726.

ÖSTLIN, ERIK. 1930. Barken ur taxorisk synpunkt. (A study of the bark a forest mensurational point of view). Svensk. SkogsvFören. Tisdkr. 28: 232-252.

ÖSTLIN, E. 1963 a. Barkuppgifter för tall, gran, björk m fl. Del. 1 Barkupp gifter för län regioner. (Bark data for pine, spruce, birch etc. Part I. Bark data for provinces and regions). Department of Forestry Survey on the Swedish University of Agricultural Sciences.

ÖSTLIN, E. 1963 b. Barkuppgifter för tall, gran, björk m fl. Del. 2 Barkuppgiffter för bonitets - och åldersklasser och för olika sortiment. (Bark data for pine, spruce, birch etc. Part 2. Bark data for site and age classes and for sawlogs and pulpwood). Department of Forest Survey at the Swedish University of Agricultural Sciences.

OSTLIND, J. 1932. Eroforderlig taxeringsprocent vid linjetaxering av skog. (The requisite survey percentage when line-surveying a forest.) Svensk. SkogsvFören.Tidskr. 30: 417-514.

PARIKKA, M. 1997. Biosims - a method for the estimation of woody biomass for fuel in Sweden. Uppsala, Sweden, Swed. Univ. of Agricultural Sciences Acta Universitatis Agriculturae Sueciae - Silvestria 27, 157 pp.

PATTERSON, H. D. 1950. Sampling on successive occasions with partial replacement of units. J. Royal Stat. Soc. B, 12: 241-255.

PATERSON, S. 1956. The forest area of the world and its potential productivity. Göteborg University, 216 pp. Sweden.

PERSSON, ERIK. 1997. MRI questionnaire for Sweden reinder/forest survey. 1 July 1997, Ümea, Sweden, Skogsvårdsstyrelsen Västerbotten. 5 pp + attachments. On EFI file, Joensu, Finland.

PERSSON, H. 1978. Root dynamics in a young Scots pine stand in central Sweden. Oikos, 30: 508-519.

PERSSON, T. (ed.) 1980. Structure and function of northern coniferous forests. An ecosystem study. Stockholm; Swedish Natural Science Research Council, 1980, 609 pp. (Ecological Bulletins no. 32). A core monography.

PERSSONS, D. 1965. Distance methods II. Dept. For. Biom., Royal Coll. For. Stockholm.

PETRINI, S. 1918. Formpunktsmethoden och dess använding för formklassbestämning och kubering. (Form point method for determination of form stem classes and volume). Medd. Statens Skogsför. 15: 233-274.

PETRINI, S. 1919. Om formpunktsbedäning. Medd. Statens. Skogsför 18: 165-220.

PETRINI, S. 1921. Stamformsundersökninger. Medd. Statens Skogsför 18.

PETRINI, S. 1927. En förenklad av stamanalys. Skogen. 14: 288-290.

PETTERSEN, HENRIK. 1925. Sambandet mellam kronan och Stamformen. Swenk. SkogsvFören. Tidskr. 23: 37-79.

PETTERSON, H. 1927. Studier över stamformen. (Studies on stem form). Medd. Stat. Skogsförsöksanst 23: 63-189.

PETTERSON, H. 1936. Studien über die Stamform. Stockholm.

PETTERSON, H. 1951. Produktionstabeller för vissa typer av svensk barrskog. (Production tables for certain types of Swedish conifer) Medd. Stat. Skogsforskningsinst. 40, 9: 1-16.

PETTERSON, H. 1955. Barrskogens volymproduction. Medd. fran Statens Skogsforskningsinstitut, tome 45, 391 pp. (Yield determination of conifers).

PRENTICE, I. C; H. HELMISAARI. 1991. Silvics of north European trees: compilation, comparisons and implications for forest succession modelling. For. Ecol. Manage. 42: 79-93.

PRODAN, MICHAIL; ROLAND PETERS; FERNANDO COX; PEDRO REAL. 1997. Mensura Forestal (Forest mensuration). IICA-BMZ/GTZ, 586 pp. printed in San José, Costa Rica.

RANNEBY, B.; E. ROVAINEN. 1994. On the determination of time intervals between remeasurements of permanent plots. For. Ecol. Manage 71 (3).

RANNEBY, BO; ROVAINEN, EVA. 1995. On the determination of time intervals between remeasurements of permanent plots. Forest Ecology and Management 71 (1995): 195-202.

RANNEBY, B.; SVENSSON, S. A. 1991. From sample tree data to images of tree populations. In: Köhl and Pelz (eds.) 1991,pp. 102-117; see Poso, S. 1991, Finland (in this section).

RANNEBY, B.; CRUSE, T.; HÄGGLUND, B.; JONASSON, H.; SWÄRD, J. 1987.Designing a new national forest survey for Sweden. Studia Forestalia Suecica No. 177, 29 pp.

RUDQVIST, LENNART. 1997. MRI questionnaire for Sweden wetlands. 27 June 1997. Jönköpling, Sweden: National Boaed of Forestry. 3.p.+ attachments. On EFI file, Joensun, Finland.

SANTANTONIO, DAN. 1990. Modelling growth and production of tree roots, In: "Process Modelling of Forest Growth Responses to Environmental Stress", Eds: Dixon, Robert K; S. Ralph Meldahl. Gregory A. Ruark; William G. Warren. Timber Press, Portland, Oregon, pp. 124-141.

SCHMID, P. 1982. Sampling at the forest edge. Offprint from Statistics in theory and practice. Essays in Honor of Bertie Natern. Swedish Univ. of Agric. Sci. Umea. Sweden 263-276.

SCHOVE, D. J. 1954. Summer temperatures and tree-rings in North-Scandinavia A. D. 1461-1950. Geografiska Annaler 1954: 40-80. Stockholm.

SCHULMAN, EDMUND. 1944. Tree-ring work in Scandinavia. Tree-Ring Bull., vol. 11, no. 1.

SKADHEIM, M. 1953. Instrumenter for maling av trehoyder. (Instruments for measuring tree heights). Tidsskr. Skogbr. 61: 290-296.

SÖDERBERG, U. 1986. Funktioner för skogliga produktionsprognoser –Tillväxt och formhöjd för enskilda träd av inhemska trädslag i Sverige. (Functions for forecasting of timber yields. Increment and form height for individual tree of native species in Sweden). Swedish University of Agric. Sciences, Section of Forest mensuration and management, report 14, 251 pp.

SÖDERBERG, ULF. 1988. Functions for forecasting of timber yields. FGMP pp. 151-158. FGMP: "Forest growth modelling and prediction", Ek, Alan; Stephen R. Shifley; Thomas Burk (eds.) U.S.A. Forest Service, North Central Forest Experimental Station, General Technical Report NC-120, Vol. 1 and 2, 1153 pp. (143 papers), St. Paul, Minnesota, - U.S.A. Proceedings, IUFRO Conference 1987, August 23-27 Minneapolis, MN.

SÖDERBERG, ULF. 1997. Country report for Sweden. In: Study on European Forestry Information and communication System-reports on forest inventory and survey systems volume 2 CH-11-97-002-EN-C. Luxemburg: European Commission; 955-1018.

SÖDERSTRÖM, V. 1958. Om ett forsook at utföra skogsvärdsplaner med hjälp av flygbilder. (Research on preparing silvicultural plans with the help of air photographs.) Swenska SkogsvFören. Tidskr. 56: 93-122.

STRAND, L. 1957. The effect of the plot size on accuracy of forest surveys. Meddel. fra detnorske Skogsfors oksvesen 1957.

STRAND, L. 1959. The accuracy of some methods for estimating volume and increment on sample plots. Medd. f.d. norske Skogsfors oksvesen.

STRIDSBERG, E. 1953. Compound interest in the calculation of increment % for periods of several years. Skr. K. Skogshögsk., Stockholm Nr. 12/19: 43-52.

STRIDSBERG, E. 1956. Bonitetsproblemen i de nordiska landerna Skogsv. Tidskr. no. 3, Skogsvårdsför. Tidskr.

STRÖMBERG, L.; L. TEGNHAMMAR. 1985. Standortsugenskaperna som bonitetsindikatorer för trädslaget boken pilostudie. (Using site variables as indicators of site index in beech stands: a pilot study). Rapporter i Skogssekologi och Skogling Marklära, Institutionen for Skogling Marklära, Sveriges Lantbruksuniversitet no. 52, 67 pp.

SVENSSON, S. A.; TOET, H.; KEMPE, G. 1989. Riksskogstaxeringen 1978-1982. Skogstillstånd, tillväxt och avverkning. (The Swedish national forest inventory 1978-82. Condition of forests, increment and logging.) Rapport, Institutionen för Skogstaxering Sveriges Lantbruksuniversitet (1989) No. 47, 236 pp.

SWEDEN. 1953. Standardized measurement of sawtimber. Skogen 40, 10, p. 220 - in Swedish.

SWEDEN. 1963. Standardized measurement of pulpwood. Skoen 40, 11, p. 240 - in Swedish.

SWEDEN, 1955. Instruktion für die Aussenaufnahmen bei der 3 schwedischen Reichswaldtaxation. (Instructions for the third inventory in southern National Forest). Übers. E. Maller, Reinbeck. Eidgen. Anst. f. d. forstl. Vers. Wesen, Zürich.

SYLVEN, N. 1909. (Studies on morphology of spruce, especially branchiness types and their importance). Wert. Mitt. Forstl. Versuchsanst. Schwedens 6.

TAMM, C. O. 1971. Primary production and turnover in a spruce forest ecosystem with controlled nutrient status. (A Swedish IBP-project). Bull. Ecological Res. Comm. 14: 114-145.

THAM, Å. 1987 a. Gran och björk i blandning. Gallring i unga bestånd, försöksuppläggning och utgångsläe. (Mixed spruce and birch. Thinning in young stands, experimental design and initial position). Swedish University of Agricultural Sciences. Department of Forest Yield Research. Report No. 20. Garpenberg, 79 pp.

THAM, Å. 1987 b. Structure of mixed Norway spruce [Picea abies (L.) Karst.] and birch (Betula pendula Roth and Betula pubescens Ehrh.) Stands in Middle Sweden Scand. J. For. Res.

THAM, ÅSA. 1988. Estimate and test frequency distributions with the Johnson Sb function from stand parameters in young mixed stands after different thinnings treatments. FGMP pp. 255-262: "Forest Growth Modelling and Prediction", Ek. Alan R.; Stephen R. Shifley; Thomas Burk (eds.). U.S.A. Forest Service, North Central Forest Experimental Station. General Technical Report NC - 120, vol. 1, and 2, 1153 pp., 143 papers. St. Paul Minnesota, U.S.A., proceedings IUFRO Conference 1987, August 23-27, Minneapolis, MN.

THAM, Å. 1988 a. Stand volume functions for young mixed stands of Norway spruce [Picea abies (L.) Karst.], silver birch (Betula pendula Roth.) and European birch (Betula pubescens Erhr.) in Sweden. Rapport., Institutionen för Skogsproduction, Sveriges Lantbruksuniversitet, no. 22, 16 pp.

THAM, Å. 1988 b. Yield prediction after heavy thinning of birch in mixed stands of Norway spruce [Picea abies (L.) Karst.] and birch (Betula pendula Roth and Betula pubescens Ehrh.). Swedish Univ. Agric. Sci. Dept. For. Yield Research. Rep. 23.

THAM, Å. 1989. Prediction of individual tree growth in managed stands of mixed Picea abies (L.) Karst. and Betula pendula Roth and Betula pubescens Ehrh. Scand. J. For. Res. 4: 491-512.

THORELL, K. E.; ÖSTLIN, E. O. 1931. The national forest survey in Sweden. Jour. Forestry 29: 585-591.

TIRÉN, LARS. 1922. Om en elevation for stamkurven. (On determination of stem curves). Svensk. SkogsvFören. Tidskr. 29: 383-399.

TIRÉN, L. 1928. Einige Untersuchungen über die Schaftform. (Some researches on stem form). Medd. Stat. Skogsförsöksanst 24: 81-152.

TIRÉN, L. 1929. Über Grundflächenberechnung und ihre Genaugkeit. (Determination of basal area and its accuracy). Mitt. d. Schwed. forstl. Vers.-Anst.

TOMTER, STEIN M. 1997. MRI questionnaire for Sweden. 18 June 1997. Ǻs, Norway; Norvegian Institute of Land Inventory. 1 p+ attachments. On EFI file, Joensuu, Finland.

VANCLAY, JEROME K. 1994. Modelling Forest Growth and Yield. Applications to mixed tropical Forests. CAB International, Wallingford, U.K.

WALLÉN, A. 1917. Om temperaturens och nederbördens inverkan på grannens och tallens höjd och redietillväxt å Stamnäs Kronopark 1890-1914. (Temperature and radial growth in spruce and pine). Skogshögskolans Festskrift: 413-427. Stockholm.

WALTER, F. 1999. Extraction of forest stand parameters from CARABAS VHF SAR images. Uppsala, Sweden, Swedish University of Agricultural Sciences. Acta Universitatis Agriculturae Sueciae (1999) No. 115, 144 pp.

WEIBULL, W. (WALODDI). 1951. A statistical distribution function of wide applicability Jour. Appl. mech. 18 (3): 293-297; AMR 6, Rev. 2 (In 1951 Weibull was working in Backamöllan Brösarps Station, Sweden).

WELANDER, ERIK. 1952. Uppskattning av trädslangblandning, trädhöjd, slutenhet ach kubikmassa med hjälpau flygbilder. (Estimating mixture of species, tree height density and volume with the help of air photographs). Norrlands Skogsv. Förb. Tidskr. (2): 209-241.

WESLIEN, H. 1995. Missing growth rings in branches of Scots pine (Pinus sylvestris L.) in Sweden. Uppsala, Sweden; Institutionen for Virkeslära, Sveriges Lantbruksuniversitet (Department of Forest products, Swedish University of Agricultural Science) Repport-Institutionen för Virkeslära, Sveriges, Lantbruksuniversitet no. 249, 22 pp.

ZACKRISSON, O. 1980. Forest fire history. Ecological significance and dating problems in the North Swedish Boreal Forest. In: Proceedings of the Fire History Workshop. October 20-24, 1980, Tucson, Arizona, p. 120-125. U.S. Department of Agriculture General Technical Report RM-81.

4. BELGIUM

General information

Land area: 30,250 sq. km (11,680 sq. mi), forest and other wooded land 6,200 sq. km (2,394 sq. mi), forest: 620,000 ha or 2,394 sq. mi. (20 % of land area, volume 145m^3/ha, biomass: 86 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: Industrial round wood 3.8 million m^3, fuel and charcoal 0.55 million m^3, total round wood 4.35 million m^3 (World Resources 1996-1997, p. 220).

Forest vegetation: temperate mixed forest

• Conifers 58 %

• Broad-leaved 42 %

• Main species: Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*), European oak (*Quercus robur*), sessile oak (*Quercus petraea)*, hornbeam (*Carpinus betulus*), *Pinus nigra*, European larch (*Larix europaea*), Norway spruce (*Picea abies*), Douglas-fir (*Pseudotsuga menziesii*), ash (*Fraxinus* spp.), poplar (*Populus* spp.).

Forestry education and research organizations involved in the areas of forest mensuration and forest management (date of establishment in brackets):

• Faculté des Sciences Agronomiques de Gembloux, Gembloux, Departement des Eaux et Forets (1897).

• Faculté des Sciences, Centre de Recherche et de Promotion Forestiers (IRSIA/CRPF), Section d'Ecologie et GIS (1980)

• University of Gent, Laboratory of Remote Sensing and Forest Management (1817)

• LISEC, Studie Centrum voor Ecologie en Bosbouw, Ghent (1948)

• Université Catholique de Louvain, Faculté des Sciences Agronomiques, Unite de Eaux et Forêts, Louvain-la Neuve (1938).

Publications:

• Bulletin de la Société Royale Forestière de Belgique, Bruxelles.

• Bulletin de l'institut agronomique et des stations de recherches de Gembloux. Bulletin des Recherches Agronomiques de Gembloux, Annales de Gembloux, Les Cahiers Forestiers de Gembloux..

• Forêt Privée

• Silva Belgica.

Associations:

• Association des Ingenieurs issus de la Faculté des sciences agronomiques de l'État Gembloux. Home of society: Gembloux, publication: "Annales de Gembloux".

Literature:

MARTIN, L. 1948/1949. Evolution de la biométrie, de Quetelet au 2me Congrès inter. de biométrie (Genève 1949). (Evolution of biometrics from Quetelet to the 2nd International Congress of Biometrics, Geneva 1949). Bull. Inst. agr. et Hort. Rech. Gembloux, vol. XVIII, 1948/49.

RONDEUX, J. 1978. Lexique des principaux termes dendrométriques. (Vocabulary of the main terms in forest mensuration). Faculté des sciences agronomiques de l'État, Sylviculture.

4.1. Tree measurement and tree growth

In 1949 Koeune proposed a quick method for volume determination of standing trees method that was reproduced in 1960. Pardé (1961) considered it as very original due to the fact that Koeune proposed formulas based on variable tapering by height categories.

A notable work was that of Wauthoz who constructed in 1965 general volume tables for trees and stands.

One-entry volume tables (tariffs) for spruce (*Picea abies* Karst.) have been constructed by Rondeux (1977) for southern Ardenne.

In a dendrometric study of elms (*Ulmus glabra* and *U. campestris*) Thill and Palm (1983) presented one-entry volume tables based on girth at dbh, tariffs taking into account the dominant stand height and two-entry volume tables based on girth and total height. They also determined equations for the calculation of the stem profile and assortments; tables for the precision of the regression equations and for the values of bark thickness, branch volume and crown dimensions. In 1988 Rondeux and Jacques constructed volume tables for mixed oak (*Quercus petraea*) and birch (*Betula pendula*) coppice in the southern Ardennes.

A portable device for forest data recording was constructed in 1983 by Rondeau and Fagot.

A synthesis on measurement of trees and stands was published by Rondeux in 1993.

An ultrasonic angular caliper, a promising new tool for computerized forest surveying was described by Eugene in 1990 while Bary-Lenger et al. (1990) presented grading and estimation of the value of standing oak in Belgium.

In 1996 Lejeune developed an individual tree growth model for uneven-aged broad-leaved stands in southern Belgium. This model predicts girth growth of individual trees growing in uneven-aged stands dominated by beech (*Fagus sylvatica*) and integrates simultaneously tree, stand and site characteristics without considering distances between individual trees. Entry data in the model are girth, tree social position represented by the total basal area of the trees greater than the subject tree, stand basal area of trees greater than the subject tree, stand basal tree and some index of stand structure corresponding to the ration of the variance over the mean girth. In the case of individual tree the obtained accuracy is relatively low because the results are used mainly after the individual trees distribution by size classes (also compiled after Forestry Abstracts summary 1075/1996).

Cited authors:

Bary-Lenger et al. 1990, Eugene 1989, Loeune 1949, 1960; Lejeune 1996, Rondeux 1977, 1993; Rondeux and Fagot 1983, Rondeux and Jacques 1988, Thill and Palm 1983, Wauthoz 1965.

4.2. Forest site and forest stand

In 1955 Lenger commented “a simple mathematique law” concerning the balanced (in equilibrium) structure of forest stands and Wauthoz (1955) determined the yield of spruce plantations in Ardennes.

Dagnélie (1956/1957) developed researches on the yield of beech stands in Ardennes in connection with phytosociological types and ecological factors. He confirmed the existence of a strong relationship between the dominant height of a mature stand and its mean annual increment that is almost always linear:

I_v = yield of stem m^3/ha/yr = f (dominant height in m at 150 years and more), and his equation is:

$$I_v=0.35\ h_{dominant} - 4.75$$

Dagnélie (1960) applied the factorial analysis to the study of vegetal communities.

Manil (1963) developed the first study on humus as a site factor in the acidophile beech forest of Belgium.

In 1960 Dagnélie et al. determined the productivity of beech forest types in Belgium (1957) and lower Luxemburg at the age of 150 years using the site criterion; some examples are given below:

	Beech forest type	Average height (m)	Average increment (m^3/ha/year)
(A)	Beech with *Asperula*	..	7.4
(F)	Beech with *Festuca*	31.58 ± 2.18	6.3
(L)	Beech with *Luzula*	25.17 ± 1.63	4.8
(I)	Intermediary type of beech	25.39 ± 1.77	4.1
(V)	Beech with *Vaccinium myrtillus*	22.61 ± 2.48	3.1

(Data reproduced after Pardé 1961, Dendrometrie, p. 253).

According to Dagnélie the site criterion is the average total height of a certain number of dominant trees at the age of the end of the cycle. Dagnélie's work represents an example of connection between site and yield in western Europe, but the difference between two adjacent types is sometimes too small and not significant from the statistical point of view, and because of this law accuracy Pardé (1961, p. 253) considered that this system cannot be used in the classical forest management.

Among the constructed yield tables in Belgium the following should be mentioned: spruce in Haute Ardenne, western and southern Ardenne, based on site types (Delvaux 1969); spruce in south-western Ardennes, computerized and based on site types (Thill and Palm 1975); for spruce in Belgian Ardennes (Delvaux 1976).

Dagnélie (1976, 1988) developed new yield tables for spruce, adopted the American site system and used simultaneous regression equations for yield tables construction using computers; he also constructed the regional yield tables.

Rondeaux et al. (1992) constructed yield tables for *Pseudotsuga menziesii* (Douglas fir) grown in Belgium, site classification being based on top heights of 36.33 and 30 m at age of 50 years and having yields similar to those in neighboring areas such as western Germany.

Biological interpretation of yield tables was underlined in Belgium since 1969 by Devaux in his paper "From yield tables to energy balances".

Vegetal stratum productivity (forest included) was investigated by Walter (1963) in connection with climate characteristics. On the other hand, yield of spruce was studies by Dagnélie et al. in 1970 in some sites in the Central Ardenne before the construction of his yield tables in 1976.

A mathematical model of even-aged stand structure and the ways in which structure is influenced by site productivity and thinnings intensity was developed by Boudru in 1971. In the same year was published the paper on the productivity of forest ecosystems presented at the UNESCO Symposium held in

Brussels in 1969 (Duvigneaud 1971 ed.) - a sort of state of art of the 1960s in this field.

Simulation of forest stands development in the context of an intensive silviculture was discussed in 1974 by Rondeaux who underlined the importance of this technique for forecasting of forest yield.

In 1973 and 1975 Dagnélie published a comprehensive textbook (2 volumes) on the theory of statistical methods and its applications in agriculture.

In 1975 Thill and Palm issued their mensurational study on Norway spruce and introduced in stand modelling the dominant height (apart from dbh). In the next year Dagnélie, Rondeaux and Thill completed their "Tables dendrométriques" (Forest mensurational tables - 128 pp.) and demonstrated that between the number of trees per hectare, age and dominant height there is a multiple correlation. In 1985 the previously mentioned authors and R. Palm published a collection of volume tables for trees and forest stands.

Stand volume tables have been used in Wallonia (especially for beech) to give a rapid estimate of volume per hectare (Tousant et al. 1983).

Site index curves for Norway spruce stands in the Ardennes have been developed by Rondeaux and Thill in 1989. They established six yield classes based on top height at the age of 50 years and supported by the data from 280 sample plots.

In 1999 Pauwels and Rondeux followed the tradition of stand volume table construction developed such a type of tables ("Tarif de cubage peuplement") for *Larix* in southern Belgium. In this table stem solid volume (log girth not less than 22 cm) depends on the land area and dominant tree height. (For. Abs. 4464/1999).

Cited authors:

Boudrou 1971, Dagnélie 1956/1957, 1960, 1973, 1976 a, 1988; Dagnélie et al. 1960, Dagnélie et al. 1970, Dagnélie et al. 1976, Dagnélie et al. 1985, Delvaux 1969, 1976; Duvigneaux (ed.) 1971, Lenger 1955, Pauwels and Rondeux 1999, Rondeux 1974, Rondeux and Thill 1989, Rondeux et al. 1992, Thill and Palm 1975 a, 1975 b; Toussaint et al. 1983, Walter 1963, Wauthoz 1955.

4.3. Biomass studies

Available biomass studies have been carried out by Kestemont (1972 - a riparian vegetation in the Ardennes), Kestemont (1973 - primary production of tree stratum in a beech stand with *Festuca*), Kestemont (1975 - biomass, necromass and above ground woody biomass in some forest stands in Belgium) - at the University of Brussels, Duvigneaud and Kestemont (1977 - biological productivity in Belgium), Lemeur and Impens (1981 - presentation of some results of "a multidisciplinary research program initiated in Belgium to assess the physical and physiological limits of plant productivity in the northern part of the country - Flanders; the authors refer especially to stand architecture, biomass production, energy flow and production efficiency in a man-made poplar ecosystem" concluding that "an ecosystem approach would be the best method to tackle the problem". In 1982 was published an annual report of the centre for the studies of biomass).

4.4. Tree-ring studies

Among a few tree-ring studies available to the author should be mentioned: a synthesis on the methods and applications of dendrochronology (Munaut 1978), a library of programs in dendroclimatology - at the Institut d'Astronomie et de Géophysique, Louvain-la-Neuve (Berger ed. 1980), models of trend in dendroclimatology (Lefebure 1980), mathematical analysis of the dendroclimatological data (Gujot 1981, doctoral dissertation, Université Catholique de Louvain), standardization and selection of the chronologies by the ARMA analysis (Gujot 1987).

4.5. Forest inventory: sampling, remote sensing and GIS

Statistical sampling applied to reconnaissance and forest inventories was generalized in Belgium before 1950 (Dagnelie 1956).

A detailed methodological guide for inventory of Walloon forest resources was published by Rondeaux in 1983.

Remote sensing was used in forest inventories since the early 1980s: classification of SAR data from central Belgium (Bartholome and Barisano 1983); inventory of Flemish forests using medium scale CIR photography and CIR orthophotoplans with the scope to develop an operational methodology for producing sequential forest inventories (Coppin, Roover, Dewispelaere, Groossens 1983).

New information on forest inventories and maps were presented later by Waterinckz (1997) and by Rondeaux, George and Lecompte (1997); the first author refers to the methods applied in the Flemish region and the second group of authors discussed the problems of regional inventories and maps.

Coppin, Gulink and Hermy (1997) advocated for the use of small-format aerial photography and GIS because of lower cost of this technique in the re-inventoring renewable natural resources.

Belgian authors as Jacques Rondeaux (1994, 1997) and Hugues Lecompte, Jacqques Hebert and J. Rondeaux (1997a, 1997b) recommended the development of multi-resource forest inventories (MRI) in their country.

Cited authors:

Dagnélie 1956, Bartholome and Barisano 1983, Coppin et al. 1983, 1997; Lecomte et al. 1997, Rondeaux 1983, 1994, 1997a, 1997b; Waterinckz 1997.

4.6. Chronology of selected events

1956: Statistical sampling in forest inventory was generalized before 1950 (P. Dagnélie).

1956/1957: Researches on the yield of beech stands in Ardennes in connection with phytosociological types and ecological factors (P. Dagnélie).

1975: Biomass, necromass and above ground biomass of some forest stands in Belgium (P. Kestemont).

1976: Dendrometrical tables and simultaneous use of regression for construction of yield tables with computers (P. Dagnélie).

1976: Norway spruce yield tables for Belgian Ardennes (J. Delvaux).

1978: A synthesis of the methods and applications of dendrochronology (A. V. Munaut).

1980: Library of programs in dendroclimatology (A. L. Berger).

1983: Use of remote sensing on a larger scale: photography and radar (E. Bartholome and E. Barisano; P. R. Choppin, B.P. de Roover, W.M. Dewispelaere, B. E. Goossens).

1989: The ultrasonic angular caliper for computerized forest surveying (C. Eugene).

1996: An individual distance-independent tree growth model for uneven-aged broad-leaved stands in southern Belgium (P. Lejeune).

1994, 1997: Proposals for multi-resource inventories - MRI (Jaques Rondeaux).

1997: Application of small-format aerial photography and GIS in re-inventoring removable natural resources. (P. Coppin, H. Gulinck and M. Hermy).

1997: Country report on forest inventory and survey systems (Hugues Lecomte, Jacques Hebert, Jaques Rondeaux).

4.7. Selected contributors

Author	Printing years	Field
P. Dagnélie	1950s-1980s	4,7
P. Kestemont	1970s	5
J. Delvaux	1970s	4
J. Rondeux	1970s-1990s	1, 4
A. Thill	1970s	1, 4
R. Palm	1970s-1980s	1, 4
A. V. Munaut	1970s	6
J. Gujot	1980s	6
A. L. Berger	1980s	6
J. Rondeux	1980s-1990s	7
C. Coppin	1980s-1990s	7

1 = tree measurement, 4 = stand growth and yield, 5 = weight and biomass, 6 = tree-ring studies, 7 = forest inventory.

4.8. Comment

In spite of small area of forests the development of forest mensuration in Belgium is located on a high level using modern methods and technologies as remote sensing and GIS. This achievement is in the main part the result of the existence for a long time of forestry education and research organizations, one of them being more than a hundred years old.

References

BARTHOLOME, E.; BARISANO, E. 1983. SAR 580 images for agricultural and forest survey. First results on Middle Belgium. E. In Proceedings EARSeL/ESA symposion on remote sensing applications for environmental studies, 1983, Brussels, edited by Longdon, N.; Melita, O, Paris, France: European Space Agency (1983): 115-121.

BARY-LENGER, A.; S. DUMONT; J. KIMUS. 1990. Le classement et l'estimation des grumes de chêne sur pied. (Grading and estimating the value of standing oak). Forêt Privée, no. 193: 55-79.

BELGIUM. 1982. Annual report no. 5, 1982: Centrum voor de studie van de Biomassa, I.W.O.N.L., Belgium (Centre for biomass studies).

BERGER, A. L. ed. 1980. Library of programs in dendroclimatology. Institut d'Astronomie et de Géophysique. UCL Louvain-la Neuve.

BOUDRU, M. 1971. La normalité dans le peuplement équenne. (Normality in the even-aged stand). Bull. Soc. Roy. For. Belg. no. 12.

COPPIN, P.; ROOVER, B. P. DE ; DEWISPELAERE, W. M.; GOOSSENS, R. E. 1983. Inventory of Flemish forests using medium-scale CIR photogrametry and CIR orthophotoplans as base for a forest management data bank. In Proceedings EARSeL/ESA symposium on remote sensing applications for environmental studies, 1983, Brussels (edited by Longdon, N.; Melita, O.), Pavis, France; European Space Agenty (1983): 249-255. (Publication No ESA SP-188, distributed by ESTEC, Noordwijk, Netherlands).

COPPIN, P.; GULINCK, H.; HERMY, M. 1997. Low-cost revision of forest maps in low-relief terrain using small-format aerial photography and GIS. Forest and LandScope Research (1996, publ. 1997) 1(4): 367-379.

DAGNÉLIE, P. 1956. L'échantillonnage statistique appliqué à la prospection et aux inventaires forestiers. (Statistitical sampling applied to prospect and forest inventories). Ann. de Gembloux, sec. trimester: 109-134.

DAGNÉLIE, P. 1956/1957. Recherches sur la production de hêtraies d'Ardennes en relation avec les types phytosociologiques et les facteurs écologiques. (Researche on the production of beech stands in connection with the phytosociological types and ecological factors). Bull. de l'institut agronomique et des stations de recherches de Gembloux, no. 3-1956 pp. 249-284, no. 4-1956 pp. 369-410 and no. 1/2-1957 pp. 44-94.

DAGNÉLIE, P. 1960. Contribution à l'étude des communautés végétales par l'analyse factorielle. (Contribution on the study of vegetal communities using factorial analysis). Bull Serv. Carte Phytogéogr. (Montpellier). Ser. B. 5, pp. 7-71 and 93-194.

DAGNÉLIE, P. 1973. Théorie et methodes statistiques. Applications agronomiques. Volume 1: La statistiques descriptive et les fondements de l'inférence statistique, Volume 2: Les méthodes de l'inférence statistique (Statistical theory and methods. Applications in agriculture. Volume 1: Descriptive statistics and fundamentals of statistical inference. Volume 2: Methods of statistical inference. 2nd edn. Gembloux. Les Presses Agronomiques - 378 et 463 pp.

DAGNÉLIE, P. 1976. L'emploi d'équations de regression simultanées dans le calcul de tables de production forestières. (The use of regression de simultaneously in computation of yield tables). In: Ziegler W. J. et al. "Contributions to applied statistics dedicated to prof. A. Linder. Basel. Bikhaüser.

DAGNÉLIE, P. 1988. Tables de production relatives à l'épicéa commun. (Norway spruce yield tables for the Belgian Ardennes). Gembloux, Belgium; Les Presses Agronomique de Gembloux, 124 pp.

DAGNÉLIE, P.; J. P. HUBERTY; A. NOIRFALISE. 1960. Recherches sur la productivité des hêtraies des macignos et des marnes du Bas-Luxembourg. (Researches on beech productivity on the marls of the Low Luxembourg). Bulletin de l'institut agronomique et des stations de recherches de Gembloux, no. 1, pp. 18-32.

DAGNÉLIE, P.; J. RONDEUX; A. THILL. 1976. Tables dendrométriques. (Dendrometrical tables). Gembloux: Les Presses Agronomiques, 128 pp.

DAGNÉLIE, P.; J. L. NIVELLE; J. RONDEUX; A. THILL. 1970. Production de l'épicea commun (*Picea abies* Karst.) dans quelques stations de l'Ardenne Centrale. (Spruce yield in some sites in Central Ardenne). Bull. Rech. Agron. Gembloux N.S. 5: 428-442.

DAGNÉLIE, P.; R. PALM; J. RONDEUX; A. THILL. 1985. Tables de cubage des arbres et des peuplements forestiers. (Volume tables for trees and forest stands). Gembloux: Les Presses Agronomiques, 148 pp.

DELVAUX, J. 1969a. Tables de production relatives à l'épicéa commun. (Norway spruce yield tables for the Belgian Ardennes). Gembloux, Belgium; Les Presses Agronomique de Gembloux, 124 pp.

DELVAUX, J. 1969b. Des tables de production aux bilan énergétiques. (From yield tables to energy balances). In: Productivity of forest ecosystems. UNESCO Brussels Symposium Oct. 1969, Ed. D. Duvigneaud. 1971, pp. 177-182.

DELVAUX, J. 1976. Tables de production pour l'Épicea commun (*Picea abies* Karst.) dans les Ardennes Belges. (Spruce yield tables for Ardennes). Stat. Rech. des Eaux et Forêts. H.S. For. no. 80.

DUVIGNEAUD, P. (ed.). 1971. Productivity of forest ecosystems. Proc. Brussels Symp. UNESCO and IBP Oct. 1969.

DUVIGNEAUD, P.; P. KESTEMONT. (ed.). 1977. The ultrasonic angular caliper - a promising new tool for computerized forest surveying. In: Adlard P.G. and Rondeux J. (eds.) Forest Growth Data: capture Retrieval and Dissemination. Proceedings of the joint IUFRO S4.02.03/4.02.04 workshop. Gembloux, Belgium. Published also in Bull. des Recherches Agronomiques de Gembloux 1990, 25 (1): 153-160.

GUJOT, J. 1981. Analyse mathématique des données géophysiques. Applications à la dendroclimatologie. (Mathematical analysis of geophysical data. Application in dendroclimatology). Doctoral dissertation. Université Catholique de Louvain.

GUJOT, J. 1987. Standardization and selection of the chronologies by the ARMA analysis. In: L. Kairiukstis, Z. Bednarz and E. Feliksik (eds): "Proceedings of Methods of Dendrochronology - 1. International Institute for Applied Systems Analysis/Polish Academy of Sciences - Systems Research Institute. Warsaw, Poland, pp. 97-105.

KESTEMONT, P. 1972. Biomass, productivité et phytogéochemie de la végetation riveraine d'un ruisseau ardennais. (Biomass, productivity and phytogeochemistry of vegetation along a small river in Ardennes). Bull. Soc. Roy. Bot. Belg. vol. 105: 209-219.

KESTEMONT, P. 1973. Production primaire de la strate arborée d'une hêtraie à féstuques. (Primary production of tree stratum in a beech stand with *Festuca* sp.). Bull. Soc. Roy. Bot. Belg. vol. 106: 305-316.

KESTEMONT, P. 1975. Biomasse, nécromasse et productivité aérriennes ligneuses de quelques peuplement forestiere en Belgique. (Biomass, necromass and woody above ground productivity of some forest stands in Belgium). These. Université de Bruxelles.

KOEUNE, FRANÇOIS. 1949. Méthode rapide de cubage d'arbres sur pied. (A quick method for volume determinations of standing trees). Editeur J. Duculat à Gembloux.

KOEUNE, FRANÇOIS. 1960. Nouvele méthode de cubage d'arbres sur pied. (A new method for volume determinations of standing trees). Gembloux. Imprimerie des éditions J. Duculat, S.A. 72 pp.

LECOMTE, HUGUES; HEBERT, JACQUES; RONDEAUX, JACQUES. 1997. Country report for Belgium. In: Study on European Forestry Information and Communication System-Reports on forest inventory and survey systems. Volume I CH-11-97-001-EN-C. Luxemburg: European Commission; pp. 75-118.

LEFEBURE, L. 1980. Modèles de la tendance en dendroclimatologie. (Models of trends in dendroclimatology). Memoire Univ. Cath. Louvain, Louvain-la-Neuve.

LEJEUNE, P. 1996. Dévelopment d'un modéle de type arbre appliqué à la croissance des peuplements teuillus irréguliers du sud de la Belgique. (Development of an individual tree growth model for uneven-aged broadleaved stands in southern Belgium. Canadian Journal of Forest Research 26 (1): 1838-1848.

LEMEUR, R. J. P.; I. I. IMPENS. 1981. Stand architecture, biomass production, energy flow and production efficiency in a man made poplar ecosystem. Proc. 17th IUFRO World Congress, Kyoto, Japan, 6-17th September 1980, pp. 206-225.

LENGER, A. A. 1955. A propos d'une loi mathématique simple concernant la structure équilibrée des peuplements forestiers. (About a simple mathematical law on a balanced (in equilibrium) structure of forest stands). Bull. de l'Institut Agr. et de Stat de Recherches de Gembloux. XXIII, no. 3.

MANIL, G. et al. 1963. Humus as a site factor in the acidophile beech forest of Belgium. (First study). Bull. Inst. Agr. Gembloux 31 (2): 183-222.

MUNAUT, A. V. 1978. La dendrochronologie, une synthèse de ses méthodes et applications. (Dendrochronology, a synthesis of its methods and applications). Liège: Société Botanique, 47 pp.

POUWELS, D.; RONDEUX, J. 1999. Tarif de cubage "peuplement" pour les mélìzes en Belgique méridionale. (Stand volume tables for larch in southern Belgium). Rev. For. Française 1999 51(5): 605-611.

RONDEUX, JAQUES. 1974. Simulation de l'évolution de peuplements forèstiers dans le contexte d'une sylviculture intensive. G. M. pp. 309-326. GM: Growth Models for Tree and Stand Simulation, IUFRO Working party S4.01-4. Proceedings of meetings in 1973. Edited by Jöran Fries Institutionen för Skogsproduction, Department of Forest Yield Research. Rapporter och Uppsatsert/Research Notes no. 30, 1974. Skogshögskolan Royal College of Forestry S-10405 Stockholm, Sweden 379 pp.

RONDEUX, J. 1977. Construction et utilisation de tariffs de cubage de peuplement pour l'épicéa (Picea abies Karst.) en Ardenne méridionale. (Construction and use of tariffs for volume determination in Ardenne spruce stands). Bul. Rech. Agron. Gembloux 12: 339-348.

RONDEUX, J. 1983: Inventaire des ressources forèstieres wallonnes. Guide méthodologique. (Inventory of Walloon forest resources. Methodology quide.) Gembloux, Belgium, 1983, vi+170pp.

RONDEUX, J. 1993. La mesure des arbres et des peuplements forestiers. (Measurement of forest trees and stands). Presses Agronomiques de Gembloux.

RONDEUX, J. 1994. Ressources naturalles et inventaire intégré: la logique du possible. Multi-resource (resource inventories-MRI: reasons and possibilities). Les Cahiers Forèstiers de Gembloux No. 12. Gembloux, Belgium: Faculté des Sciences Agronomiques de Gembloux. 18 pp.

RONDEUX, JACQUES. 1997. MRI questionnaire for Wallonia Forest, Belgium, 3 october 1997. Gemblaux, Belgium: Faculté Universitaire des Sciences Agronomiques de Gembloux. 5 pp. On EFI file, Joensuu, Finland.

RONDEUX, J.; J. FAGOT. 1983. Les encodeurs portables: une nouvelle voie pour l'enregistrement électronique des données en forêt. (Portable devices: a new way for electronical recording of data in forest). Gembloux: I.R.S.I.A., 16 p. (Document 83-1).

RONDEUX, J.; D. JACQUES. 1988. Tarifs de cubage pour les taillis de chênes et de bouleaux en Ardenne. (Volume tables for mixed oak (*Quercus petraea*) and birch (*Betula pendula*) coppice in the southern Ardennes). Revue Forestière Française, 40 (5): 387-392.

RONDEUX, J.; A. THILL. 1989. L'estimation de la productivité des peoplements d'épicéa commun *(Picea abies* Karst.) en Ardennes. (Site index curves for Norway spruce (*Picea abies*) stands in the Ardennes). Document-Section Écologie, Centre de Recherche et de Promotion Forestières (1989), no. 3, 18 pp.

RONDEUX, J.; C. LAURENT; A. THIBAUT. 1992. Construction d'une table de production pour le Douglas (*Pseudotsuga menziesii*) (Mirb.) Franco en Belgique. (Yield tables for Douglas fir (*Pseudotsuga menziesii* grown in Belgium). Bull. de Recherches Agronomique de Gembloux, 27 (3): 327-347.

RONDEUX, J.; GEORGE, B.; LECOMTE, H. 1997. Inventaire forèstier regional et applications cartographiques. (Regional forest inventories and maps). Silva Belgica 104(3): 7-17.

THILL, A.; R. PALM. 1975 a. Étude dendrométrique de l'épicéa commun. (Dendrometrical study of Norway spruce). Notes technique du Centre d'Écologie forestière 21, Gembloux.

THILL, A.; R. PALM. 1975 b. Production de l'épicéa commun dans le sud-ouest des Ardennes Belges. (Norway spruce yield in south-west Ardennes in Belgium). Centre d'Écologie forestière no. 28.

THILL, A.; R. PALM. 1983. Étude dendrométrique des ormes (*Ulmus glabra* Huds. et *Ulmus campestris* L.) Bulletin des Recherches Agronomiques de Gembloux 18 (4): 241-256 (Dendrometrical studies on *Ulmus glabra* and *U. campestris*).

TOUSSAINT, A.; J. FAGOT; H. LECOMTE; J. RONDEUX. 1983. Tarif de cubage peuplement pour le hêtre (*Fagus sylvatica* L.) en Wallonie. [Stand volume tables for beech (*Fagus sylvatica*) in Wallonia]. Bull. Rech. Agron. de Gembloux, 18 (3): 165-172.

WALTER, H. 1963. La productivité du tapis végétal Lejennia. (Productivity of vegetal layer in Lejennia). Rev. Bot. (Liège), 22.

WATERINCKZ, M. 1997. De bosinventarisatie van het Vlaamse Gewest: methodologie. (Forest inventories in the Flemish region: methods) Silva Belgica 104(3): 19-26.

WAUTHOZ, LÉON. 1965. Tables generales de cubage des arbres et des peuplements. (General volume tables for trees and stands). Laboratoire Forèstier de l'Université de Louvain, 166 pp.

WAUTHOZ, V. 1955. Rendements de l'épicéa dans ses cultures artificielles ardennaises. (Productivity of artificial cultures of Norway spruce in Ardennes). Bull. De la Soc. Roy. Forestière de Belgique, May 1955: 225-268.

5. DENMARK

General information

Land area: 42,530 sq. km (16,241 sq. mi.), forest and other wooded land 4,660 sq. km (1,799 sq. mi.), forest; 466,000 ha or 1,799 sq. mi. or 11 % of land area; volume 145 m^3/ha, biomass 82 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: industrial round wood 175 million m^3, fuel and charcoal 0.5 million m^3 total round wood 2.25 million m^3 (World Resources 1996-97, p. 220).

Forest vegetation: temperate mixed forests.

- Conifers 57 %
- Broad-leaved 35 %
- Shrubs 8 %

Main species: Norway spruce (*Picea abies*) - the most important species in Danish forest, Sitka spruce (*Picea sitchensis*), pine (*Pinus uncinata*), fir (*Abies alba*), European beech (*Fagus sylvatica*), oak (*Quercus robur*), Douglas-fir (*Pseudotsuga menziesii*), poplar sp. (*Populus* sp.), *Fraxinus excelsior, Ulmus glabra, Tilia platyphyllos, Betula* spp. *Sorbus aucuparia*. Acclimatized species (others than Douglas fir and Sitka spruce): A*bies grandis, Abies concolor, Abies nordmaniana, Pinus contorta, Larix leptolepis*.

Forestry education and research organization involved in the areas of forest mensuration and forest management (date of establishment in brackets):

- Danish Forest and Landscape Research Institute, Hörsholm (1901).
- The Royal Veterinary and Agricultural University, Unit of Forestry, Hörsholm (1936). The university was founded in 1858.

Publications:

- The Danish Forest Experiment Station published 42 volumes of the journal "Det Forstlige Forsogsvaesen i Danmar" (ISSN: 0367-2124).
- "Forest and Landscape Research" represents a reviewed continuation and enlargement of "Det Forstlige Forsøgsvaesen i Danmark". This publication is issued jointly by the Danish Forest and Landscape Research Institute and The Royal Veterinary and Agricultural University.
- Dansk Scovforenings Tidsskrift.
- Dansk Dendrologisk Årsskrift.

Early literature on forest: De Danske Skove by Vaupell C., 1863. P. G. Philipsens Forlag.

5.1. Tree measurement, volume and taper

In 1939 Sabroe determined form and form factor in Norway spruce. Ullens constructed an increment hammer in 1944/1945 (Christiansens 1945). Tests of various instruments, especially hypsometers were carried out by the Danish State Forest Experiment Station and presented by Lovengreen in 1952 who improved the JAL hypsometer which was described before in Switzerland by Flury in 1905 and recommended later (1954) for use by FAO (the principle of this device is based on four triangles which represents the faces of a tetrahedron).

Olsen (1971) advocated the use of the water displacement method being a fast and accurate procedure for determination of green volume of wood samples.

A general volume table for beech was constructed in Denmark in 1954 by Fog and Jansen, and one for Norway spruce by Olsen in 1976. In 1977 Olsen established the interrelation between basic density and ring width of Norway spruce. Andersen et al. (1982) examined and compared the tree-volume functions by cross-validation.

Compatible tree taper and volume functions have been developed by Madsen in 1985 for *Picea sitkensis, Pseudotsuga menziesii, Larix leptolepis, Abies alba* and *Abies grandis* as a part of a project to develop new volume and form equations suitable for computers. Two years later (1987) Madsen published volume equations for some important Danish (cultivated and native) tree species for different conversion limits and levels of accuracy. This is a remarkable work which contains total and merchantable volume for *Picea sitchensis, Pseudotsuga menziesii, Larix leptolepis, Abies alba, Abies nordmaniana, Fagus sylvatica, Quercus robur* and *Fraxinus excelsior*.

In 1992 Madsen developed a computer program for use of stem-taper functions for Norway spruce, Sitka spruce, Douglas-fir, Japanese larch, European silver fir and grand fir in Denmark. This work was followed in the same year by an appendix, completed by Madsen and Heusèr, to volume and stem-taper functions for Norway spruce in Denmark, analyses of basic data and functions.

In 1993 Madsen and Heusèr developed sets of logarithmic functions for predicting above ground stem volume and merchantable volume between stump height and top diameter of 5, 7 or 10 cm for Norway spruce. Their volume and stem-taper functions are based on the measurement of 4,587 trees and refer to spruce single trees in Denmark. The basic parameters refer to d = dbh, h = total tree height, D_g = stand diameter before thinning, d_3 and d_6 = stem diameters in 3 or 6 m height, H_g = stand height before thinning, T = age and d_l = predicted stem diameters at different heights (l) above ground.

Madsen's and Heusèr's volume functions are generally of the type:

$$\hat{v} \; or \; \hat{v}_s = \exp_e\left(b_0 + \sum_i b_i x_i + \frac{s_k^2}{2w_j}\right)$$

where $\hat{v}$ = the predicted total stem volume above ground for each tree;

$\hat{v}_s$ = the predicted merchantable volume above stump and above the top diameter s for each tree;

s in $\hat{v}_s$ assumes the values 5, 7 and 10 corresponding to the top diameter of the merchantable volume in cm;

x_i=the transformations of parameters d, h, D_g, H_g, T and the top-diameter limit a expresses in metres (a=0.00; 0.05; 0.07; or 0.10 m);

i assumes integer values in the interval $1 \le i \le 25$;

w_j=weight functions for variance homogenising;

j=assumes integer values in the interval $1 \le j \le 4$;

$\frac{s_k^2}{(2w_j)}$ = a correction term for logarithmic bias.

Madsen and Heusèr classified their models in "small volume functions" using for volume the parameters d, h, D_g and in some models (functions) d_3 or d_6, and "large volume functions" containing d, h, Dg, H_g and T, and in some models d_3 and d_6.

Examples of small and large volume functions are shown in Tables 5.1-1. and 5.1-2.

The developed stem-taper functions are of the following type:

$$\hat{d}_l^{\,2} = \left(\frac{\hat{v}_0}{\left(\frac{\pi}{4}\right)h} \sum_{i-1}^{10} b_i \left[\frac{l}{h}\right]^{i-4} \right), \; 0.49 < l < h$$

$\hat{d}_l^{\,2} = (\hat{d}_{0.49}^{\,2})$, $\qquad h_s \le l \le 0.49$

where $\hat{d}_l$= the predicted stem diameter at l metre above ground,

$\hat{v}_0$ = predicted total stem volume above stump height (h_s) calculated for the appropriate tree through a compatible stem volume function, h=total height of tree above ground

TABLE 5.1-1. Small volume functions for Norway spruce variating in type of functions and with different top-diameter limits. The extremes of the basic data are stated opposite each type of function.

Standard functions; $2.9 \le h \le 34.8\text{m}, 0.024 \le d \le 0.506\text{m}, 0.06 \le D_g \le 0.41\text{m}.$

$$\hat{v} = \exp_e(-1.753576 + 1.775814\, x_1 + 1.136852\, x_2 + 0.524851\, x_4 + 0.725722\, x_{24} - 1.108216\, x_{25} + 0.001411/w_3)$$

$$\hat{v}_5 = \exp_e(-1.968223 + 1.573607\, x_1 + 1.157948\, x_2 + 0.973479\, x_{15} - 1.685292\, x_{17} + 0.906558\, x_{18} + 0.244828\, x_{24} + 0.001306/w_3)$$

$$\hat{v}_7 = \exp_e(-2.115425 + 1.490901\, x_1 + 1.197033\, x_2 + 1.695886\, x_{15} - 2.376159\, x_{17} + 1.056454\, x_{18} + 0.236993\, x_{24} + 0.001331/w_3)$$

$$\hat{v}_{10} = \exp_e(-2.386383 + 1.361796\, x_1 + 1.285676\, x_2 + 2.544124\, x_{15} - 3.366831\, x_{17} + 1.064439\, x_{18} + 0.186363\, x_{24} + 0.001465/w_3)$$

Functions with d_6; $12.0 \le h \le 34.8\text{m}, d > a, 0.10 \le D_g \le 0.41\text{m}.$

$$\hat{v} = \exp_e(-1.438803 + 0.779034\, x_1 + 1.096649\, x_2 + 1.151673\, x_{12} + 1.347999\, x_{13} + 0.291075\, x_{24} + 0.000401/w_3)$$

$$\hat{v}_5 = \exp_e(-1.509697 + 0.705851\, x_1 + 1.107120\, x_2 + 1.208675\, x_{12} + 1.335448\, x_{13} + 1.234132\, x_{22} + 0.222961\, x_{24} + 0.000310/w_3)$$

$$\hat{v}_7 = \exp_e(-1.595448 + 0.681635\, x_1 + 1.126241\, x_2 + 1.225642\, x_{12} + 1.409601\, x_{13} + 1.007488\, x_{22} + 0.237495\, x_{24} + 0.000308/w_3)$$

$$\hat{v}_{10} = \exp_e(-1.927629 + 0.597723\, x_1 + 1.203896\, x_2 + 1.278350\, x_{12} + 1.715717\, x_{13} + 1.007007\, x_{22} + 0.241250\, x_{24} + 0.000429/w_4)$$

Functions with d_3: $6.0 \le h < 15.0\text{m}, d > a, 0.06 \le D_g \le 0.28\text{m}.$

$$\hat{v} = \exp_e(-0.758842 + 0.813140\, x_1 + 0.960253\, x_2 + 1.104489\, x_{10} + 0.707386\, x_{11} + 0.083253\, x_3 + 0.000610/w_3)$$

$$\hat{v}_5 = \exp_e(-0.942588 + 0.645181\, x_1 + 0.997074\, x_2 + 1.261699\, x_{10} + 0.723476\, x_{11} + 0.855003\, x_{20} + 0.068296\, x_3 + 0.000509/w_3)$$

$$\hat{v}_7 = \exp_e(-1.360570 + 0.528361\, x_1 + 1.092444\, x_2 + 1.326014\, x_{10} + 1.167152\, x_{11} + 1.006636\, x_{20} + 0.066332\, x_3 + 0.000541/w_3)$$

SOURCE: Madsen, S. and M. Heusèr: “Volume and stem-taper functions for Norway spruce in Denmark”, “Forest and Landscape Research”, 1993, vol. 1, no. 1, p. 61, table 1

TABLE 5.1-2. Large volume functions for Norway spruce variating in type of functions and with different top-diameter limits. The extremes of the basic data are stated opposite each type of function.

Standard functions; $2.9 \le h \le 34.8\text{m}, 0.024 \le d \le 0.506\text{m}, 0.06 \le D_g \le 0.41\text{m}, 6 \le H_g \le 32\text{m}, 18 \le T \le 99$ years.

$$\hat{v} = \exp_e(-1.719802 + 1.789036\, x_1 + 1.138836\, x_2 + 0.658342\, x_4 - 0.023795\, x_5 - 0.018546\, x_7 + 0.072345\, x_8 + 0.001477/w_3)$$

$$\hat{v}_5 = \exp_e(-1.899967 + 1.586343\, x_1 + 1.146216\, x_2 + 1.751575\, x_{15} - 2.358959\, x_{17} + 1.048696\, x_{18} - 0.018779\, x_5 - 0.015727\, x_7 + 0.061089\, x_8 + 0.001364/w_3)$$

$$\hat{v}_7 = \exp_e(-2.085199 + 1.447811\, x_1 + 1.198480\, x_2 + 2.652520\, x_{15} - 3.510579\, x_{17} + 1.110589\, x_{18} - 0.022766\, x_5 - 0.018828\, x_7 + 0.062721\, x_8 + 0.001383/w_3)$$

$$\hat{v}_{10} = \exp_e(-2.324993 + 1.268038\, x_1 + 1.293226\, x_2 + 3.383499\, x_{15} - 4.573888\, x_{17} + 1.079804\, x_{18} - 0.032842\, x_5 - 0.029587\, x_7 + 0.072835\, x_8 + 0.001529/w_3)$$

TABLE 5.1-2 (continuation)

Functions with d_6; $12.0 \leq h \leq 34.8$m, $d > a$, $0.10 \leq D_g \leq 0.41$m, $10 \leq H_g \leq 32$m, $24 \leq T \leq 99$ years.

$\hat{v} = \exp_e(-0.021347 + 0.770419\,x_1 + 1.059245\,x_2 + 1.163844\,x_{12} + 1.257098\,x_{13} + 0.014925\,x_7 - 0.711578\,x_8 + 0.093827\,x_9 + 0.000407/w_3)$

$\hat{v}_5 = \exp_e(-0.478477 + 0.695085\,x_1 + 1.086367\,x_2 + 1.214100\,x_{12} + 1.256466\,x_{13} + 1.253393\,x_{22} + 0.011726\,x_7 - 0.537743\,x_8 + 0.071198\,x_9 + 0.000316/w_3)$

$\hat{v}_7 = \exp_e(-0.466159 + 0.670024\,x_1 + 1.101645\,x_2 + 1.231687\,x_{12} + 1.309858\,x_{13} + 0.998043\,x_{22} + 0.011925\,x_7 - 0.581529\,x_8 + 0.077074\,x_9 + 0.000313/w_3)$

$\hat{v}_{10} = \exp_e(-0.484479 + 0.580622\,x_1 + 1.169852\,x_2 + 1.288962\,x_{12} + 1.573010\,x_{13} + 1.002892\,x_{22} + 0.012788\,x_7 - 0.716035\,x_8 + 0.092941\,x_9 + 0.000438/w_4)$

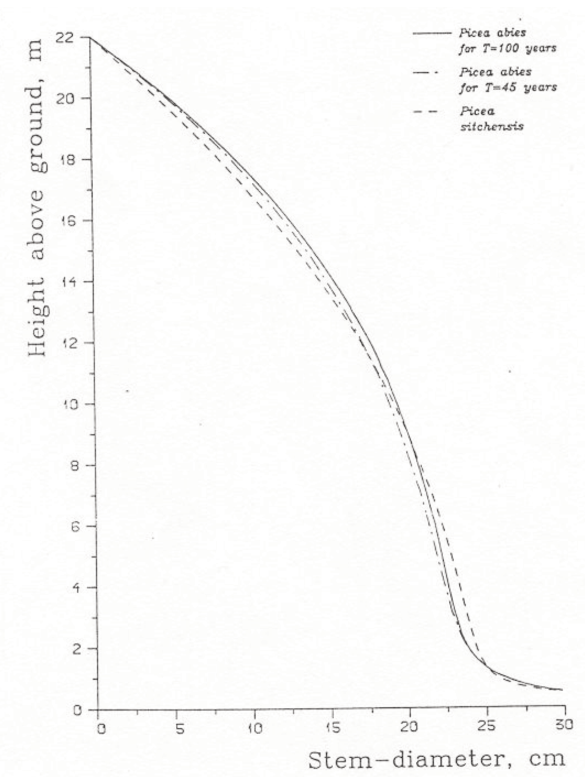
Functions with d_3; $6.0 \leq h < 15.0$m, $d > a$, $0.06 \leq D_g \leq 0.28$m, $6 \leq H_g \leq 21$m, $18 \leq T \leq 62$ years.

$\hat{v} = \exp_e(-1.043385 + 0.809712\,x_1 + 0.946761\,x_2 + 1.134382\,x_{10} + 0.787177\,x_{11} + 0.008754\,x_7 + 0.009873\,x_9 + 0.000665/w_3)$

$\hat{v}_5 = \exp_e(-1.150091 + 0.635593\,x_1 + 0.973742\,x_2 + 1.293576\,x_{10} + 0.754850\,x_{11} + 0.839648\,x_{20} + 0.006392\,x_7 + 0.009385\,x_9 + 0.000540/w_3)$

$\hat{v}_7 = \exp_e(-1.497349 + 0.522648\,x_1 + 1.054983\,x_2 + 1.358463\,x_{10} + 1.127991\,x_{11} + 0.990782\,x_{20} + 0.005530\,x_7 + 0.009137\,x_9 + 0.000564/w_3)$

SOURCE: Madsen, S. and M. Heusèr: "Volume and stem-taper functions for Norway spruce in Denmark", "Forest and Landscape Research", 1993, vol. 1, no. 1, p. 65, table 4



The cited authors noted (p. 70) that "The compatible stem volume function holds the same variables and is based on the same basic material as the large standard function for total stem volume above ground in table 4 (in our text table 5.1-2.). Comparative graphical development of some stem taper functions is given in Figure. 5.1-1.

Fig. 5.1-1. Stem taper functions, for d = 25 cm, h = 22 cm, D_g = 25 cm, H_g = 22 cm

SOURCE: Madsen, S. and M. Heusèr: "Volume and stem taper functions for Norway spruce in Denmark", Forest and Landscape Research, 1993, vol. 1, no. 1, p. 71, Fig. 2.

The problem of growth equations was examined in a short working paper by Garcia (1997) at the Agricultural University of Copenhagen.

Cited authors:

Andersen 1982, Christiansen 1945, Fog and Jensen 1954, Garcia 1997, Lovengreen 1952, Madsen 1985, 1987, 1992; Madsen and Heusèr 1993, Olsen 1971, 1976, 1977; Sabroe 1939.

5.2. Forest site evaluation

A remarkable study on the problem of yield tables standardization as a criterion for evaluation of forest site productivity was presented by Møller in 1960. Møller (1933, 1960) applied in his yield tables a method of standardization which was considered by Pardé (1961, p. 273) as superior to others: “for every species average height at the end of the cycle in the fifth and last site class of productivity (lowest) represents a half of the first class at the same age”.

The heights which correspond to the second, third and fourth classes divide the precedent interval in equal parts. Figure 5.2.-2. presents the case of beech where the average heights are normalized at the age of 100 years, but in case of oak this age is 120 years and 50 years for spruce which is represented in Denmark only by plantations.

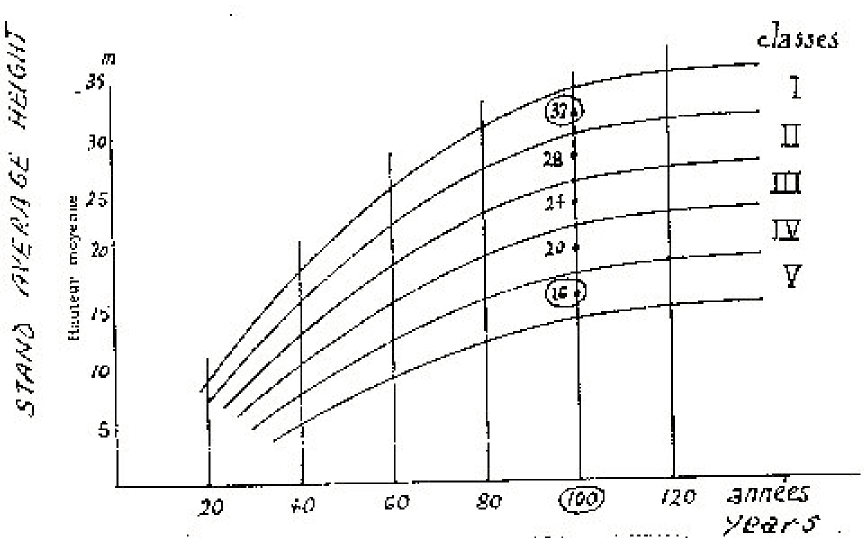


Fig. 5.2.-2. Møller’s (1960) procedure of standardization (normalization) of yield tables - beech case.
SOURCE: Reproduced after Pardé 1961, p. 272, fig. 127, Dendrometrie

According to Vanclay (1994) biomass production (tons/hectare/year) may provide an acceptable base for site evaluation but it should be taken into account that it refers just to one species or a specified group of species. In the mixed forests an index of the site is more useful than an index. Notwithstanding these limitations, we are in agreement with Vanclay that the historic volume production of a well-stocked and well-managed forest may provide a good measure of site productivity, and may serve as a benchmark with which to test other more practical measures of site. In fact this idea is not new and was practiced in Germany during the period of early yield tables (see chapter 2. Germany).

Based on two large-scale silvicultural experiments of beech natural regeneration Skovsgaard and Henriksen (1995, 1996) demonstrated a significant increase of site productivity during consecutive generations of naturally regenerated and planted beech. Causes of this phenomenon are not explained.

Cited authors:

Møller 1933, 1960; Pardé 1961, Skovsgaard and Henriksen 1995, 1996; Vanclay 1994.

5.3. Stand structure

Plantations are predominant in Denmark and there are a few “natural” forests in the country. The National Forest and Nature Agency established (1994) the following definition of natural forests: “Natural forests originate in the original forest cover, e.g. forest reproduced naturally”. The natural forest is thus a forest which has spontaneously generated itself on the location and which consists of naturally immigrant tree species. Natural forests can be more or less influenced by culture, e.g. by logging or regeneration techniques, but the forests must not have been subject to regeneration by sowing or planting.” Natural succession, spontaneous development processes, but also anthropogenic influences characterize the Danish definition of natural forests.

In Danish forests, predominantly man-made forests, the problem of thinnings - as artificial mortality - is considered very important and was investigated in detail especially by Møller and Holmsgaard (1947): crown thinning, thinning from below and selection thinning from above - an experiment with Norway spruce. An experiment in spacing of Norway spruce was carried out by Kjersgård (1964). The problem of thinnings was examined in 1974-1976 by Bryndum - 1974 (spruce thinning), 1976 (thinning experiments with Norway spruce on fertile soils).

Height-diameter relationship with logarithmic diameter was examined by Henricksen in 1950 and the allocation of trees to diameter classes for beech, in 1951.

Stem number reduction and diameter development in non-thinned Norway spruce stands with various spacings was examined by Heding (1969), for *Picea sitchensis* by Skovsgaard (1988) who discovered that unthinned Sitka spruce stands in Denmark do not obey the self-thinning rule (v = kN-1/2) and the exponent is approximately -0.95 to -0.5 and diameter distribution develops a clear bimodality. It should be mentioned that Sitka spruce is an alternative to the Norway spruce in some sites where its volume (yield) is 10-50 % higher than that of the Norway spruce: A special study on structure and development of unthinned stands of Sitka spruce was completed by Skovsgaard in 1994.

One hundred years ago the landscape in western Jutland was dominated by heathland and oak scrubs representing the only woodlands in the area and considered to be remnants of the original forest (*Quercus robur* and *Q. petraea*). Degn (1989) determined age distribution of each scrub which presented different aspects that suggested human influence and established that more than 50 % of trees are from the 1900-1914 period, none of them dating later than 1950, the oldest tree dated from 1844 and had 18 cm stem diameter and many trees stopped with growing or died because of competition (Forestry Abstracts 7385/1989).

The distribution of trees by diameter categories was analyzed by Vanclay (1994) who considered that the SB distribution is more flexible and can represent some bi-model distribution of Sitka spruce trees mentioned before.

A revue of competition indices (1992) and their critical examination was completed by Vanclay (1994). He considered that "competition indices are an attempt to quantify in a simple expression the effects of neighbouring plants on the growth of an individual tree" (1992, p. 446) and "some limitations are evident in most studies of competition in forest stands and these may contribute to our present inability to define a general competition index" (p. 61); "In their present stage of development competition indices are of limited use for management-oriented models of mixed forests. However, this remains the considerable scope for further research in this area" (1992, p. 62).

An interesting detailed study on the landscape history (Fritzboger and Emborg 1996) and the structure of Suserup Skop, a near-natural temperate deciduous forest in Denmark (Emborg et al. 1996) was published in "Forest and Landscape Research". Suserup Skov has now only 19.2 ha and is considered as a near-natural forest dominated by *Fagus sylvatica* L., *Fraxinus excelsior* L., *Quercus robur* L. and *Ulmus glabra* Huds. This forest was divided into three parts: one dominated by *Fagus* and characterized by a minimum human impact during the last 200 years, part B - grazed until 1792 and now dominated by *Quercus* and *Fagus* and part C - a strip dominated by *Alnus glutinos*a. Figure

5.3.-1. presents diameter class distributions which are different from one species to another and reflect the ecological role of each species. In all cases the diameter-distributions resemble negative exponential functions for trees 3-60 cm dbh which is characteristic for natural temperate forests affected by small disturbances.

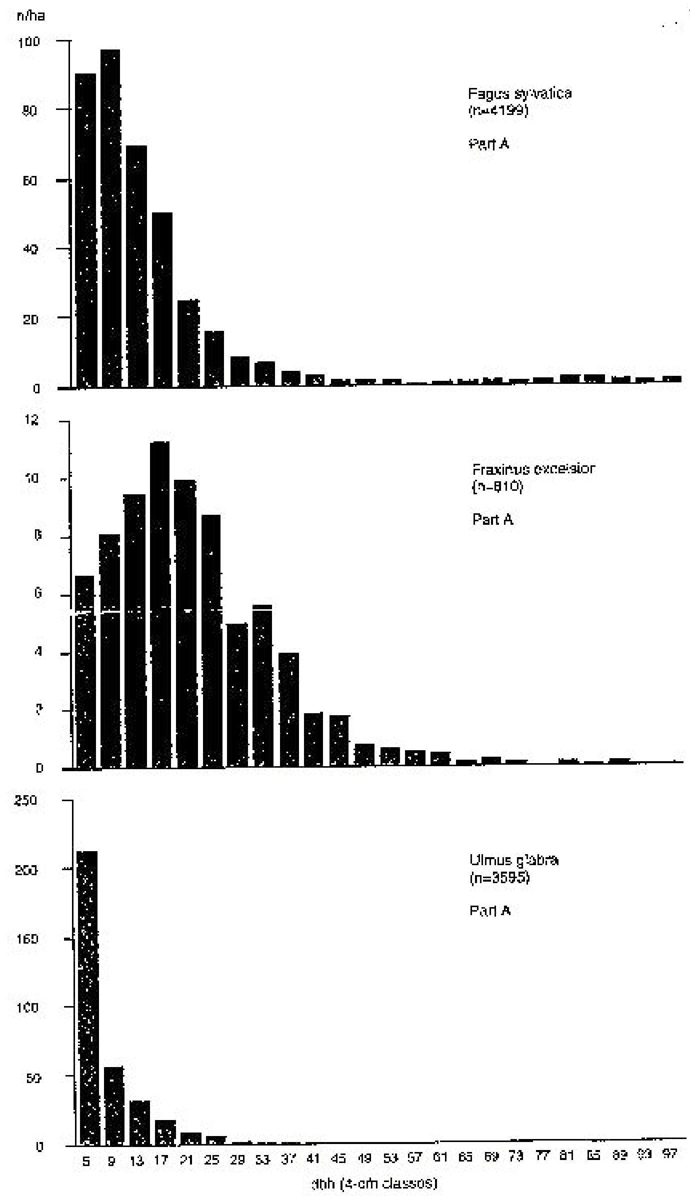


Fig. 5.3.-1. Part A

Fig. 5.3.-1. Part B

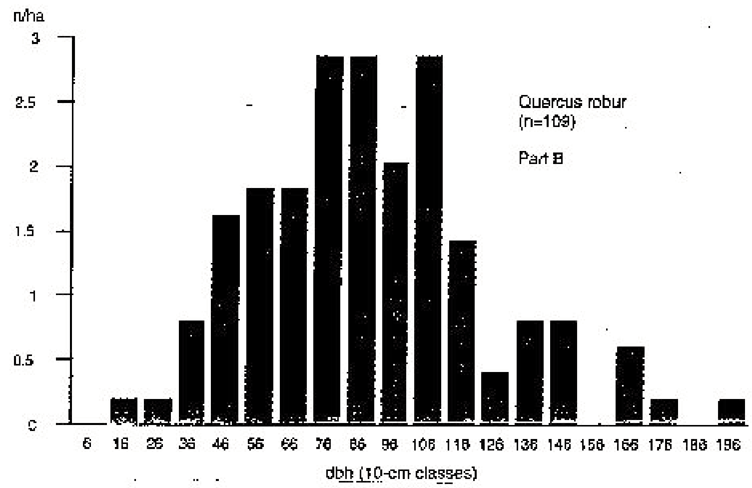


Fig. 5.3.-1. Diameter class distribution of different tree species in Suserup Skov, a near natural temperate deciduous forest in Denmark. SOURCE: Emborg et al. 1996, p. 320, 321, figs. 6 and 7 in Forest Landscape Research vol. 1, no. 4, Denmark: "Landscape history of the deciduous for best Suserup Skov, Denmark, before 1925".

Cited authors:

Bryndum 1974, 1976; Degn 1989, Emborg et al. 1996, Fritzboger and Emborg 1996, Heding 1969, Henrichsen 1950, 1951; Kiersgård 1964, Moller (Moeller) and Holmsgaard 1947, Skovsgaard 1988, 1994; Vanclay 1992, 1994.

5.4. Stand growth and yield. Biomass

Early yield tables have been constructed by Møller in 1933 for beech, oak and spruce and tested again in 1953 by the previous author and Nielsen.

Ladefoged investigated in 1939 the periodicity of root growth of the main species in Denmark and later, in 1959, Holstener-Jörgensen published the results of his investigations of the root systems, of oak, beech and Norway spruce on ground water, affected moraine soils and estimated the biomass of the roots of these species.

Møller (1949) developed detailed studies on leaves quantity, the loss of chemical elements and biomass production of forest.

The calculation of increment percent was presented in 1940 by Christensen. Bornebusch (1944) analyzed the connection between thinning and increment production in beech and Henriksen (1953) determined the yield in the beech stands.

A remarkable book on the increment and health condition of Sitka spruce in

Denmark was published by Henriksen in 1958.

In 1981 Wunsch verified for Norway spruce a yield model independent of the thinning regime and in 1983 Magnussen constructed yield tables for Norway spruce on clay-rich soils in southern Denmark having three yield classes: m.a.i. 14, 16 and 18 m^3/ha and giving data for stand ages 14 to 50 years. In the same year (1983) Jensen compared growth of silver fir with the growth of Norway spruce in pure and mixed stands on sandy soils in the western parts of Denmark. Elingård-Larsen and Jensen (1985) constructed increment tables for *Abies procera*.

Madsen (1985) analyzed the mean tree method for direct computation of stand volume (Danish formulae) and suggested that the errors frequently found in the practice are caused by the discrepancy between the usual stand height concepts and the functions for wood volume and the employed form factors.

Korsgaard completed a manual for the stand table projection simulation model in 1988.

A remarkable synthesis on “Danish yield tables in the past century” was published by Holten-Anderson (1989) who analyzed and classified them according to the methodology used in their construction.

Growth and yield estimation from successive forest inventories was a subject of the IUFRO conference held in Copenhagen in June 1993 (Vanclay, Skovsgaard and Gertner editors).

Sorensen (1993) compared empiric and prognostic yield tables for grand fir [*Abies grandis* (Dougl.) Lindley] in Denmark, constructed in 1992 by him and Thygesen (The empirical yield table is based on graphical smoothing assuming a light low thinning, but in the prognostic table the first two thinnings are a kind of high thinning with the purpose of removing big trees of low quality, followed by light low thinnings, the result is a more even stand with less low quality trees at the end of the rotation). According to these authors “The comparison of the two yield tables for Grand fir shows that there is a reduction in mean annual ring width with the high thinning variant, resulting in a lower crop diameter. There is also an effect on economic return of the high thinning, by means of larger incomes in the beginning of the rotation and an improvement of crop tree quality” (Sorensen 1993, p. 260).

In 1994 CAB International published in the UK an outstanding textbook written by Jerome K. Vanclay (Professor at the Royal Veterinary and Agricultural University, Denmark): “Modelling Forest Growth and Yield. Application to Mixed Tropical Forests”. This book provides an introduction into growth modelling, especially in mixed forests. It is nor a “how to” manual with the instructions to construct a model, but a review of different aspects of modelling in growth and yield putting an emphasis on empirical-statistical models and less on physiological process-type models. This reference manual contains: whole stand models, size class models, simple-tree models, data requirements, constructing growth models, forest site evaluation, modelling diameter increment, mortality and merchantibility, regeneration and recruitment, validation and calibration, using growth models, future directions.

Many pertinent and critical comments of Vanclay deserve to be underlined, but only very few will be mentioned in this text.

“A growth model is a synthesis of dynamic inventory data indicating growth and change in the forest ... A model is an abstraction, or a simplified representation of some aspects of reality (and should not be confused with the normative meaning of the word, sometimes worthy of being imitated” (p. 3 and 4).

Vanclay classified models on the level of detail they provide: “1) whole stand models; 2) size class models and 3) single-tree models. Other classes of models are beyond the scope of this book, but they are mentioned: a) process models - known as mechanistic or physiological models that attempt to model the processes of growth having as input the light, temperature and soil nutrient levels and modelling photosynthesis, respiration and the allocation of photosynthesis to roots, stems and leaves; b) ecosystem succession models attempt to model species succession, but are generally unable to provide reliable information on timber yields. It is useful to distinguish between models for understanding (e.g. process models) and models for prediction, providing information for forest management ... Finally, irrespective of its detail a model may be deterministic or stochastic. A deterministic growth model gives an estimate of the expected growth of a forest stand, in the same way that the mean indicates the expected trend for a population. A stochastic model (the term “stochastic” is used in preference to the term “probabilistic” which is sometimes used in other contexts) attempts to illustrate this natural variation by providing different predictions, each with a specific probability of occurrence” (Vanclay 1994, p. 6, 7).

“Whole stand models are these growth and yield models in which the basic units of modelling are stand parameters such as basal area, stocking, stand volume and parameters characterizing the diameter distribution” e.g.: stand growth and yield tables, growth and yield equations (p. 14). “Size class models employ a class of trees as the basic unit for modelling” (p. 34) and contains size class models, matrix models and cohort models. Single tree and tree list models: ”the distinction between them is based on the use of an expansion factor which indicates the number of stems (per hectare or per plot) represented by each tree record” (p. 57). Single tree models can be, on the other hand, distance-dependent or distance-independent, depending on the fact if the distance between trees is taken or not into account. Vanclay remarked: “You should have noticed that the many alternative modelling approaches form a continuum rather than discrete classes, and that the classification of models under various headings is an arbitrary one for the purposes of discussion. In reality, possible modelling approaches merge seamlessly from one to another” (p. 32).

Concerning Bertalanffy’s equation of growth applied to stands Vanclay (1994) underlined that “the deviation of the equation is rather different, because catabolism may not remain proportional to stand volume or basal area (hartwood does not respire) and anabolism is asymptotic to an upper limit, reaches at canopy closure” (p. 109).

Speaking about future direction Vanclay (1994) considered that: “Many forest growth models are excessively empirical, and a stronger basis for the functional relationships used in our models will help to (i) provide a better understanding of the processes involved, (ii) identify deficiencies in current knowledge and gaps in our empirical data, and should (iii) lead to models that extrapolate more safely to new situations” (p. 246). Referring to presentation of information Vanclay (1994) wrote: “The technology exists to link growth models with other resource information (e.g. geographic information systems [GIS], inventory databases) interactively and to display outputs on a virtual reality (VR) interface. Model users could wear a VR headset, and take a magic carpet ride over their forests, stopping to study sites of interest, watching alternative silvicultural experiments unfold before their eyes, turning back the clock to try different alternatives, and observing several crop rotations on different sites to gauge the long-term effects. A VR interface could include non-visual outputs, allowing users to hear the birds, to smell the flowers, and feel the microclimate in the forest. Thus users could devise a management regime through their own experience, in a relatively short time. This may sound like science fiction, but the technology exists, and we could devise and implement models in this way if we thought it was appropriate (subject to sufficient financial and other resources)” (p. 249).

In the next year, 1995, Skovsgaard presented growth trends of forests in Denmark, Ireland and Great Britain, and in cooperation with Vanclay and Garcia exposed an overview of approaches to evaluate forest growth models which in their opinion “should include qualitative as well as quantitative examinations of the model” and insisted on model logic and its theoretical and biological realism.

Cited authors:

Bornebusch 1944, Christensen 1940, Elingård-Larsen and Jensen 1985, Henriksen 1953, 1958; Holstener-Jörgensen 1959, Holten-Andersen 1989, Jensen 1983, Korsgaard 1988, Ladefoged 1939, Madsen 1985, Magnussen 1983, Møller 1933, 1940; Møller and Nielsen 1953, Skovsgaard 1995, Skovsgaard et al. 1995, Sorensen 1993, Vanclay 1994, Vanclay et al. (eds.) 1993, Wunsch 1981.

5.5. Tree-ring studies

The periodicity of wood formation was studies in Denmark by Ladefoged (1952).

In 1955 Holmsgaard published a comprehensive study on tree-ring analyses of Danish forest trees (246 pp.). He mentioned a few works performed by Reventlow and published posthumously in 1879 and (1934), Lovengreen 1935 and 1951 and Holmsgaard 1945. According to Holmsgaard "it is difficult to draw conclusions in Denmark based on investigations performed in neighbouring countries. He mentioned that "Reventlow (1879) made extensive ring measurements of 61 oaks and 181 beeches, and he calculated the mean ring-width for each year in the period from 1763 to 1792 for four groups of trees" in order to find out whether climatic conditions or other chance conditions furthered or checked the growth in any year as compared to that in any other year (p. 25), but Reventlow did not indicate under which climatic conditions the variation of tree ring widths was caused. Holmsgaard mentioned that Lükten (1891) found that the increment of silver fir in 5-year periods agreed with the relative precipitations of the period (mean precipitation for the whole year divided by the mean temperature for March-November. After Lovengreen (1935) volume increment of Norway spruce in the Früsenborg forest district depended on April-July rainfall. Holmsgaard (1945) showed that spruce ring-width in a heath plantation on poor sandy soil depends mainly on May-July rainfall, but in the case of Scots pine on good soils there is a remarkable correlation between ring-width and February-April temperatures.

Holmsgaard's (1955) investigations refer to beech, Norway spruce, oak and other species. His work presents the investigated data, the methods applied and their accuracy, ring variations at different heights above ground, ring variations due to thinnings, seed-bearing, ring variations in stands of different provenances, ring variations in different localities and their dependency on the stand age, ring variations in beech, in a stand border affected by the wind and in isolated beeches, and on the application of tree ring indices in the correction of increment investigations.

Cited authors:

Holmsgaard 1945 a, 1945 b, 1955; Ladefoged 1952, Lovengreen 1935, 1951; Lütken 1891, Reventlow 1879.

5.6. Forest inventory

Available information on forest inventory problems are very scarce and refer to 1991-1997 period but they are sufficient to appreciate the actual high level of concepts (MRI), methods and techniques (remote sensing and existence of permanent plots for monitoring).

Olsen (1991) presented the use of SPOT data (satellite imagery) in the digital mapping of Danish forests. This work was a part of a major Nordic research project sponsored by Smarbetsnämden för Nordisk Skogforskning initiated in 1986 to investigate the possibilities of using remotely sensed satellite data for forest management planning. The results were promising but a lot of aspects have not been clarified. (For. Abs. 7016/1993).

In 1996 Dralle and Rudemo estimated stem number of a thinning experiment by kernel smoothing of digitized aerial panchromatic photos. The number of stems per hectare estimated from the number of maxima above a certain level of smoothed image (For. Abs. 269/1998).

An interesting discussion was summarized in a work by Vanclay (1992) on permanent plots for multiple objectives by definiting goals and resolving conflicts.

The recent data on forest inventory situation in Denmark are included in a country report on forest inventory and survey published in 1997 (Plum, P. M.) by European Commission (25 pp).

For the future development of multi - resource forest inventories (MRI) a special very short questionnaire was completed in 1997 by Fleming Skov.

Cited authors:

Dralle and Rudemo 1996, Olsen 1991, Plum 1997, Skov 1997, Vanclay 1992.

5.7. Chronology of selected events

1879 (1934) - posthumous publication: The first Danish tree ring studies performed by Reventlow.

1933: Early yield tables (tested again in 1953) for beech, oak and spruce [C. M. Møller (Moeller)].

1954: General volume table for beech in Denmark (D. Fog and A. Jensen)

1955: Tree-ring analyses of Danish forest trees (Erik Holmsgaard).

1992: Permanent plots for multiple objectives (Jerome K. Vanclay

1985: Compatible tree taper and volume functions for five different conifers: *Picea sitchensis, Pseudotsuga menziesii, Larix leptolepis, Abies alba, Abies* *grandis* (A. F. Madsen).

1988: A manual for the stand table projection simulation model (S. Korsgaard).

1989: Danish yield tables in the past century (P. Holten-Andersen).

1991, 1996: Application of remote sensing (aerial photographs and satellite imagery) in forest mensuration (H. H. Olsen; K. Dralle and M. Rudemo).

1993: Volume and stem taper functions for Norway spruce in Denmark - small and large functions for tree volume (S. Madsen and M. Heuser).

1994: Modelling forest growth and yield (Jerome K. Vanclay).

1997: A country report on forest inventory and survey (Peter Munk Plum).

5.8. Selected contributors

Author	Printing years	Field
C.D.F. Reventlow	1879 (1934)	6
J. A. Lovengreen	1930s	6
C. M. Møller	1930s-1960s	2, 4
E. Holmsgaard	1940s-1950s	6
H. A. Henricksen	1950s	3, 4
S. F. Madsen	1980s-1990s	1, 4
J. P. Skovsgaard	1980s-1990s	2, 3, 4
J. K. Vanclay	1990s	2, 3, 4

1 = tree, 2 = site evaluation, 3 = stand structure, 4 = stand growth and yield, 6 = tree-ring studies, 7 = forest inventory

5.9. Comments

The landscape of Denmark represents a sandy plain resulted after the last glacial period. The predominant species were oaks (*Quercus robur* and *Q. petraea*). These original postglacial forests have been destroyed by human activities and abusive grazing. Present forest are dominated by even-aged type of plantations and this is the reason why the main problems of forest mensuration in this country have been concentrated on the construction of volume tables (especially those based on step taper functions (S. Madsen, S. Heuser/and Standardized yield tables for even-aged stands (Møller 1933, 1963). One of the most important problem is that of thinnings (as artificial mortality) and a lot of works were published on this subject.

On the other hand, the remarkable works of Vanclay in the field of modelling (especially of mixed stands) ought to be mentioned.

It is interesting to underline that in Denmark was developed early tree-ring study. A comprehensive study in this field was completed by Reventhlow in 1879 on oaks and beech trees and republished in 1934.

The methods and techniques applied in forest inventory are at European standards (permanent plots, statistical methods, remote sensing and GIS, forest monitoring and willingness to sustain multi resource forest inventories (MRI)).

The following is the repartition of the 64 cited papers:

(5.1) Tree measurement, volume and taper	20 %
(5.2) Forest site evaluation	9 %
(5.3) Stand structure	22 %
(5.4) Stand growth and yield. Biomass	30 %
(5.5) Tree ring studies	11 %
(5.6) Forest inventory	8 %
Total	100 %

Out of 64 mentioned works 52 % have been published after 1980 and 28 % after 1990.

The major topics of Danish forest mensuration could be considered stand growth, structure and tree measurement.

References

ANDERSEN, S.; MADSEN, S. F.; RUDEMO, M. 1982. Examination and comparison of tree-volume functions by cross-validation. Forstl. Forsogsv. Danm. 38: 273-286.

BORNEBUSCH, C. H. 1944. Udhugning og Produktion i Bogeskov. Forsog i Aarhus Kommunes Skove. (Thinning and increment production in beech). Forst. Forsogsv. Danm. 16: 273-304.

BRYNDUM, H. 1974. Rødgranhugstforsoget på Ravnholt. (A thinning experiment in Norway spruce at Ravnholt Estate). Forstl. Forsogsv. Danm. 34: 1-159.

CHRISTENSEN, C. C. 1940. Tilvaekst-procentberegning. (Calculation of increment percent). Dansk Skovforen. Tidsskr. 25: 448-455.

CHRISTIANSEN, ERIK. 1945. Jagmästare G. Ullenstilvacksthammer. (Ullen's increment hammer). Dansk Skovforen Tidsskr. 30: 509-511.

DEGN, H. J. 1989. Altersfordeling of ege (*Quercus robur* og *Q. petraea*) fra 4 vestjyske egekrat. (Age distribution of oaks [*Quercus robur* and *Q. petraea*] in 4 oak scrubs). Dansk Dendrologisk Årsskrift 7: 22-29.

DRALLE, K.; RUDEMO, M. 1996. Stem number estimation by kernel smoothing of aerial photos. Canadian Journal of Forest Research 26(7): 1228-1236.

ELINGÅRD-LARSEN, E.; JENSEN, N. P. D. 1985. Tilvaekstoversigt for nobilis. (Increment table for *Abies procera*). Dansk Skovforenings Tidsskrift 70 (3): 249-272.

EMBORG, JENS; CHRISTENSEN, MORTEN; JACOB HEILMANN-CLAUSEN. 1996. The structure of Suserup Skov, a near-natural temperate deciduous forest in Denmark. For. and Landsc. Res. 1: 311-333.

F.A.O. 1954. Dendromètrie Jal.-Note sur l'équipment A.2.54 du ler février 1954, 2 pp., Rome. (Jal hypsometer. Note on equipment A.2.54. of 1st of February 1954).

FOG, D.; A. JENSEN. 1954. General volume table for beech in Denmark. Det Forstlige Forstgsw. i. r. Danmark no. 171: 93-197.

FRITZBOGER, BO.; JEANS EMBORG. 1996. Landscape history of the deciduous forest Suserup Skov, Denmark, before 1925. For. and Landsc. Research 1: 291-309.

GARCIA, O. 1997. Another look at growth equations. Working paper, Royal Veterinary and Agricultural University, Copenhagen, 7 pp.

HEDING, N. 1969. Stamtalsreduktion og diameterrudvikling i ikketynnede rødgranbevoksninger med. forskellige planteafstande (Stem-number reduction and diameter development in non-thinned Norway spruce stands with various spacings). Forstl. Forsogsv. Danm. 32: 189-243.

HENRICKSEN, H. A. 1950. Hojde-diameter diagram med logaritmisk diameter. (Height-diameter diagram with logarithmic diameter). Dans Skovforen. Tidsskr. 35: 193-202.

HENRICKSEN, H. A. 1951. Allocation to diameter classes for beech. Saertryk af det forstlige Fors. i Danmark. No. 163.

HENRICKSEN, H. A. 1953. Die Holzmasse der Buche. (Yield of beech). Saertryk af det forstlige Fors. i Danmark no. 172.

HENRICKSEN, H. A. 1958. Sitkagranens vaekst og sundhedstilstand i Danmark. (The increment of Sitka spruce in Denmark). Forst. Forsogsv. Danmark 24: 1-372.

HOLMSGAARD, E. 1945. Arringsanalyser fra Midtjylland. (Tree-ring analyses in Jutland). Dansk Skovforenings Tidsskr. 30. Published also in Schweizerische Zeitschr. Forstwesen 96.

HOLMSGAARD, ERIK. 1955. Arringsanalyser of Danske Skovtraeer. (Tree-ring analyses of Danish forest trees). Det forstlige Forsogsoesen i Danmark, 22 (1): 1-246. (Selections from the author's summary). Historical Review in Tree-Ring Bull. vol. 21, no. 1-4: 25-27.

HOLSTENER-JÖRGENSEN, H. 1959. Investigations of root systems of oak, beech and Norway spruce on ground-water-affected moraine soils with a contribution to elucidation of evapotranspiration of stands. Det forstlige Forsogsvaesen i Danmark, Band XXV, pp. 227-289.

HOLTEN-ANDERSEN, P. 1989. Danish yield tables in the past century. Forstlige Forsogsvaesen i Danmark 42 (2): 71-145.

JENSEN, A. M. 1983. Aedelgranens (*Abies alba* Mill) vaekst sammenlignet med rødgranens [*Picea abies* (L.) Karst.] i henholdsvis rene og blandede beroksninger på sandede jorder i Midt- og Vestjylland. (Growth of silver fir (*Abies alba* Mill.) compared with the growth of Norway spruce [*Picea abies* (L.) Karst] in pure and mixed stands on sandy soils in the western parts of Denmark). Medd. Skovbrugsinst., Raekke 2: Forskning, 14.

KJERSGÅRD, O. 1964. Et planteafstandsforsg i rødgran. (An experiment in spacing of Norway spruce). Forstl. Forsogsv. Danm. 29: 55-68.

KORSGAARD, S. 1988. A manual for the stand table projection simulation model. Viborg, Denmark, 78 pp., Danish Land Development Service.

LADEFOGED, K. 1939. Untersuchungen über die Periodizität im Ausbruch und Längenwachstum der Wurzeln bei einigen unserer gewöhnlichsten Waldbäume. (Researches on periodicity of roots growth in length of our common trees). Det. Forstl. Forsogsvesen i Danm. 16: 365-400.

LADEFOGED, K. 1952. The periodicity of wood formation. Det kongelige Danske Videnskabernes Selskab, Biologiske Skrifter 7.

LOVENGREEN, J. A. 1935. Undersogelse over den tidlige og hyppige Udhugnings Virkninger paa Rødgranens Vaekst. Dansk Skovforenings Tidsskr. 20.

LOVENGREEN J. A. 1951. Fra Bregentveds Egeskove. Tal og Tilvaekst. Dansk Skovforenings Tidsskr. 36.

LOVENGREEN, J. A. 1952. Hojdemalere. Afprovning af forskellige Hojdemaalere udfort af Statens forstlige Forosogsvesen. (Hypsometers. Tests on various instruments carried out by the Danish State Forest Experiment Station). Dansk Skovforen. Tidsskr. 37: 590-601.

LÜTKEN, C. 1891. Nogle Iagttagelser over de meteoriske Forholds Indflydense på Traeernes Tilvaextgang. Tidsskr. Skovbrug 12.

MADSEN, S. F. 1985 a. Overensstemmende stammeside-og vedmassefunktioner for fem forskellige nåletraearter. (Compatible tree taper and volume functions for five different conifers). Forstlige Forsogsvaesen i Danmark 40 (1): 95-140.

MADSEN, S. F. 1985 b. Middeltraemetoden til bevoksningsvis vedmasseberegning. (The mean three methods for direct computation of stand volume). Forstlige Forsøgsvaesen i Danmark 40 (2): 201-209.

MADSEN, S. F. 1987. Vedmassefunktioner ved forskellige aflaegningsgraenser og nøjagtighedskrav for nogle vigtige danske skovtraearter. (Volume equations for some important Danish tree species for different conversion limits and levels of accuracy). Forstlige Forsogsvaesen i Danmark 41 (2): 41-242.

MADSEN, S. F. 1992. Computer program for exploitation of stem-taper functions for Norway spruce, Sitka spruce, Douglas-fir, Japanese larch, European silver fir and grand fir in Denmark. Danish Forest and Landscape Research Institute, 13 pp.

MADSEN, S. F.; HEUSÈRR, M. 1992. Appendix to volume and stem-taper functions for Norway spruce in Denmark, analyses of basic data and functions. Danish Forest and Landscape Research Institute.

MADSEN, S. F.; M. HEUSÈRR. 1993. Volume and stem-taper functions for Norway spruce in Denmark. Forest and Landscape Research 1 (1): 51-78. Danish Forest and Landscape Research Institute.

MAGNUSSEN, S. 1983. En tilvaekstoversigt for rødran på østersønaere lerede moraene-jorder. (Yield table for Norway spruce on clay-rich soils in southern Denmark). Dansk Skovforenings Tidsskrift 68 (3): 214-246.

MINISTRY OF ENVIRONMENT - The National Forest and Nature Agency. 1994. Strategy for natural forests and other forest types of high conservation value in Denmark Ministry of Env. The Nat. For. and Nature Agency, 48 pp.

MØLLER, C. M. 1933. Bonitetsvise tilvaekstvoersigter for bog, eg og rodgran i Danmark. (Site productivity and yield tables for beech, oak and spruce). Dansk Skovforen. T. 457-513.

MØLLER (MÖLLER), C. M. 1946. Untersuchungen über Laubmenge. Stoffverlust und Stoffproduktion des Waldes. (Researches on leaves quantity, chemical element loses and bio-mass production of forest). Forstl. Forsögsw. Danm. 21: 1-287.

MØLLER, C. M.; NIELSEN, J. 1953. Afprøvning af de bonitetsvise tilvaekstoversigter af 1933 for bøg, eg og rødgran i Danmark. (Testing of the Danish yield tables of 1933 for beech, oak and Norway spruce). Soertryk of Dansk Skovforen T. 1 Hefte.

MØLLER, C. M. 1960. Bonitätssysteme. (Site index system). Allgemeine Forst- und Jagdzeitung. Jan. p. 9-17.

MØLLER, CARL MAR; HOLMSGAARD, E.. 1947. Staerk Hugst, svag Hugst og Hugst fra Tppen: et Forsög i Rödgran. Danish crown thinning, thinning from below, and selection thinning from above: an experiment with Norway spruce). Dansk. Skovforen. Tidsskr. 393-445.

OLSEN, H. H. 1991. SPOT data in the digital mapping of Danish forests. Scandinavian Journal of Forest Research 6(2): 227-242.

OLESEN, P. O. 1971. The water displacement method, a fast and accurate method of determining green volume of wood samples. For. Tree Impr. Arbor no. 3, Horsholm, Denmark: 1-23.

OLSEN P. O. 1977. The interrelation between basic density and ring width of Norway spruce. Forstl. Forsogsv. Danm. 34: 340-359, Copenhagen, Denmark.

OLSEN, H. C. 1976. Vedmassetabel for rodgran i Danmark. (Volume table for Norway spruce in Denmark). Forstl. Forsogsv. Danm. 34: 361-409.

PLUM, PETER MUNK. 1997. Country report for Denmark. In: Study on European Forestry Information and Communication System-Reports on forest inventory and survey systems. Volume I. CH-11-97-001-EN-C. Luxembourg: European Commision; pp. 119-144.

REVENTLOW, C. D. F. 1879. Forslag til en forbedret skovdritt. (Tree-ring studies).

SABROE, A. S. 1939. Rodgranens form og formtal (Form and form factor in Norway spruce). Forst. Forsogsv. Danm. 14: 281-428.

SKOV, FLEMMING. 1997. MRI questionaire for Denmark. 27 June, 1997. Roende, Denmark; National Environmental Research Institute. 1 p. On EFI file, Joensuu, Finland.

SKOVSGAARD, J. P. 1988. Self-thinning in Sitka spruce [*Picea sitchensis* (Bong.) Carr.] stands in Denmark. Preliminary results. FGMP pp. 627-635. FGMP: “Forest Growth Modelling and Prediction”, Ek, Alan; Stephen R. Shifley, Thomas Burk (eds.) Forest Service North Central Forest Experimental Station, General Technical Report NC-120, vol. 1 and 2, 1153 pp (143 papers), St. Paul, Minnesota, USA, Proceedings, IUFRO conference 1987, August 23-27, Minneapolis, MN.

SKOVSGAARD, J. P. 1995. Growth trends of forests in Denmark, Ireland and Great Britain. Abstract IUFRO XX World Congress, Tampere, Finland.

SKOVSGAARD, J. P. 1994. Structure and development of unthinned stands of Sitka spruce [*Picea sitchensis* (Bong.) Carr.] in Denmark. Thesis, Royal Vet. and Agric. Univ. Copenhagen (in Danish with English abstract).

SKOVSGAARD, J. P. 1995, 1996. Increasing site productivity during consecutive generations of naturally regenerated and planted beech (*Fagus sylvatica*) in Denmark. In IUFRO XX World Congress, Inviting papers, p. 276, Tampere, Finland. Reprinted in “Growth Trends in European Forests”, H. Spiecker et al. eds. pp. 89-98, Springer, 1996.

SKOVSGAARD, J. P.; VANCLAY, J. K.; GARCIA, O. 1995. An overview of approaches to evaluating forest growth models. IUFRO XX World Congress, Inviting papers, p. 293, Tampere Finland.

SORENSEN, VIVIAN KVIST. 1993. Comparison of an empiric and a prognostic yield table for Grand fir [*Abies grandi*s (Dougl.) Lindley] in Denmark. GYD pp. 260-266. GYD: “Growth and Yield Estimation from Successive Forest Inventories”. Proceedings from the IUFRO Conference held in Copenhagen 14-17 June 1993; Vanclay J. K.; Skovsgaard, J. P.; G. Z. Gertner (eds.) Forskningsserien Nr. 3/1993, 286 pp. Forskningscentret for Skov and Landskab (FSL). (The Danish Forest and Landscape Research Institute) in co-operation with Den Kgl. Veterinaer og Landbohojskole (KVL) “The Royal Veterninary and Agricultural University”.

VANCLAY, JEROME K. 1992a. Review of competition indices: what have we learned, where should we use them and what additional research is required? IUFRO Centennial, Eberswalde, Proceedings p. 446.

VANCLAY, JEROME K. 1992b. Permanent plots for multiple objectives: defining goals and resolving conflicts. In Lund 1992 (ed.) Proceedings of a IUFRO meeting on remote sensing and permanent plot techniques for world monitoring. In L, P, T, eds. pp. 157-167.

VANCLAY, JEROME K. 1994. Modelling Forest Growth and Yield. Applications to mixed tropical forests. 312 pp. © CAB International, Wallingford, U.K. Printed in the U.K. by Biddles Ltd., Guildford.

VANCLAY, J. K.; J. P. SKOVSGAARD; G. Z. GERTNER. (eds.) 1993. Growth and yield estimation from successive forest inventories. Proceedings from the IUFRO conference held in Copenhagen, 14-17 June 1993. Lyngby, Denmark: Danish Forest and Landscape Research Institite.

VAUPELL, C. 1863. De Danske Skove. (Danish forest). P. G. Philipsens Forlag.

WUNSCH, K. 1981. En hugstuafhaengig zilvaekstmodel, verificeret for rodgran. (A yield model independent of the thinning regime. Verified for Norway spruce). Medd. Skovbrugsinst. Ser. 2; 11.

6. IRELAND

General information

Land area: 68,900 sq. km. (26,603 sq. mi.), forest and other wooded land 4,290 sq. km. (1,656 sq. mi.), forest: 396,000 ha or 1,529 sq. mi. (6 % of land area), volume: 76 m^3/ha, biomass 34 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: industrial round wood 1.75 million m^3, fuel and charcoal 0.05 million m^3, total round wood 1.8 million m^3 (World Resources 1996-97, Table 9.3 p. 220).

Forest vegetation: Temperate mixed forests

- Conifers (80 %)
- Broad-leaved (20 %)
- Main species: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), European larch (*Larix europaea*), oak (*Quercus robur*), ash (*Fraxinus* sp.), European beech (*Fagus sylvatica*); acclimatized species: *Picea sitchensis, Larix leptolepsis, Pinus murrayana.*

Forestry education and research organizations involved in the area of forest management:

- University College Dublin, Council for Forestry and Agriculture Building (COFORD), Dublin.

Publications:

- Irish Forestry, published by Society of Irish Foresters, Wexford.

Literature:

NEESON, EOIN. 1991. A history of Irish forestry. Dublin: Lilliput Press in association with the Dept. of Energy, 388 pp.

O'CARROLL, NIALL. 1984. The Forests of Ireland: history, distribution, and silviculture,. edited for the Society of Irish Foresters by Niall O'Caroll, Dublin, Ireland: Turoe Press; New York: Marian Boyars, 1984, 128 pp.

Available works on forest mensuration

One of the available works refers to the allometric interpretation of self–thinning rule (White 1981). White considered that the traditional allometric derivation of the rule (established by Shinozaki and Kira (1956), proposed in print by Todaky and Shidey (1959) but known especially from the work of Yoda et al. (1959 – see chapter 11.2. Japan) is unrealistic and he made an attempt to reformulate this rule.

In the area of tree–ring studies some works published after 1943 refer to Northern Ireland and have been presented within the chapter 8. United Kingdom.

In 1998 Alberne et al. discussed the application of the SAFE model to a Norway spruce stand at Ballyhooly.

In Ireland were underlined. the inventory needs of private forest growers (Whelan D. 1996) who are members of the Irish Timber Growers Association (IIGA).

Colour infrared (CIR) aerial photography is developing in Ireland especially for photointerpretation keys for Sitca spruce (*Picea sitchensis*) and lodgepole pine (*Pinus contorta*). These were part of an UN programe for investigating methods of monitoring forest health. CIR aerial photographs have been used to detect nutrient deficient forest stands and top dying of Norway spruce (*Picea abies*).

References

ALBERNE, J.; H. SVERDRUP; E.P. FARELL; T. CUMMINS. 1998. Application of the Safe model to a Norway spruce stand at Ballyhooly, Ireland. Forest Ecology and Management 101: 331-338.

STANLEY, B.; DUNNE, S.; KEANE, M. 1996. Forest condition assessments and other applications of colour infrared (CIR) aerial photography in Ireland. Irish Forestry 53 (1/2): 19-27.

WHELAN, D. The inventory needs of private forest growers. Irish Forestry 53 (1/2): 78-83.

WHITE, J. 1981. The allometric interpretation of the self–thinning rule. J. Theoretical Biology 89: 475-500.

7. NETHERLANDS

General information

Land area 33,920 sq. km (13,097 sq. mi), forest and other wooded land 3,340 sq. km (1,290 sq. mi), forest: 334,000 ha or1,290 sq. mi. (10 % of land area), volume: 156 m^3/ha, biomass 95 tons/ha (FAO 1995/124: Forest resources assessment).

Round wood production: industrial round wood 1.24 million m^3, fuel and charcoal 0.156 million m^3 total round wood 1.396 million m^3. (World Resources 1996-97. p 220).

Forest vegetation: Temperate mixed forests

- Conifers (76 %)
- Broad-leaved (24 %)
- Main species: conifers, oaks, European beech (*Fagus sylvatica*), poplar spp. (*Populus* spp.).

Forestry education and research organizations involved in forest mensuration and forest management (date of establishment in brackets):

- Department of Forestry, Agricultural University, Wageningen (1883).
- International Agricultural College Larestein, Velp (1903).
- Institute for Forestry and Nature Research (IBN-DLO), Wageningen (1947).
- Tropenbos Foundation, Wageningen (1988).
- Research Institute for Forestry and Landscape Planning “De Dorchkamp”, Wageningen.

Publications:

- Nederlandsch Boschbouw Tijdschrift (1938) and 1953
- Plant and Soil. Vol. 1 (1948) +, The Hague; Kluwer Academic, irregular, 1948 -, bimonthly, 1976 -.
- Vegetatio. Vol. 1 (1948) +. The Hague; W. Junk. Bimonthly.
- Forest Ecology and Management. Vol. 1 (1967/77) +. Amsterdam, Elsevier, Scientific Publ. Co. Quarterly.
- New Forests. Vol. 1 (1986)+. Dordrecht and Boston: M. Nijhoff Quarterly.
- Netherlands Journal of Agricultural Science.

Early information in: JANSEN, W.L.; A. STOFFELS.1958. Les forêts et l’économie forestière néerlandaises. (Forests and forest economics in the Netherlands). Bull. Soc. Roy. For. Belg. Nr. 10.

7.1. Tree and primary products measurements

The Mac Dougal's textbook (1938) contains some information on tree dendrometrical characteristics. Soest and Tiemens (1953) analyzed the use of Blume-Leiss hypsometer. In 1953 Stoffels described stand volume determination using one entry volume tables (tariffs); he developed 34 tariffs for pine (*Pinus sylvestris*) based on the equation $v = a*d^{2,20}$ ($d = dbh$ and a constant characteristic for every tariff. Determination of the tariff number is completed using a table with two entries: the average stand diameter and average total height.

Soest (1956) prepared volume tables for Douglas fir and used the following types of equations for form factor $f_{1,3}$:

$$f_{1.3}=b_0+b_1\frac{1}{h}+b_2\frac{1}{h}+b_3\frac{1}{dh}+b_4\frac{1}{d^2}+b_5\frac{1}{d^2h} \qquad f_{1.3}=f(dbh, h)$$

$$f_{1.3}=b_0+b_1d+b_2d^2 \qquad f_{1.3} = f(d)$$

In 1957 Essed examined in his dissertation the problem of "estimation of standing timber". Essed expressed the relationship between tree volume and dbh in the following form:

$$v_i = b_o \cdot \left(\bar{d}+e_i\right)^{b_1}$$

where: $e_i = d_i - \bar{d}$, d= dbh

b_o, b_1= parameters of the function

$$v = b_o\,(d)^{b_1}$$

$\bar{d}$ = quadratic mean diameter

In the same period, Soest (1959) also determined in a dissertation the stem form and volume of Japanese larch in the Netherlands.

The methods for the examination of root systems and roots have been proposed by Schuurmann and Goedewaagen in 1965.

Estimation of wood volumes of standing trees based on regression functions were presented in a textbook by Dik (1984) which contains volume tables for wood and bark (vol. to 8 cm. top) from dbh and trees total height; all measurements are based on sectional measurements made during the last 25 years on 13 conifer and 8 broad-leaved species.

In 1986 new guidelines for the measurement and formation of assortments for round wood have been published and replaced those dated 1960. The new recommendations correspond to the EEC guidelines relating to this subject.

Cited authors:

Dik 1984, Essed 1957, Mac Dougal 1938, Schuurmann and Goedewaagen 1965, Soest 1956, Soest and Tiemens 1953, Stoffels 1953.

7.2. Stand structure

In the problem of the dynamics of vegetation, Hulst (1979) proposed Markov chains as models of succession connected with the future structure of a stand.

The succession as a population process was examined by Peet and N. L. Christiansen (1980). Faber (1988) used for the Austrian pine a Weibull diameter distribution while Schoonderwoerd and Mohren (1988) investigated autocorrelation and competition in even-aged stands of Douglas fir and concluded that: “the correlation between neighbour trees indicated that competition may play a major role in determining the spatial pattern of homogeneous stands. The occurrence of negative correlations as a result of competition, however, depends on site quality and soil homogeneity, in combination with the applied thinning regime” (p. 619).

An explanatory model to stimulate competition between trees within forest stands is presented in three versions by Van Gerwen et al. in 1987. This is a process model or physiological model based on the distribution of photo synthetically active radiation (PAR) over the trees in the stand and the rates of assimilation and volume increment of trees (grouped in size classes) calculated from the amount of absorbed PAR.

Mohren et al. (1991) underlined the importance of successional models as an aid for forest management in mixed stands.

Cited authors:

Faber 1988, Hulst 1979, Mohren et al. 1991, Peet and Christiansen 1980, Schoonderwoerd and Mohren 1988, Van Gerwen et al. 1987.

7.3. Stand growth and yield. Modelling

Two events in the 1950s: Grandjean and Van Soest’s (1953) yield data for Douglas –fir, and Stoffels’s (1954) results on the application of Bitterlich’s method for the determination of stand basal area.

Revised yield tables for six tree species were published by Bastide and Faber in 1972.

A set of works as Seligman’s (1976) critical analysis of some grassland models, Jorgensen’s (1986) “Fundamentals of Ecological Modeling”, Kallio ‘s et al. ed (1986) “System Analysis in Forestry and Forest Industries” stimulated the modelling in forest mensuration, e.g. Mohren's (1987) "Simulation of Forest Growth Applied to Douglas Fir Stands in the Netherlands."

In 1988 new yield tables have been constructed: for pedunculate oak (*Quercus robur*) by Oosterbaan, and for the Austrian pine by Faber.

Mohren and Rabinge (1990) presented the results of a model for Douglas-fir growth based on influencing factors on growth such as weather, soil conditions, air pollution and acidification, and that can be analyzed with the aid of dynamic models of plant growth, based on underlying physical, chemical and biological processes.

Faber (1991) described a distance-dependent model of tree growth (RUIM/SIMU – written in FORTRAN) and calibrated with data from poplar plantations with a wide variety of spacings (RUIM calculates and maps growing spaces of trees in a forest stand and SIMU predicts future growth and distributes the basal area increment per hectare over individual trees in proportion to their growing spaces computed by RUIM).

In 1994 Mohren modelled Norway spruce growth in relation to the conditions and atmospheric CO_2.

Olsthoorn (1995), and Olsthoorn and Dik (1995) discussed the (expected) growth trends of forest in the very high nitrogen availability in forest (based on nitrogen contents of this foliage) and low contents of other nutrients (e.g. P, K, Mg) reflecting an unbalanced nutrition but rising CO_2 levels. They concluded that "At this moment the measured growth is higher than indicated in the yield tables, but this could be due to underestimations in the yield tables, Therefore, the growth data should be examined carefully to avoid effects of age differences in different periods" (p. 275 in Olsthoorn and Dik).

Schoonderwoed and Daamen (1995) compared the increment of forests in the Netherlands from Dutch yield tables (generally constructed from OPTAB model) and from HOSP (Timber Harvest Statistics and Forecast of Harvestable Wood) which is based on more than 3000 permanent sample plots. They analyzed the main first species (*Pinus sylvestris, Pseudotsuga menziesii, Larix* sp. *Picea abies, Quercus robur* [native]) and concluded that the progressive differentiation of Dutch forests (in composition and structure) reduced the applicability of increment models based on even-aged monocultures (OPTAB) and the alternatives to this system should be used.

Because no suitable Dutch tables was available for beech (*Fagus sylvatica*) in the Netherlands Jansen used an OPTAB modification by empirical simulation based on permanent plots in North Germany and South Sweden, this is an example how to prepare a suitable yield table based on existing tables from other countries.

Cited authors:

Bastide and Faber 1972, Faber 1988, 1991; Grandjean and Van Soest 1953, Jensen 1996, Jorgensen 1986, Kallio et al. 1986, Mohren 1987, 1994; Mohren and Rabinge 1990, Olsthoorn 1995, Olsthoorn and Dik 1995, Oosterbaan 1998, Schoonderwoerd and Daamen 1995, Seligman 1976, Stoffels 1954.

7.4. Biomass studies

Fine-root production, mortality and decomposition in first ecosystems was brought into discussion by Persson (1979) in the Dutch publication "Vegetatio".

In 1997 Bartelink established allometric relationship among stem and crown dimensions, biomass and leaf area, determining the relative above ground biomass distribution in the case of *Fagus sylvatica* trees in age from 8-59 years; nonlinear models on dbh explained more than 90 % of the biomass variance and above ground stand biomass ranged from 6 to 167 tons/ha and increased linearly with stand age (After Forestry Abstracts 6893/1997, vol. 58, no. 9).

7.5. Tree-ring studies

Kapteyn - a Dutchman who emigrated in the U.S.A. - should be considered according to Eckstein et al. (1975) among the pioneers of tree ring research due to his article published in "The Pasadena Star", 19 December 1908, pp. 11-12. Kapteyn was preceded by The Russian author, Svedov (1892) who considered tree as a chronicle for dry periods. These pioneers were followed by an American Douglass (1919), the author of "Climate cycles and tree growth " and father of the classical dendrochronology.

The interest for tree-ring studies started in the Netherlands after 1965 with dating of oak panels of Dutch 17th painting (Bauch 1968, Bauch and Eckstein 1970). On the other hand, Munaut (1966) and Munaut and Casparie (1972) investigated ecological evaluation of tree-ring of stumps of subfossil *Pinus sylvestris*, in peat bogs (Atlanticum period), and Eckstein and van Es (1972), developed dendroclimatological researches on early settlement, Dorestat using material from woody spring pipes. Bronger (1973) developed dendroclimatological investigation on recent oak species.

A short synthesis of tree-ring research in the Netherlands was published by Eckstein, Brongers and Bauch in 1975 in the Tree-Ring Bulletin (U.S.A.), and presented two independent local tree-ring oak chronologies using wood from mills and paintings; the first chronology covers the 1973–1385 period and the second ranges from 1623 to 1140.

In 1986 Visserand and Molenaar applied Kalman filter to time dependent responses of trees to weather variations, and Mettes and Visser completed KALFIMAC: a software package to analyze time series with trend, cyclic and explanatory variables.

In 1988, Schweingruber published "Tree Rings. Basic and Applications of Dendrochronology", at Dordrecht – a useful synthesis with presentation of conceptual models, tree-growth relationship on processes. Another valuable book was published by Cook and Kairiukstis (eds) in Kluwer Academic Publishers Dordrecht in 1990 and contains methods of dendrochronology and applications in the Environmental Science (statistical models to process and standardize tree ring data, past climate data and events, data bank dendrochronological–growth relationship, past climate reconstruction).

Brakel and Visser (1996) analyzed the influence of environmental conditions on tree-ring series of Norway spruce for different canopy and vitality classes using more sophisticated, methods (a model for simultaneous, adjustment of trend explanatory variables, time–dependent on stochastic response functions obtained by writing these models in so-called state–space form and analyzing them with the discrete Kalman filter. Their conclusions are interesting especially for the fact that "the addition of SO_2 emission curve as explanatory variable, simultaneously with trend and climate variables for tree-ring, chronologies, did not reveal a significant air pollution effect on tree-ring development "(For. Abs. 9164/1996).

Burgt (1996) discovered that the age of old *Pinus sylvestris* trees in the Netherland is about 400 years.

Cited authors:

Bauch 1968, Bauch and Eckstein 1970, Brakee and Visser 1996, Brongers 1973, Burgt 1996, Cook and Kairiukstis (eds.) 1990, A. E. Douglass 1919, Eckstein and Es 1972, Eckstein et al. 1975, Kapteyn 1908, Munaut 1966, Munaut and Casparie 1971, Mettes and Visser 1987, Schweingruber 1988, Svedov 1892, Visser and Molenaar 1986.

7.6. Forest inventory: sampling, remote sensing and GIS

Early aerial photographs were used in Netherlands for: the estimation of standing timber (Essed 1957), the use of unequal probability sampling methods (Stellingwerf 1971), and the determination of mean annual volume growth (Stellingwerf 1973).

Application of aerial volume tables and aspects of their construction were analized and presented by Stellingwerf in 1971.

Remote sensing methods were applied to determine the vitality of vegetation assessing especially the damage caused by air pollution. Usually, there were used colour infra-red (CIR) films to obtain large scale photos (1:5000 to 1:6000) stereo pairs. It was used also a non film technique- the spectroradiometry which proved to be the most promising. A review from the literature of these technologies and methods was published by van de Lustgraaf in 1984.

In 1987 was completed the fourth National Survey of the Netherlands. In connection with this event Nas (ed.) published in the same year (1987) a collection of seven articles in which have been included: a history of the survey, aims and methods, tables and maps, important results, changes during the period 1968-1983, trends and forecasts, regeneration and afforestation in the 1950-2000 period and the Nature function of forests of the Netherlands (Based on information from For. Abstracts 4519/1987.).

Stellingwerf and de Gier (1988) used a two-phase linear regression sampling (TPLRS) (with 112 circular photo plots in the first phase and 55 dependent plots in the second phase) to discover the changes in timber volume. This was one of the early monitoring works based on modern methods. In 1991 de Gier used a two-phase sampling design for volume table construction and woodland inventory. In the same year de Gier and Stellingwerf used two-phase sampling (aerial photo-field) for determination of beech-oak timber volume.

The use of remote sensing in modelling of forest productivity was summarized in a notable paper edited by Gholz, Nakane and Harushia in 1997 and published by Kluwer Academic Publishers (336 pp.).

Modelling of radiative transfer through forest canopies: implications for canopy photosynthesis and remote sensing was examined by Nilson and Ross (1997). This work is in connection with the use of remote sensing in the modelling of forest productivity.

Stellingwerf and Hussein (1997) presented measurements and estimation of forest stand parameters using remote sensing.

Cited authors:

Essed 1957, de Gier 1991, de Gier and Stellingwerf 1991; Gholz, Nakane and Harushia (eds.) 1997, Lustgraaf 1984, Nas (ed.) 1987, Nilson and Ross 1997, Stellingwerf 1971a, 1971b, 1973; Stellingwerf and de Gier 1988, Stellingwerf and Hussein 1997.

7.7. Chronology of selected events

1908: J.C. Kapteyn’s early work on tree-rings published in the U.S.A.

1938: A textbook on tree growth containing some information of tree biometrical characteristics (D. T. Mac Dougal).

1953: Tariffs (volume tables) for Scots pine based on equation (A. Stoffels).

1956: Volume tables for Douglas fir (J. van Soest).

1957: Estimation of standing timber volume (F. E. Essed).

1959: Stem form and volume of Japanese larch in the Netherlands (J. van Soest).

1965: Methods for the examination of root systems and roots (J. J. Schurmann and M. A. J. Goedewaagen).

1971: Application of aerial volume tables and aspects of their constructions (D. A. Stellingwerf).

1971: Aerial photographs used for unequal probability, sampling, methods (D. A. Stellingwerf).

1972: Revised yield tables for six tree species in the Netherlands (J. G. A. Bastide and P. J. Faber).

1973: Application of aerial photography to gross mean annual volume growth determination. (A. D. Stellingwerf).

1975: A short synthesis on tree ring research in the Netherlands and construction of two dendrochronologies.

1984: Regression functions for volume tables and tables for 13 conifer and 8 broad–leaved species (E. J. Dik).

1984: Remote sensing methods to determine the vitality of vegetation (B. van de Lustgraaf).

1986: New guidelines for measurement and formation of assortments for round wood in the Netherlands.

1986: System analysis in forestry and forest industries (Markku Kallio et al.).

1986: Fundamentals of ecological modelling (S. E. Jorgensen).

1986: Simulation of forest growth applied in Douglas fir stands in the Netherlands (G. M. J. Mohren).

1988: Tree–rings. Basic and applications of dendrochronology (F. H. Schweigruber).

1987: A history of forest inventories in the Netherlands (R. M. W. J. Nas, ed.).

1988: Use of aerial photo plots and field plots in a two-phase sampling design for monitoring changes in timber volume (D. A. Stellingwerf and A. de Gier).

1990: Methods of dendrochronology: applications in the environmental science (E. R. Cook and L. Kairiukstis – eds.).

1991: RUIM/SIMU – a distance–dependent model of tree growth (P. J. Faber).

1996: A model applied for simultaneous adjustment of trend and explanatory variables for tree–ring chronologies (J. A. Van Den Brakel and H. Visser).

1996: A method used to prepare a suitable yield tables from other countries (J. J. Jonsen).

1997: Measurements and estimation of forest stand parameters using remote sensing (D. A. Stellingwerf and Y. A. Hussein).

1997: The use of remote sensing in modelling of forest productivity (H. L. Gholz, K. Nakane, S. Harushia-eds.).

7.8. Selected contributors

In chronological order:

Author	Printing years	Fields
J. C. Kapteyn	1900s	6
F. E. Essed	1950s	1
J. van Soest	1950s	1
A. Stoffels	1950s	1, 4
A. V. Munaut	1960s-1970s	6
D. Eckstein	1970s	6
D. A. Stellingwerf	1970s-1990s	7
E. J. Dik	1980s	1
P. J. Faber	1980s-1990s	3, 4
A. de Gier	1980s-1990s	7
G. M. J. Mohren	1980s	4
H. Schoonderwoerd	1980s	3, 4
F. H. Schweingruber	1980s	6
A. F. M. Olsthoorn	1990s	4

1 = tree and primary products, 3 = stand structure, 4 = stand growth and yield, 6 = tree-ring studies, 7 = forest inventory

7.9. Comment

The repartition of cited papers in this chapter is the following: tree 12 %, stand structure 11 %, stand growth and yield including modelling 25 %, biomass studies 3 %, tree ring studies 28 %, forest inventory 21 %.

Papers published after 1980 represent 37% and those after 1990 16%. The most important fields remain stand growth-yield and forest inventory. The high percentage of papers on tree ring studies was determined by the fact that some remarkable scientists as Bauch, Eckstein, Schweingruber and Munaut followed the tradition of Kapteyn- a Duchman who emigrated in the USA and became one of the first pioneers in the discovery of the connection between tree-rings and climate.

References

ANONYMOUS. 1986. Niewe richtlijnen voor het meten en indelen van inlands rondhout in druk verschenen. (New guidelines for measurement and formation of assortments for round-wood in the Netherlands). Gravenhage Netherlands; Het Bosschap. From review in Netherlands Bosbouwtijdschrift 59 (1-2), 34.

BARTELINK, H. H.1997. Allometric relationships for biomass and leaf area of beech (Fagus sylvatica L.). Annales des Sciences Forestières 54 (1); 39–50.

BAUCH, J. 1968. Die Problematik der geographischen Reichweite von Jahrringdatierungen an Beispielen aus norddeutschen Tiefebene. (The problem of geographical area of tree-ring dating in northern plain of Germany). Kuustchronik 21: 144–145.

BAUCH, J.; D. ECKSTEIN. 1970. Dendrochronological dating of oak panels of Dutch 17th paintings. Studies in Conservation 15: 45–50.

BRAKEL, J. A. VAN DEN ; H. VISSER. 1996. The influence of environmental conditions on tree–ring series of Norway spruce for different canopy and vitality classes. Forest Science 42 (2): 206–219.

BRONGERS, J. A. 1973. Dendrochronological investigation of recent oak (Quercus sp.) in the Netherlands. Berichten van de Rijksdienst voor het Oudheidkundig Bodemondirzoek 23: 456–459.

BURGT, X. M. VAN DER. 1996. De leeftijd van oude grove dennen in Nederland (The age of old Scots pine trees in the Netherlands). Nederlands Bosbouwtijdschrift 68 (2): 50– 52.

COOK, E. R.; L. KAIRIUKSTIS (eds). 1990. Methods of Dendrochronology; Applications in the Environmental Science. Kluwer Academic Publishers, Dordrecht.

DIK, E. J. 1984. De schatting van het houtvolume van staande bomen van een aantae in de bosbouw gebruikte soorten. (Estimating the wood volumes of standing trees in forestry practice). Ditvoering Verslag, Rijksinstuut voor Onderzoek in de Bos – en Landschpsbouw "De Dorschkamp", Netherlands 19 (1) 144 pp.

DOUGLASS, A. E. 1919. Climatic cycles and tree-growth. Vol. I. Carnegie Institution of Washington Publication 289.

ECKSTEIN, D.; W. A. van ES. 1972. Dendrochronologische Untersuchungen von Daubenbrunnen aus frühmittelterlichen Siedlung Dorestad, Holland. (Dendrochronogical researches in early settlement Dorestad, Netherlands). Kunde, Vol. 23: 220–226.

ECKSTEIN, D.; J. A. BRONGERS; J. BAUCH. 1975. Tree-ring research in the Netherlands. Tree–Ring Bulletin Vol. 35: 1–13.

ESSED, F. E. 1957. Estimation of standing timber. H. Veenmann u. Zonen Wageningen. Ph. D. Diss, 60 pp.

FABER, P. J. 1988. Oostenrijkse den: groei en opbrengst en Weibull – verdeling van de diameters. (Austrian pine: growth and yield and a Weibull diameter distribution). Uitvoering Verslag – Rijksinstitut voor Onderzoek in de Bos- en Landschapshouw. De Dorshkamp 22 (2): 1–67.

FABER, P. J. 1991. A distance–dependent model at tree growth. Forest Ecology and Management 41 (1–2): 111-123.

GRANDJEAN, A. J.; J. VAN SOEST. 1953. Yield data for Douglas fir in the Netherlands. Experiment Station T. N. O. 19, Wageninen.

GIER, A. de 1991. Tree selection for volume table construction and its effect on sampling error in a two-phase, sampling design for woodland inventory. In: Köhl and Pelz (eds.), 1991, pp. 128-142; see Poso S., Finland 1991, chapter 1 this volume.

GIER. A. de; STELLINGWERF, D. A. 1991. Beech-oak timber volume by two-phase (aerial photo-field) sampling. In: Köhl and Pelz (eds.), 1991, pp. 164-175; see Posso S., Finland 1991, chapter 1 this volume.

GHOLZ, H. L.; NAKANE, K.; HARUSIA, S. 1997. The use of remote sensing in modelling of forest productivity. Dordrecht, Netherlands: Kluwer Academic Publishers.

HULST, R. van. 1979: On the dynamics of vegetation: Markov chains as models of succession. Vegetatio 40: 3-14.

JANSEN, J. J. 1996. Opbrengsttabel voor de beuk (Fagus sylvatica L.) In Nederland; een OPTAB – modificatie door middel van empirische simulatie gebaseerd op proefperken uit Noord – Duitsland en Zuid – Zweden. [Yield table for beech (Fagus sylvatica L.) in the Netherlands; an OPTAB modification by empirical simulation based on permanent plots in North Germany and South Sweden]. Wageningen Agricultural University. Department of Forestry Hinkeloord Report no. 16, 45 pp.

JANSEN, W. L.; A. STOFFELS. 1958. Les forêts et l'économie forestière néerlandaises. (Forest and forest economics in Netherlands). Bull. Soc. Roy. For. Belg. Nr. 10.

JORGENSEN, S. E. 1986. Fundamentals of Ecological Modelling. Elsevier, Amsterdam.

KALLIO, MARKKU et al. (eds.) 1986. System Analysis in Forestry and Forest Industries, Amsterdam and New–York; North–Holland, 487 pp. (TIMS Studies in the Management Science no. 21).

KAPTEYN, J. C. 1908. Complete authorized text of a lecture. The Pasadena Star, 19 December, pp. 11–12.

LA BASTIDE, J. G. A.; P. J. FABER, 1972. Revised yield tables for six tree species in the Netherlands. Stichting Bosbouwproefstation "De Dorschkamp", Wageningen, 11,1 64 and 36 pp.

LUSTGRAAF, B. van de. 1984. Remote sensing methoden voor het beoordelen van de gezondheidstoestand van vegetaties. (Remote sensing methods to determine the vitality of vegetation). Wageningen, Netherlands. Literatuurovesischt No. 42. Pudoc, 61 pp.

MAC DOUGAL, D. T. 1938.Tree growth. Leiden, Holland. Chronica Botanica Co. 240 pp.

METTES, M.; H. VISSER. 1987. KALFIMAC: A software package to analyze time–series with trend, cyclic, and explanatory variables. Part. I: Report 50835 – MOA – 87 – 3129, N. V. Kema, Ainhem, The Netherlands.

MOHREN, G. M. J. 1987. Simulation of forest growth, applied to Douglas fir stands in the Netherlands. Pudoc, Wageningen, the Netherlands 184 pp.

MOHREN, G. M. J. 1994. Modelling Norway spruce growth in relation to the conditions and atmospheric CO_2. In: Veroustraite, F. et al. (eds.). Vegetation, Modelling the Hague, pp. 7–22.

MOHREN, G. M. J.; R. RABBINGE. 1990. Growth–influencing factors in dynamic models of forest growth. In Process Modelling of Forest Growth Responses to Environmental Stress, pp. 229 – 240, Timber Press Portland Oregon (441 pp.) eds.: Dixon, Robert K; Ralph S, Mildahl; Gregory A. Ruark, G. William Waren.

MOHREN, G. M. J.; A. F. M. VAN HEES; H. H. BARTELINK. 1991. Successional models as aid for forest management in mixed stands in the Netherlands. Forest Ecology and Management 41: 111–127.

MUNAUT, A. V. 1966. Recherches dendrologiques sur Pinus sylvestris, II. Première application des methodes dendrochronologigues a l'étude de pins sylvestres sub-fossiles, (Dendrochronological researches on Scots pine. II First application of dendrochronological methods on the study of subfossil Scots pines). Terneuzen, Netherlands, Agricultura 14, Ser. 2, 361–389.

MUNAUT, A. V.; W. A. CASPARIE. 1971. Étude dendrochronologigue des Pinus sylvestris L. Subfosiles provenant de la tourbière d'Emmen. (Dendrochronological study of subfosil Scots pines from Emmen pet bog). Drenthe, The Netherlands. Rev. Paleobot, Polynol. 11: 361–389.

NAS, R. M. W. J. (ed.). 1987. Nederlands Bosbouwtijdschrift 59(4): 75-127. (Netherlands forest inventory).

NILSON, T.; ROSS, J. 1997. Modelling radiative transfer through forest canopies: Implications for canopy photosynthesis and remote sensing pp. 23-60 in: The use of remote sensing in the modelling of forest productivity, Gholz, H. L., K. Nakane and H. Shimoda (eds.), Kluwer Acad., Dordrecht.

OLSTHOORN, A. F. M. 1995. Growth trends of forests in the Netherlands and Belgium . Abstract, IUFRO XX World Congress, Tampere, Finland.

OLSTHOORN, A. F. M. 1995. The observation of expected growth trends in the Netherlands. IUFRO XX World Congress, Tampere, Finland, Inviting papers, pp. 274–275 (summary).

OOSTERBAAN, A. 1988. Opbrengsttabel voor zomercik (Quercus robur L.) in Nederland. (Yield table for pedunculate oak (Quercus robur L.) in Netherlands). Uitvoering Verslag. Rijksintitut voor, Onderzoek in de Bos – en Landschapsbouw "De Dorschkamp", Netherlands 22 (1) 31 pp.

PEET, R. K.; N. L. CHRISTENSEN 1980. Succesion: a population process. Vegetatio 43: 131–140.

PERSSON, H. 1979. Fine–root production, mortality, and decomposition in forest ecosystems. Vegetatio 41: 101–109.

SCHOONDERWOERD, H.; W. P. DAAMEN. 1995. De bijgroei van bos in Nederland. (The increment of forests in the Netherlands). Neterlands Bosbouwtijdschrift 67 (1): 16–22.

SCHOONDERWOERD, H.; G. M. J. MOHREN 1988. Autocorrelation and competition in even – aged stands of Douglas – fir in the Netherlands. Ek. Alan R.; Stephen R. Shifley; Thomas Burk (eds), Forest Service North Central Forest Experimental Station, General Technical Report NC – 120, Vol. 1 and 2, 1153 pp. (143 papers), St. Paul, Minnesota, U.S.A., Proceedings IUFRO Conference 1987, August 23–27, Minneapolis, MN.

SCHUURMANN, J. J.; M. A. J. GOEDEWAGEN. 1965. Methods for the examination of root systems and roots. Centre for Agr. Publ. And Documentation, Wageningen, the Netherlands.

SCHWEINGRUBER, F. N. 1988. Tree Rings. Basic and Application of Dendrochronology. D. Reidel Publishing Co., Dordrecht.

SELIGMAN, N. G. 1976. A critical analysis of some grassland models. In: Arnold, G. W., and C. T. de Wit, eds. Critical Analysis of Systems in Ecosystems Research and Management. Centre for Agriculture Publication and Documentation, Wageningen, the Netherlands, pp. 84–97.

SOEST, J. VAN. 1956. Massentafel für Douglasie. (Volume table for Douglas fir). Vervielf Bosbouwproefstation T. N. O.

SOEST, J. VAN. 1959. Stem form and volume of Japanese Larch in the Netherlands. Diss. Wageningen.

SOEST, J. VAN; F. TIEMENS. 1953. De hoogtemeter van Blume – Leiss. (The Blume–Leiss hypsometer). Ned. Boschb. Tijdschr. 25: 279–282.

STELLINGGWERF, D. A. 1971a. Aplication of aerial volume tables and aspects of their construction ITJ Journal: 480-498.

STELLINGGWERF, D. A. 1971b. Aerial photographs used for unequal probability, sampling methods. IUFRO XV World Congress, Proceedings Methods. (International Training Centre for Aerial Survey and Earth Sciences (ITC), Delft, Holland).

STELLINGGWERF, D. A. 1973. Application of aerial photography to gross mean annual volume growth determination. Proc. Symp. IUFRO S6.05 Freiburg, pp. 229-251.

STELLINGGWERF, D. A. ; GIER, A. de 1988. Monitoring changes in timber volume using aerial photo plots and field plots in a two-phase sampling design. Netherlands Journal of Agricultural Science 36(2): 119-125.

STELLINGGWERF, D. A.; HUSSEIN, Y. A. 1997. Measurements and estimation of forest stand parameters using remote sensing. Ridderprint VSP. Utrecht pp. 226-337.

STOFFELS, A. 1953. De Inhoudsbepaling van Grovedennen - Opstanden met behulp van standaardkrommen. (Scots pine stands volume determination with tariffs). Nederlandsch Boschbouw Tijdschrift, February , pp. 29–42.

STOFFELS, A. 1954. (Accuracy of basal area determination per hectare using Bitterlich's method). Ned. Bosch. Tijdschr. 26: 256–268.

SVEDOV, O. 1892. Derevo kak letopis zasuh. (Tree as a chronicle for dry periods). Meteorologiceskij vestnic 5: 163–178 (Russian).

VAN GERWEN, C. P.; C. T. J. SPITTERS; G. M. J. MOHREN. 1987. Simulation of competition for light in even–aged stands of Douglas fir. Forest Ecology and Management 18: 135–152.

VISSER, H.; J. MOLENAAR, 1986. Time dependent responses of trees to weather variations: an application of the Kalman filter. Report 50385 – MOA 86 – 3041, N.V. KEMA, Arnhem, the Netherlands.

8. UNITED KINGDOM

General information

Land area: 240,860 sq. km (93,000 sq. mi.), forest and other woded land: 23,800 sq. km (9,190 sq. mi), forest: 2,207,000 ha or 8,522 sq. mi (9 % of land area) volume 93 m^3/ha, biomass: 56 tons/ha (FAO 1995/124 Forest resources assessment).

Round wood production: industrial round wood 5.9 million m^3, fuel and charcoal 0.263 million m^3, total round wood 6.163 million m^3 (World Resources 1996-97, p. 220).

Forest vegetation: temperate mixed forest

- Conifers: ca. 55 %
- Broad-leaved ca. 45 %
- Main species: European oak (*Quercus robur*), Scots pine (*Pinus sylvestris*), spruce (*Picea abies*), fir (*Abies alba*), beech (*Fagus sylvatica*), European larch (*Larix europaea*). Acclimatized species: *Pinus sitkensis, Pseudotsuga menziesii*.

Forestry education and research organizations involved in the areas of forest mensuration and forest management (date of establishment in brackets):

- University of Edinburgh, School of Forestry, Institute of Ecology and Resources Management, Edinburgh (1889).
- Newton Rigg College, Newton Rigg (1896).
- University of Aberdeen, Department of Forestry, Aberdeen (1904).
- University of Oxford, Department of Plant Sciences, Forestry Institute, Oxford, U.K. (1905)
- University of Wales, School of Agricultural Forest Sciences, Bangor, Wales.
- Oxford Forestry Institute, Oxford-U.K. (1905).
- The Forestry Authority, Forestry Commission, Forest Research Station, Alice Holt Lodge Wrecclesham, Farnham, U.K.-Surrey (1946)

Publications (Primary Journals and Serials):

- Nature, vol. 1 (1869) +. London; Macmillan, weekly.
- Annals of Botany, vol. 1-50, 1887-1936;
- The Journal of Ecology. Vol. 1 (1913) +. Oxford;
- The Commonwealth Forestry. Vol. 1 (1922) +. Oxford; Commonwealth Forestry Association. Quarterly.
- Forestry, vol. 1 (1927) +. London, Oxford University Press. (Institute of Chartered Foresters – London.
- Annals of Botany. New Series. Vol. 1 (1937+. London and New York; Academic Press. Bimonthly. Continues: Annals of Botany (vol. 1-50, 1887-1936).

• Forestry Abstracts. Oxford U.K.

• Journal of Experimental Botany. Vol. 1 (1950)+. Oxford; Clarendon Press. Three times a year.

• Journal of Applied Ecology. Vol. 1 (1964)+.

• Environmental Pollution. Vol. 1 (1970)+. Barkingham, U.K. Elsevier Applied Science Pub. Semimonthly.

• The International Tree Crops Journal. Vol. 1 (1980)+. Berkhamsted, U.K.: A B Academic Publishers, quarterly.

• The Journal of World Forest Resource Management. Vol. 1 (1984)+. Berkhamsted, U.K. A B Academic Publishers. Semiannual. An international journal on "biology, biotechnology, and management of afforestation and reforestation".

• The Scottish Arboricultural Society established in 1854 became later the Royal Scottish Society. Twenty-six years later, the English arboricultural Society was founded and became "The Royal Forestry Society of England, Wales and Northern Ireland. The latter organization began the "Quarterly Journal of Forestry" in 1907 which is still published (after N. D. G. James, 1981).

A short chronology of events and situations during the development of British forestry:

• 1184: The Assize of Woodstock (the Assize of the Forest).

• 1217: The Charter of the Forests.

• 1482: An Act by which woods were enclosed in forests, chases and purlieus.

• 1543: An Act for the Preservation of Woods; 35 Hen. 8, c. 17.

• 1558 An act which forbid the use of standing trees to make coals for burning of iron.

• 1611: The first work on planting of trees for timber production: "The Commons Complaint" by Arthur Standish.

• 1663: An Act for the Punishment of unlawful cutting or stealing or spoiling of Wood and Underwood, and Destroyers of young Timber-Trees. 15 Cha. 2, C 2.

• 1758: The Society of Arts (now the Royal Society of Arts) instituted awards for the establishment of young plantations of exceptional merit.

• 1809: Charles Waistell published the first yield tables.

• 1847: James Brown published "The Foresters".

• 1884: The International Forestry Exhibition was held in Edinburgh.

• 1889: Was published the first volume of Schlich's Manual of Forestry.

• 1903: A lecturership in Forestry was established at Armstrong College, Newcastle-on-Tyne.

• 1905: The School of Forestry was founded at Oxford.

• 1907: A readership in Forestry was established at Cambridge.

•1919: Under The Forestry Act 1919 was established The Forestry Commission.

• 1924: First Report on Census of Woodlands published in 1928.

• 1956: One million acres of forest was planted by the Forestry Commission, and two million acres were planted by this commission up to 1975.

• The "Census of Woodlands 1965-67" is published.

• The Forestry Commission adopted the metrication in 1971.

• On 1st of January 1973 U.K. joined the European Economic Community.

(Sources: N. D. G. James 1981, 1996).

An excellent history of English forestry was published in 1981 by James and covers a period of approximately nine hundred years from the Normans to 1980. The first part refers to the medieval forests: (1) Early development of laws, (2) Administration of the laws, (3) Vert and Venison, (4), (5) Some English Forests of the Middle Ages. Part two refers to the development of Modern Forestry: (6) The overture to forestry, (7) The wooden walls, (8) The old forestry, (9) The new forestry, (10) The First World War and its aftermath, (11) The second World War, (12) The post war era, (13) The changing scene.

In the 17th century, after firewood, the greatest demand was for timber for construction of houses and other buildings and the use of foreign woods became general after the beginning of the 18th century.

James' (1981) comments deserve to be quoted: "From the earliest times ships had been built of timber and since the beginning of the sixteenth century oak had provided the key to British sea power and had consequently dominated both the shipyards and the woodlands of this country. The need for it had been emphasized by the Act of 1543 and since that date increasing quantities of oak had been sawed for both the Navy and the mercantile fleets" (p. 189).

"By 1900 many of the conifers which had been introduced into Britain during the nineteenth century had reached an age and size that clearly demonstrated their value as timber trees and in some cases their adaptability to growth on the poorer quality site. Sitka spruce, Douglas-fir, the giant silver fir (*Abies grandis)*, the western red cedar (*Thuja plicata)* and Japanese larch are examples of some of these introductions" (p. 213).

In his last paper James (1996, he died in 1993) appreciated that "Two developments had been taken place by 1883 that were ultimately to replace traditional forestry in Britain. Since medieval times, ships had been built largely of oak but timber suitable for the navy had long been in short supply, and by 1850 a major crisis could not be averted. The problem was solved by chance in 1862 by a naval encounter which took place in Hampton Roads, near Norfolk, Virginia, during the American Civil War. The Merrimac, an ironclad, engaged two timber-built ships, the Congress and the Cumberland and sank them both, their guns being ineffective against the armour of the Merrimac. This event signed the death warrant for timber-built ships in the Royal Navy and eliminated the demand for oak by the dockyard. This battle had far-reaching effects on forestry throughout the United Kingdom. The second development was the introduction to the British Isles of fast-growing conifer [Douglas fir *(Pseudotsuga menziesii*) and Sitka spruce (*Picea sitkensis*) were introduced to Britain by Douglas in 1827, and in 1831, respectively], which were of considerable value as timber trees. This was the result of expeditions by plant collectors, such as David Douglas and John Jeffreys, who operated mainly in western North America" (James 1996, p. 40 and 41).

On the other hand, after 1850 some writers produced more accurate textbooks on forestry: G. Cree (1851), J. L. L. MacGregor (1883) and especially W. Schlich's 1889 Manual of Forestry, which is based on German experience.

Literature

ALLABY, M. 1999. Ecosystems: temperate forests. London; Fitzroi Dearbom Publishers, viii+216 pp. (A reference book).

ALBION, R. G. 1926. Forest and Sea Power. U.K.

ARBORICULTURAL ASSOCIATION (Great Britain) and INTERNATIONAL

ASSOCIATION OF ARBORICULTURE. 1983. Trees in the 21st century/based on the First International Arboriculture Conference, sponsored by the Arboricultural Association in conjunction with the International Association of Arboriculture. Berkhamsted (U.K.): A.B. Academic Publisher, 133 pp.

BERESFORD-PIERSE, H. 1958. La Foresterie en Grande-Bretagne. (Forestry in Great Britain). Bull. S.R.F.B. no. 4, Belgium.

BINNS, W. O.; REDFERN, D. B.; RENNOLLS, K. 1985. Forest decline - the view from Britain pp. 69-82. In: Hutchinson, T. C.; Meema, K. M. (eds.), "Effects of Atmospheric Polluants on Forests, Wetland and Agricultural Ecosystems", Springer Verlag.

BRITISH FORESTRY ASSOCIATION. 1953. British Commonwealth Forestry Terminology.

BÜSGEN, M.; E. MUNCH; T. THOMPSON. 1929. The structure and life of forest trees. London, Chapman Hall.

DIFFERENT AUTHORS. 1952. Census of woodlands (woodlands of five acres and over) – London: Forestry Commission, 264 pp. (Census/Report no. 1).

DAVIDSON, J. E. 1932. The History of the Royal English Forestry Society. Quarterly Journal of Forestry, vol. XXVI.

EDLIN, H. L. England's Forests. U.K.

EDLIN, L. H. (ed.) 1975. Cambrian forests / edited by Herbert L. Edlin. London H.M.S.O., 2nd edn., 107 pp. (Forest reserves – Wales –Guide book).

EMPIRE FORESTRY ASSOCIATION. 1953. British Commonwealth forest terminology. Part 1. Silviculture, protection, mensuration and management, together with allied subjects. The Royal Empire Soc., Londres.

F.A.O. 1995. Forest resources assessment 1990, Rome, 44 pp.

FORBES, A. C. 1932. Fifty years of English forestry. Quarterly Journal of Forestry, vol. XXVI.

FORESTRY COMMISSION. 1943. Post-War Forest Policy. Report by H. M. Forestry Commissioners, Cmd., 6447, 1943.

FORESTRY COMMISSION. 1983. South West England. Census of Woodlands and Trees 1979-1982. East England, Census of Woodlands and Trees 1979-1982. For. Comm., Edinburgh.

FORESTRY COMMISSION. 1983. East England. Census of Woodlands and Trees 1979-1982. East England, Census of Woodlands and Trees 1979-1982. For. Comm., Edinburgh.

FORESTRY COMMISSION. 1983. South East England. Census of Woodlands and Trees 1979-1982. East England, Census of Woodlands and Trees 1979-1982. Forestry Commission, Edinburgh.

FORESTRY COMMISSION. 1994. Lowland acid beech and oak woods. The management of semi-natural woodland. Forestry Commission, Forest Practice Guide 1; (ed.) Forest Practice Division, The Forest authority, Edinburgh, 49 pp.

HINDE, THOMAS. 1985. Forest of Britain. London: Gollancz, 296 pp.

HOLLAND, A. J. 1971. Ships of British Oak. U.K.

JAMES, N. D. G. 1981. A History of English Forestry. Basil. Blackwell Publisher, Oxford, 399 pp., © N. D. G. James 1981.

JAMES, N. D. G. 1982. A forestry centenary: the history of the Royal Forestry Society of England, Wales and Northern Ireland. Oxford: Basil Blackwell, 196 pp.

JAMES, N. D. G. 1996. A History of Forestry and Monographic Forestry Literature in Germany, France and the United Kingdom. In: McDonald, P. and Lassoie, J. (eds.): The Literature of Forestry and Agroforestry, Cornell Univ. Press, Ithaca and London, pp. 15-44.

MITCHELL, A. F.; V. E. SCHILLING, J. E. J. WHITE. 1994. Champion trees in the British Isles. Edinburgh, U. K., Technical Paper – Forestry Commission (1994), no. 7, 92 pp.

OVINGTON, J. D. 1962. Quantitative ecology and the woodland concept. Adv. Ecol. Res. 1: 103-192.

OXFORD UNIVERSITY DEPARTMENT OF FORESTRY. 1936. Forest bibliography to 31st December 1933, 3 vols. Oxford, Oxford University, U. K. (A chronology listing of forestry citations dating back to the 1820s – over 11,000 citations. The bibliography is in three broad subjects: General forestry (by country, silviculture (with seven subheadings) and Forest protection.

RATTRAY, J.; R. M. MILL. 1885. Forestry and Forest Products. Prize Essays of the Edinburgh International Forestry Exhibition 1885.

RENDLE, B. J. 1976. Fifty years of timber research. U.K.

TANSLEY, A. G. 1939. The British Isle and their vegetation. London, Cambridge, University Press. (Semi-natural forest is a term most commonly used in U.K. and represents an important forest type for the establishment of forest reserves; it was introduced by Tansley in 1939).

TAYLOR, W. L. 1945. Forest and Forestry in Great Britain, U.K.

THE WORLD RESOURCE INSTITUTE et al. 1996. World Resources 1996-97. New York, Oxford, Oxford University Press, 365 pp.

WOOD, R. F. 1974. Fifty years of Forestry Research. Forestry Commission Bulletin no. 50.

8.1. Books containing information on forest mensuration and books from other fields that influenced the development of forest mensuration

For the development of an early industry and the most powerful navy in the world for a long time, and for its empire, Great Britain paid a high price. This price was the destruction of almost all valuable native forests, especially oak forests.

Forests cannot be imported but could be recreated, more or less successfully, during a long period of time. This problem became very important in the middle of the 19th century. An acceptable solution was adopted: (1) reconstruction of forest by plantations and sowing, (2) the use of fast-growing native or foreign species, and (3) a sustainable forest management.

Among the most important earlier textbooks on forestry published in Great Britain was the well-known "Schlich's Manual of Forestry" in five volumes, the first one published in 1889 and the fifth in 1896. The first three volumes were written by Schlich himself. The fourth (forest protection) represented a translation by W. R. Fisher of "Der Forstschutz" written by Richard Hess; the fifth (forest utilization) was also Fischer's translation of "Die Forstbenutzung" by Karl Gayer from the University of Munich.

The third volume of Schlich's Manual was published in 1895 (first edition), in 1905 (3rd ed.), 1911 (4th ed.) and 1925 (5th ed.) and contains yield tables for eight different species, "based on various district yield tables constructed in Germany". The absence of a 2nd edition of volume III was explained by a note in the 3rd edition: "Strictly speaking, this is the second edition of volume III, but as the first edition consisted of a larger number of copies than those of volume II, and in order to bring this volume into line with volume II, it has been issued as the third edition".

In the field of forest mensuration the second half of the 19th century in UK was strongly influenced by German literature. James (1981) noted: "Up to this time (about 1850, authors' note) English forestry had chiefly consisted of allowing trees to grow and then felling them, and forest management, as it is known today, was non-existent. As a new interest in forestry began to develop, so a demand arose for more information, improved techniques and a new approach to growing timber. The obvious source of help lay on the continent where the French and the Germans had applied themselves to the management of their forests over a long period" (p. 194). In 1905, in Nisbet's "The Forester …" German influence was evident and the yield tables, which Nisbet included in his book, were all of German origin (James 1981, p. 204). Charles Waitell yield tables published in 1809 were considered to be the first English tables of this kind by many authors, but the detailed information on English forests did not appear until "The Practice of Forestry …" published by Maw in 1909.

Table 8.1.-1. shows a selected list of books and textbooks published in the United Kingdom since 1736 when Edward Hoppus developed his tables that represent in fact a simple log rule that was applied in the U.K. until metrication in 1971 (see also 8.2.).

Among the authors mentioned in table 8.1.-1. some deserve a special comment: Waistell (1809) who made the first attempts to calculate the value and yield of stands of growing timber, Newton (1859) for his "Treatise" on the growth and future management of timber trees, Schlich (1895) vol. III of "Manual of Forestry" with his German yield tables for eight species, Hanson's (1911) "Forestry for Woodman" considered by James (1966, p. 43) as "a small and valuable book which helped many who wished to take up forestry as a career"; Maw's (1912) yield tables for British woodlands, tables which were not replaced until 1920 when the Forestry Commission began to construct yield tables; Forestry Commission's (1928) growth and yield of conifers in Great Britain.

The forest mensuration textbooks completed after 1939 by Jerram (1939), Davey (1941), Philip (1983), Hamilton (1988), Philip (1993, 2nd ed.) should be noted.

Philip's (1983) text was originally written for students in Africa, but the 1993 edition is international in scope and contains measurements, measuring single trees, measuring tree crops, forest inventory, statistical principles in forest inventory, site assessment, forest growth models, and was considered by Howard I. Wright from the Oxford Forestry Institute as "…the best general mensuration textbook in the English language". Two core monographs should not be forgotten: "Climate from Tree Rings" (Hughes et al. 1982) and "Utilization of Residual Forest Biomass" (Hakkila 1989).

A selection of the books on silvicultural aspects of forestry and biology that influenced the development of timber mensuration and tree-ring studies is shown in table 8.1-2. A lot of them are of historical interest but some of them, published after 1980, remain useful in our days. Among the books mentioned in Table 8.1-2 we consider as more remarkable those written by Watkins (1753), Nisbet (1893), Schlich (1889), Russell (1912 and 1988 edited by Alan Wild), Busgen et al. (1929), Warling and Phillips (ed. 1981), Philipson et al. (1971), Landsberg (1986), Dallimore and Jackson (ed. 1966).

TABLE 8.1.-1. Textbooks published in the U.K. containing information on timber mensuration

Year	Author(s)	Title	Publisher, Place, editions
1736	Edward Hoppus	Practical Measuring made easy to the Meanest Capacity by A New Set of Tables which upon a Bare Inspection show … The Solid or Superficial Content and consequently the Value of all Kinds of Square or Round Timber whether it be Standing or Felled	Publ. Gall and Inglis, London. 2nd ed. 1738 which was followed by further 19 numbered editions, the 21st being dated 1838. In 1837 a new edition was published and thereafter all editions were either described as 'New" or simply dated.
1794	Samuel Hayes	A Practical Treatise on Planting and the Management of Woods and Coppices	2nd ed. 1822
1809	Charles Waistell	The Method of Ascertaining the Value of Growing Timber Trees at Different and Distant Periods of Time with observations on the Growth of Timber	London
1851	Gavin Cree	Essays on the Scientific Management of Forest Trees	Lanark, Engl. Printed by R. Wood.
1859	G. W. Newton	A Treatise on the Growth and Future Management of Timber Trees	
1883	J. L. L. Mc Gregor	Organization and Valuation of Forests	London: Wyman and Sons.
1895	William Schlich	Manual of Forestry vol. III	London 2nd ed. (!) 3rd ed. 1905; 4th ed. 1911; 5th ed. 1925
1909	Percival T. Maw	The Practice of Forestry, Concerning also the Financial Aspects of Afforestation	Brockenhurst: Hants, Walter and Walter
1911	C. O. Hanson	Forestry for Woodmen	Oxford: Clarendon Press, 2nd ed. 1921
1912	Percival T. Maw	Complete Yield Tables for British Woodlands and the Finance of British Forestry	London: C. Lockwood and Son

TABLE 8.1.-1 (continuation)

Year	Author(s)	Title	Publisher, Place, editions
1913	W. F. A. Hudson	A Handbook of Forestry	
1926	M. D. Chaturvedi	Measurements of the cubical contents of forest crop	Oxford Forestry Mem. 4
1928	Great Britain Forestry Commission	Growth and Yield of conifers in Great Britain	
1939	M. R. K. Jerram	Elementary Forest Mensuration.	London: Thomas Murby and Co. 2nd impression 1949
1941	R. Davey	Measurement of Trees	
1951	C. F. Laver	Principles of log measurements	London: Ernest Benn Ltd.
1953	H. L. Edlin	The Forester's Handbook	
1954	W. E. Hiley	Woodland Management	2nd ed. 1967 revised by C. W. Scott and R.W.v. Palmer
1960	Forestry Commission	Conversion tables for forest research workers	For. Commission, London
1966	R. T. Bradley J. M. Christie D. R. Johnson	Forest management tables	For. Commission, London
1967	D. R. Johnson A. J. Grayson R. T. Bradley	Forest Planning	
1968	F. C. Osmaston	The Management of forests	
1969	Forestry Commission	Metric guide for forestry. A guide to the introduction of the metric system in British forestry	For. Commission, London
1970	British For. Commission	Metric volume ready reckoner for round timber	London
1970	Victor Serry	Metrication in the timber and allied building trades	Ernest Benn Ltd., London
1971	G. J. Hamilton J. M. Christie	Forest Management Tables (Metric)	For. Commission, London
1975	G. J. Hamilton	Forest mensuration handbook	For. Commission, London

TABLE 8.1.-1 (continuation)

Year	Author(s)	Title	Publisher, Place, editions
1977	CAB	Forest planning and forecasting Annotated bibliography	Commonwealth Agricultural Bureau
1982	M. K. Hughes P. M. Kelly J. R. Pilcher V. C. LaMarche (eds.)	Climate from Tree Rings	Cambridge University Press, U.K.
1983 1994	M. S. Philip	Measuring Trees and Forest	Wallingford Wallingford, Univ. of Aberdeen, U.K. 2nd ed., 1994 CAB International
1988	G. J. Hamilton	Forest Mensuration Handbook	For. Commission. HMSO, London
1989	P. Hakkila	Utilization of Residual Forest Biomass	London, Springer-Verlag
1990	P. G. Adlard	Procedures for monitoring tree growth and site change	Oxford, U.K.

TABLE 8.1.-2. Books on silviculture, forestry and biological problems published in the U.K. and that influenced the development of timber mensuration and tree ring studies

Year	Author(s)	Title	Publisher or/and place where it was published
1664	John Evelyn	Sylva or a Discourse of Forest-Trees In 1776 A. Hunter: "A John Evelyn's Silva or a Discourse of Forest-Trees". 2nd ed. 1787, 3rd ed. 1801, 4th ed. 1812, 5th ed. 1825	London 2nd ed. 1670, 3rd ed. 1679, 4th ed. 1706, 5th ed. 1729. Since the 4th ed. The word 'Sylva" is spelt 'Silva'
1753	William Watkins	A Treatise on Forest-Trees	London (?)
1827	J. Mitchell	Dendrologia or A Treatise of Forest Trees with Evelyn's Silva Revised, Corrected and Abridged	
1887	J. Sachs	Lectures on the Physiology of Plants	Oxford, England
1893	John Nisbet	British Forest Trees and Their Sylvicultural Characteristics and Treatment.	Macmillan, London and New York
1889	William Schlich	Manual of Forestry (Schlich's Manual of Forestry) Vol. I	London 2nd ed. 1896, 3rd ed. 1906, 4th ed. 1922
1894	John Nisbet	Studies in Forestry	Clarendon Press, Oxford
1905	John Nisbet	The Forester, a Practical Treatise on British Forestry and Aboriculture for Landowners, Land Agents and Foresters (contains yield tables of German origin)	W. Blackwood, Edinburgh and London
1911	John Nisbet	The Elements of British Forestry: A Handbook for Forest Apprentices and students of Forestry	W. Blackwood and Sons, Edinburgh and London:
1912 (1st ed.)	Edward W. Russell	Soil conditions and plant growth	Longmans Green, London and New York 11th edition edited by Alan Wild in 1988, Harlow, Longmans
1923 (1st ed.) 1966 (4th ed.)	William Dallimore A. Bruce Jackson	A handbook of conifers and ginkoaceae (4th edn. – 1966, revised by S.G. Harrison)	1966 edition: E. Arnold, London
1929	M. Busgen E. Munch T. Thomson	The structure and life of forest trees	London
1959	W. E. Hiley	Economics of plantations	London
1967	L. E. Rodin N. I. Bazilevich	Production and mineral cycling in terrestrial vegetation	Oliver and Boyd, London
1970 (1st ed.) 1981 (3rd ed.)	P. F. Wareing D. J. Phillips	The control of growth and differentiation in plants (3rd ed.: Growth and differentiation in plants). A core monograph	Oxford UK and New York Pergamon Press (1981)

TABLE 8.1.-2. (continuation)

Year	Author(s)	Title	Publisher or/and place where it was published
1971	William R. Philipson Josephine M. Ward B. G. Butterfield	The vascular cambium; its development and activity (A core monograph).	Chapman and Hall, London
1977	J. L. Harper	Population biology of plants	Academic Press, London
1977	Robert S. Russell	Plant root systems: their functions and interactions with the soil (A core monograph)	McGraw-Hill, London and New York
1986	J. J. Landberg	Physiological ecology of forest production	Academic Press, London
1989	G. Russell A. Marshall B. P. G. Jarvis	Plant canopies: their growth, form and functions (A core monograph)	Cambridge University Press UK and New York
1990	C. Watkins	Britain's ancient woodland, woodland management and conservation	David and Charles, London
1996	Brian Walker Will Steffen (eds).	Global change and terrestrial ecosystems	Cambridge University, © International Geosphere-Biosphere Programme 1996.

Mathematical statistics had a determinant role in the progress of forest mensuration in the U.K. especially due to the development of this discipline in the country. A sample of works on mathematical statistics frequently quoted by the authors of forest mensuration papers is presented in Table 8.1.-3. and among the works on mathematical statistics published in the UK and frequently quoted will be mentioned those signed by Yule, Pearl, Pearson, Fisher, Kendall, Queenouil, Hamming, Barnnet, Yates, and Hawkins. It should be mentioned that the foundation of the famous journal "Biometrika" in 1901 was completed by the English statisticians Galton, Pearson and others.

TABLE 8.1.-3. Books on mathematical statistics that contributed to the development of forest mensuration

Year	Author(s)	Title	Publisher, place, editions
1906	W. P. Elderton	Frequency curves and correlation	C. and E. Layton, London.
1919	G. U. Yule	An introduction to the theory of statistics	G. Griffin and Co., London
1924	R. Pearl	Introduction to medical biometry and statistics	London
1930	Karl Pearson	Tables for statisticians and biometricians Part I	Biometrics Laboratory Univ. College London 3rd ed
1930	M. Ezekiel	Methods of correlation analysis	New York - London
1937	G. U. Yule M. G. Kendall	An introduction to the theory of statistics	G. Griffin and Co. Ltd. London
1938	R. A. Fischer	Statistical methods for research workers.	Oliver and Boyd London
1947	M. G. Kendall	The advanced theory of statistics	London
1948	M. G. Kendall	Rank correlation methods	London
1948	R. A. Fisher	Statistical methods for research workers. 10th edition	Oliver and Boyd Ltd. Edinburgh and London
1949	R. A. Fisher	The design of experiments. 5th edition	Edinburgh
1949	K. Mather	Statistical analysis in biology. 3rd edition.	London
1949	Frank Yates	Sampling methods for census and surveys	Charles Griffin and Co., Ltd. London
1950	G. U. Yule M. G. Kendall	An introduction to the theory of statistics	London
1952 a	D. J. Finney	Statistical method in biology essay	London
1952 b	D. J. Finney	Probit Analysis. A statistical treatment of the sigmoid response curve	Cambridge Univ. Press
1952	M. H. Quenouille	Associated measurements.	London
1953	M. H. Quenouille	The design and analysis of experiment	London

TABLE 8.1.-3. (continuation)

Year	Author(s)	Title	Publisher, place, editions
1956	R. A. Fisher	Statistical method for research workers	Edinburgh, Oliver and Boyd.
1957	R. A. Fisher F. Yates	Statistical tables	Oliver and Boyd, Edinburgh
1963	R. A. Fisher F. Yates	Statistical tables for biological, agricultural and medical research	Oliver and Boyd Ltd., Edinburgh
1965	R. W. Hiorns	The fitting of growth and allied curves of the asymptotic regression type by Steven's method	Cambridge Univ.
1969	P. Sprent	Models in Regression and related topics. Methuen's monographs on applied probability and statistics	London Methuen and Co. Ltd.
1973	A. D. Cliff J. K. Ord	Spatial autocorrelation	Pion Ltd., London, 178 pp.
1975	C. Chatfield	The analysis of time series: theory and practice	Chapman and Hall, London
1976	R. K. Som	A manual of sampling techniques	Heineman, London
1976	P. J. Harrison C. F. Stevens	Bayesian forecasting (with discussion)	London
1977	R. W. Hamming	Digital filters	Prentice Hall, Englewood Cliffs
1978	V. Barnett T. Lewis	Outliers in statistical data.	John Wiley, Chichester
1979	R. J. Bennet	Spatial time series	Pion Ltd., London
1980	D. M. Hawkins	Identification of outliers	Chapman and Hale London
1981	A. C. Harvey	Time series models	Philip Allan Publishers Ltd., Oxford, U.K.
1983	P. Diggle	Statistical analysis of spatial point patterns	Academic Press, London
1984	M. J. Greenacre	Theory and application of correspondence analysis	Academic Press, London
1984	A. Stuart	The ideas of sampling. Statistical Monograph No. 4	

Apart from the works included in table 8.4-3 a special mention refers to the articles of Frank Yates published in 1946 (a review of statistical developments in sampling and sampling surveys) and 1948 (systematic sampling), and mentioned in the list of references at the end of the present chapter (U.K.).

Table 8.1.-4. contains selected books on modelling printed in the U.K. and frequently quoted in this country in the works on forestry in general, and growth and yield modelling in particular.

TABLE 8.1.-4. Works referring generally to problems of modelling that contributed to the development of these techniques in forestry and especially in forest growth and yield

Year	Author(s)	Title	Publisher, place, editions
1958	K. R. Popper	The logic of scientific discovery	Hutchinson, London
1964	J. M. Hammersly D. C. Handscomb	Monte Carlo methods	Chapman and Hall, London.
1971	J. N. R. Jeffers (ed.)	Mathematical models in Ecology: The 12th Symposium of The British Ecological Society	Blackwell, Oxford U.K.
1972	A. C. Day	FORTRAN Technique	Univ. Press Cambridge, U.K.
1976	J. Thornly	Mathematical models in plant physiology	Academic Press, London
1978	J. N. R. Jeffers	An introduction to system analysis: with ecological applications	Edward Arnold, London
1979	J. B. Dent M. J. Blackie	Systems simulation in agriculture	Applied science Publishers, London
1981	G. J. H. Hamilton J. M. Christie J. Edwards	Yield models for forest management	For. Commission
1983	E. Tufte	The visual display of quantitative information.	Graphic Press, Cheshire CT
1989	M. Aitkin A. Anderson B. Francis J. Hinde	Statistical modelling in GLIM (GLIM is a package using Generalized Linear Models, to allow logistic functions to be fitted to data without the conversion to a linear form)	Clarendon Press, Oxford U.K.
1989	J. Vandermeer	The ecology of intercropping	Cambridge University Press, U. K.
1990	E. Tufte	Envisioning information	Graphics Press, Cheshire CT

A relative interest for modelling in forestry presented the works based on the Monte Carlo Method (Hammersly and Handscob 1964), mathematical models in ecology (Jeffers 1972) and plant physiology (Thornley 1976), whereas more attention was paid to system analysis with its ecological applications.

Cited authors:

(1) Authors of the works containing information on forest mensuration:

Adlard 1990, Bradley et al. 1966, British Forest Commission 1970, Chaturvedi 1926, Cree 1851, Davey 1941, Edlin 1953, Great Britain Forestry Commission 1928, Forestry Commission 1960, 1969, Hakkila 1989, Hamilton 1975, 1988, Hamilton and Christie 1971, Hanson 1911, Hayes 1794, Hiley 1954, Hoppus 1736, Hudson 1913, Hughes et al. 1982, Jerram 1939 (1949), Johnson et al. 1967, Laver 1951, Maw 1909, 1912, Mc Gregor 1883, Newton 1859, Osmaston 1968, Philip 1983, Serry 1970, Schlich 1895, Waistell 1809.

(2) Authors of the works on silviculture, forestry and biology:

Busgen et al. 1929, Dallimore and Jackson 1923 (1966), Evelyn 1664 (1825), Harper 1977, Hiley 1959, Landberg 1986, Mitchell 1827, Nisbet 1893, 1894, 1905, 1911, Philipson et al. 1971, Rodin and Bazilevich 1967, Russel E. W. 1912 (1988 ed. Harlow, 11th ed.), Russell R. S. 1977, Russel et al. 1989, Schlich 1889, Walker and Steffen 1996, Wareing and Phillips 1970 (1981), Watkins W. 1753, Watkins C. 1990.

(3) Authors of mathematical statistics works published in the U.K. and used frequently in forest mensuration research:

Barnett and Lewis 1978, Bennet 1979, Chatfield 1975, Clif and Ord 1973, Crawley 1993, Diggle 1983, Elderton 1906, Ezekiel 1930, Finney 1952a, 1952b; Fisher 1938, 1948, 1949, 1956; Fisher and Yates 1957, Greenacre 1984, Hamming 1977, Harrison and Stevens 1976, Harvey 1981, Hawkins 1980, Hiorns 1965, Kendall 1947, 1948; Mather 1949, Pearl 1924, Pearson 1930 (3rd ed.), Quenouille 1952, 1953; Som 1976, Sprent 1969, Yates 1946, 1948, 1949; Yule 1919, Yule and Kendall 1937, 1950.

(4) Authors of modelling textbooks published in the U.K. and used frequently in forestry modelling:

Aitkin et al. 1989, Day 1972, Dent and Blackie 1979, Hamilton et al. 1981, Hammersly and Handscomb 1964, Jeffers 1972, 1978, Popper 1958, Thornley 1976, Tufte 1983, 1990, Vandermeer 1989.

8.2. Measurement of trees and primary products

It is very difficult to establish the origin time of the conventional measures of timber, but a part of them was clearly established in the early decades of the 17th century. Till 1971 when the Forestry Commission adopted metrication (the metric system), the so-called British system was in use in the country, but for wood some special units were adopted.

As far as we know the measurement of fuel was regulated in 1553 by “An act for the Assize of Fuel” (7 Edw. 6, c 8).

In 1633 Samuel Pepys, whose hobby was log measurement, referred in his diary to duodecimals as being a system which had just been brought to his notice, and for which he had “a mind to learn”; it appears unlikely that duodecimals subdivisions (of twelve or twelfths subunits system - auth. note) had, without his knowledge, been up to him employed in log measure. “Duodecimals were probably introduced into log measure towards the end of the seventeenth century; quite a long time before Edward Hoppus published his duodecimal tables” (Laver 1951, p. xiv). The diary of Samuel Pepys with Lord Braybrooke’s notes was edited by Henry B. Wheatley in 1893. According to Pepys information logs were lightly hewn up where the lay felled in the forest. Their average cross caliper measurements were used as a basis upon which to compute volume, thus treating the logs as if they were actually square in section. Both slide-rules and decimal ready-reckoners were used for this purpose” (Laver 1951, p. xiii).

Edward Hoppus published his “Practical Measuring made easy to the Meanest Capacity by A New Set of Tables ...“ (for complete title see References) usually abridged as “Hoppus’s Measurer” round about 1736, the 21st edition being dated 1834 but in 1837 a “New” edition was published and after that all editions were described as ‘New’ or simply dated. Hoppus tables were widely used in the U.K. and India, in the UK until metrication was adopted (1971).

Hoppus foot (H. ft.) is 1.2732 times as large as the cubic foot and is equal to 0.7854 of the volume expressed in cubic ft. Other data:

- 1 cu. ft per acre = 0.06978 m^3/ha
- 1 Hoppus ft. per acre = 0.089092 m^3/ha
- 1 cubic fathom per acre = 0.15114 m^3/ha

According to Chapman and Demeritt (1936) from the U.S.A., Hoppus rule is in fact a log rule, also known under the name of Quarter Girth, in which when girth (G) is measured in inches and length of log (L) in feet, volume in cubic feet

$$= \left(\frac{G}{4}\right)^2 * \frac{L}{144}$$

this rule gives 78.4 % of the cubic volume of the cylinder allowing a waste of 21.6 % and to obtain the full cubic volume of cylinders the formula would be

$$\text{Volume} = \left(\frac{G}{4}\right)^2 * \frac{L}{133}$$

On the other hand, it should be remembered that fifty Hoppus feet equal a cube of 3.993 ft.-side and if a cube of 2.391 ft. side is taken away, fifty ordinary cubic feet remain. Four logs equal one load when they are measured by the quarter girth tape and if measured by caliper only three logs are necessary to make a load. On the market the Hoppus feet had a similar role as the board feed in the USA.

In 1809 Charles Waistell presented, among other data concerning stand characteristics, tables for calculating volume, basal areas and tree heights.

In 1888 Burt published “The railway rates, standard measurer” and in 1898 a guide to round timber cubing rule.

Maw’s (1909) work contains data on trees measurement and interest tables.

A detailed work on measurements of the cubical contents of forest crops was published by Chaturvedi in 1926 and could be considered as an early elementary first mensuration textbook. Mac Donald (1931) detailed the measurement of standing trees in a paper published in the Scottish Forestry Journal.

Hide (1950) tried to square the circle to escape forester from π and as far as we know such attempt was performed in the USA by Thompson in 1805.

In 1950 the measurements of trees using the relascope were introduced in the UK by Keen, and a description of instruments used for the measurement of height, diameter and taper on standing trees was presented by Hummel in 1951. Barr and Strand Ltd. (1956) presented their dendrometer as an universal dendrometric device. In fact it is a very efficient and the best dendrometer constructed till 1956, especially the FP 7 type. Jeffers (1956) constructed a caliper that used a paper tape for punching which could be introduced in an electronic computer. This type of caliper was in 1966 still in experimental stage.

An excellent textbook (now of historical interest because of metrication) on log measurement was published in 1951 by Laver and refers to log measures and measurement, rectangular log and round log measure, unequal-diameter log measure, Waney log measure, miscellaneous log measures, logs having regular or irregular taper, fall of and stops, bark allowance, abatement for defects, conversion losses and miscellany. Bailey (1970) proposed a simplified method of sampling logging residues, and J. R. Smith published a textbook on the measurement of distances by optical means (1970).

One year before the introduction of the metric system (in 1971) the British Forest Commission published a booklet on metric volume ready reckoner for round timber (1970) and Serry (1970) a more detailed book on metrication in the timber and allied building trades. Later Hamilton (1974) presented a short comment on metrication in British forestry.

Timber measurement for standing sales was explained by Hamilton (1971). A new instrument for measurement of crown radius was constructed by Ayhan in 1977.

A field guide for timber measurement written by Edwards was published by the Forestry Commission in 1983 and the same commission published the top diameter sawlog tables in which volume in m^3 is given for top diameters 10, 12, 14, ... 80 cm and length 1.8, 1.9, 2.0, ... 8.3 m for softwood logs.

Helliwell (1986) published interesting comments on the determination of the extent of tree roots using a simple method in estimating root volume based on the assumption that soil volume in which roots occur is approximately equal to one tenth of the volume of the tree canopy, but this ratio is variable and depends on factors like soil moisture deficit, soil available water, soil fertility and wind exposure.

Cited authors:

An Act ... 1553, Ayhan 1977, Bailey 1970, Barr and Straud Ltd. 1956 (?), British Forestry Commission 1970, Burt 1888, 1898, Chapman and Demeritt 1936 (U.S.A.), Chaturvedi 1926, Edwards 1983, Hamilton 1971, 1974, Helliwell 1986, Hide 1950, Hoppus 1736, Hummel 1951, Jeffers 1956, Keen 1950, Laver 1951, Macdonald 1931, Maw 1909, Papys 1663 (1893), Serry 1970, Smith 1970, Thompson 1805 (U.S.A.), U.K. Forestry Commission 1987, Waistell 1809.

8.3. Tree form and volume tables

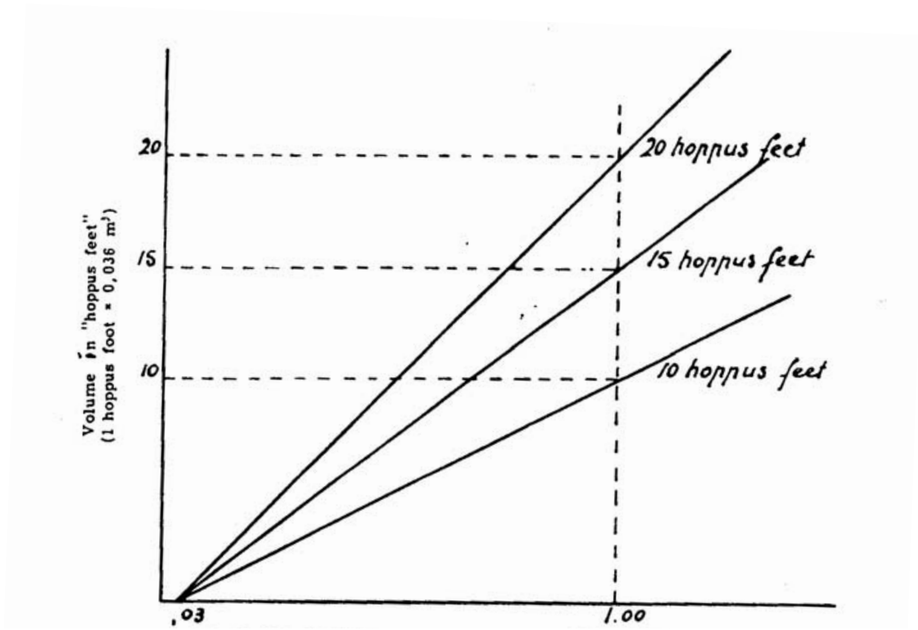
The form factor was mentioned in Great Britain for the first time in Waistell's "The practice of Forestry ..." in 1809. The first form factors of various conifers were published by Robinson in 1911 in the "Quarterly Journal of Forestry" and the first expression of stem form was published by Anderson in 1927 in the "Scottish Forestry Journal".

During 1932-1934 the data on the form of the stem in coniferous trees growing in the U.K. were presented by James Macdonald. Laver (1951) dedicated two chapters in his book to logs having regular or irregular taper, and a detailed work on the form and taper of forest-tree stems was completed by Gray in 1956.

The construction of volume tables began in the U.K. in 1950 and seems to be concentrated during the 1950s.

In 1950 Hummel and Waters constructed general volume tables for beech, birch, oak, European larch and Scots pine (1950a, 1950b, 1950 c, Hummel et al. 1950). In 1955 and 1956 Hummel used the equation $v = a + bx^2$ (the volume-basal area) for construction of tariffs or one entry volume tables (this equation was used in Germany in 1951 by Laer and Spiecker: see Germany, References). Hummel used it also for determination of volume series for conifers (1955). The function used by Hummel (1955) is based on the Kopezky-Gerhardt volume line which assumes a linear relationship between tree cross-sectional areas at breast-height and stem volume. According to van Laar and Akça (1997, p. 192) this is equivalent to the model $v_i = b_0 + b_1 d_i^2 + \varepsilon_i$ with the same assumptions about the distribution of residuals. The function produces unbraced estimates of the stem volume, but the assumption of homoscedasticity does not usually hold true and requires weighting, e.g. $w_i = 1/d_i$ or $w_i = 1/(d_i)^2$.

Hummel's (1956) "Tariff tables for conifers in Great Britain" based on the equation $v = a + bg$ (g = tree basal area) were expressed also in a graphical form (51 tariffs noted from 10 to 60) using the hoppus foot (Fig. 8.3.-1.)



Basal area in sq. ft., 1 sq. ft=11.83 dm^3

Fig. 8.3.-1. Principle of Hummel's tariffs; SOURCE: Pardé 1961, Dendrometrie, p. 171.

For the determination of the tariff's number is used the dominant height of stand or the result of the volume determination of a few numbers of typical trees. In 1957 Finch presented new ways of using the general tariff tables for conifers.

Cited authors:

Anderson 1927, Finch 1957, Gray 1956, Hummel 1955, 1956; Hummel and Waters 1950 a, 1950 b, 1950 c; Hummel et al. 1950, Laver 1951, Macdonald 1932-1934, Robinson 1911, Waistell 1809.

8.4. Tree growth

The Proceedings of the Cambridge Philosophical Society, published in1883, included a very interesting communication on "Determination of the greatest height consistent with stability that a vertical pole or mast can be made and of the greatest height to which a tree of given proportions can grow", by A. G. Greenhill, presented on February 7, 1881. Greenhill used a mathematical demonstration based on differential equation which is equivalent to Bassel's differential equation under some conditions. As an example he considered that a tree (neglecting the weight of branches) with a diameter of 20 inches at the base would allow a vertical stable growth of about 300 feet and added that: “Perhaps the best assumptions for our purpose as to the growth of a tree are (i) to assume a uniform tapering trunk as a central column, and (ii) to adopt Ruskin’s assumption (Modern Painters), that the sectional area of the branches of a tree, made by any horizontal plane, is constant” (p. 73).

Gompertz growth function, used sometimes in forest mensuration, was developed in 1825, but initially with no connection to forestry.

One of the earliest works on tree growth in the U.K. was completed by Christison in 1893 and refers to size, age and rate of girth-increase attained by trees of the main species, particularly in Scotland.

Hiley and Cunlitte (1922, 1923) investigated the relation between height growth of trees and meteorological conditions.

Some data on tree growth are mentioned in Busgen’s et al. (1929) “The structure and life of forest trees” published in London.

Before 1959 the three best-known “growth functions” are as follows: (all of them of German origin):

	Monomolecular	Autocatalytic	Gompertz
Equation	$w=A(1-be^{-kt})$	$w=A/(1+be^{-kt})$	$w=Ae^{-be^{-kt}}$
Growth-rate	$k(A-w)$	$kw(A-w)/A$	$kw\log_e(A/w)$

In 1959 F. J. Richards - from the Research Institute of Plant Physiology, Imperial College of Science, London - proposed a flexible growth function for empirical use, that represents an extended form of von Bertalanffy’s growth function. For a better understanding, the original Bertalanffy’s equation $dY/dt=ß_1Y^{\infty}-ß_2Y^{\gamma}$ should be remembered, *Y* being the mass, *t* the time and ∞ and γ the constants of anabolism and catabolism, respectively. Bertalanffy considered that ∞ could vary between 2/3 and 1, it will be 2/3 for animals, but did not proposed any value of ∞ for plant individual or populations. Richards considered ∞ as a non-constrained value and in this case this generalized form of Bertalanffy equation was sometimes called Chapman-Richards equation, as a result of Richards (1959) studies on plant growth and Chapman’s (1961) investigations on fish populations, but from historical point of view it should be pointed out that the generalized form of Bertalanffy equation was reported by E. Mitscherlich in 1919 and was used by German foresters during the 1950s (e.g. Weck 1951).

"Growth and Differentiation in Plants" (1970, 1981, 3rd ed.), originally entitled "The Control of Growth and Differentiation in Plants" (1971) is a useful monograph for forestry and was written by Wareing and Phillips.

A balanced quantitative model for root/shoot rations was developed by Thornley (1972) who stated that "total shoot activity is proportional to the total root activity in a plant undergoing steady-state growth ... dependence of stem root rations in vegetative growing plants on the rate of supply carbohydrate", in other words it was shown that, with certain assumptions, root and shoot activities are proportional to one another.

A computer modelling of individual tree growth was developed in 1980 by Grace in a doctoral thesis at the Oxford University, U.K.

In 1999 Thornley presented a model of stem height and diameter growth. This model "was formulated and implemented within the framework of an existing tree plantation growth model (the ITE Edinburgh Forest Model). If was proposed that the height/diameter growth ratio is a function of a within-plant allocation ratio determined by the transport- resistance model of partitioning, multiplied by a foliage turgor of crops although it was developed using a tree submodel" (For. Abs. 819/2000).

Cited authors:

Bertalanffy 1941 (Germany), Busgen et al. 1929, Chapman 1961 (U.S.A.), Christison 1893, Gampertz 1825, Grace 1980, Greenhill 1883, Hiley and Cunlitte 1922, Mitscherlich 1919, Richards F. J. 1959, Thornley 1972, 1999; Wareing and Phillips 1970 (1981), Weck 1951 (Germany).

8.5. Forest site evaluation

In 1912 was published the first edition of Russel's "Soil Conditions and Plant Growth", edited in many editions. The 11th edition (1988) edited by Alan Wild was available to the author. This book is a core monograph and could be considered as an valuable guide for the evaluation of forest site on the basis of soil properties.

In 1944 Foggie considered that the determination of site quality class should be based on top height instead of mean height as it was done before for conifers in Great Britain. A short review of methods assessing site capacity were shown by Rennie (1963). Johnston et al. 1967 considered that the Peterson's CVP climatic index of forest growth is the best and was designed to predict the maximum growth potential in terms of volume production over large areas. The Paterson index is based on evapotranspiration, annual temperature range, mean annual precipitation, length of growing season and monthly temperature of the warmest month. On the other hand, Vanclay (1994) noted: “Although it has been adopted on a national scale by several countries, it is probably only useful for economic geography and general forest statistics where estimates of potential production are required for large scale inaccessible and non-inventoried areas” (p. 145).

Blyth (1974) underlined the importance of initial check and tree form in the estimation of yield class as a growth index for site assessment.

Dawkins and Field (1978) described a permanent plot system designed for long-term monitoring of forest site, environmental change respectively.

In 1981 Hägglund described the ways for evaluation of forest site productivity, and Kirkpatrick and Saill determined top height curves for Sitka spruce in Northern Ireland as indicators of site productivity.

Forest site productivity is influenced by climate change. Wigley (1993) analyzed climate change and forestry, underlining that there is a strong evidence between the levels of carbon dioxide and other gases in the atmosphere (greenhouse effect) and climate change and forest vegetation development.

Hassall et al. (1994) investigated the effects of site characteristics on the growth rate of Sitka spruce using General Yield Class (GYC) as a site index. The degree of correlation between GYC and Land Classification for Forestry (LCF) class was also analyzed.

Cited authors:

Blyth 1974, Dawkins and Field 1978, Foggie 1944, Hägglung 1981, Hassall et al. 1994, Johnston et al. 1967, Kirkpatrick and Savill 1981, Rennie 1963, Russel 1912 (1988), 1977, Russel et al. ed. 1989, Vanclay 1994 (Denmark), Wigley 1993.

8.6. Stand structure

One of the indicators of stand structure is the distribution of trees by diameter categories. Different distribution functions have been used for this scope. One of them is the Weibull function applied in practice in 1939. In fact, the so-called Weibull function was developed by Fischer and Tippet in 1928 and obtained under the name of “Weibull” a large popularity among foresters who used it in numerous works especially in simulation of stand development. An example is given by Rennolls et al. (1985) who investigated the diameter distribution in 120 Sitka spruce stands and 90 stands of other conifers through Great Britain using the Weibull distribution.

In 1954 Hopkins proposed a new method for determination of the distribution type of plant individuals.

Incorporated in 1977 in forestry by Hafley and Schrender (USA) SA-Johnson distribution function was developed in 1949.

Hummel introduced in 1955 the mean height of the 10 thickest trees per acre as a measure for top height assuming that the tallest trees are uniformly distributed.

In 1978 Rennolls defined for UK "top height" and indicated the ways for its estimation.

In "Trees, woods and man" Edlin (1970) showed that in the United Kingdom the term "Old Growth" refers to forests which have been considered ancient or even natural, but were planted within the last centuries while "ancient woods" is a term commonly used (and refers) to sites which have been wooded continuously and some may be remnants of prehistoric woodlands (primary woods) whilst others arose as secondary woodland on ground cleared at some time in the past "...These forests can be over 400 years old but that does not mean at the same time that the present trees are as old as that although this can be possible" (Forestry Commission 1994, The Forest Authority, Edinburgh, Peterken 1993).

In 1962 Ovington developed - in a detailed article - quantitative ecology and the Woodland Ecosystem Concept. Referring to forest (especially tropical multistorey and multiaged forest) Ovington underlined: "Each plant layer supports a variety of animal life, has its own characteristic microclimate and is heterogeneous both vertically and horizontally. Of all terrestrial communities, woodlands are probably the most complex and massive, and not unexpectedly woodland ecologists have attempted to restrict their research to whatever features they felt were of greatest importance or could be recorded most readily" (Ovington: Adv. Ecol. Res. 1962, No. 1, p. 103). Ovington's conception may be summarized by the structure of his paper: (1) Introduction, (2) The ecosystem concept (in relation to forest research, terminology), (3) Organic matter dynamics (lack of weight data, organic matter in woodland ecosystems, organic matter production, organic matter turnover), (4) Energy dynamics (energy fixation, energy accumulation and release), (5) Water circulation (water loss from woodland ecosystems, water balance, (6) Circulation of chemical elements (weights of chemical elements in woodland ecosystems, removal of chemical elements by harvesting of tree trunks, nutrient update, retention and release, soil changes, input, output, long-term balance), (7) conclusions. It is clear that modern forest mensuration and especially stand structure is in a strong relationship with forest ecology.

Ford and Newbould (1970) investigated stand structure and dry weight production through the sweet chestnut coppice cycle. They described the process of growth and death of individuals and the relation of this to canopy structure and concluded that stand structure embraces all the physiological and geochemical properties of a woodland.

Competition and mortality determined the structure of a stand and this subject was examined also by British authors. The competition was estimated in 1964 by Greig-Smith who used distance measurements (the quadrate method used in plant ecology). Adlard (1974) developed an empirical competition model for individual tree within a stand based on three indices of competition: (1) an influence-zone overlap index, (2) an index based on a single count method and (3) growing space calculated on different assumptions of overlap of individual tree growth zones. A spatial stochastic model of interplant competition was developed by Diggle (1976). Aikman and Watkinson (1980) developed a model for growth and self-thinning in even-aged monocultures of plants of different densities using computer simulation of the growth and survival of plants. Yoda's et al. paper (1963) is relevant for this model. According to the summary of mentioned authors "The growth rate is described by a modification of the logistic growth differential equation in which the increase in weight of an individual plant depends on its area s_i rather than on its weight. The effective area for growth of a plant is restricted by an empirical function $f(s_i)$ with two terms: one term expresses the constraint imposed upon the increasing total area of plants by the limited physical area of the plot; the other term allows for a competitive advantage or disadvantage for plants of varying sizes. Depending on the value of the parameter controlling the relative competitive advantage form, intrinsic variability between plants can be amplified or suppressed. An individual plant dies if the $f(s_i)$ results in a negative growth rate for that plant." (Aikman and Watkinson 1980, Annals of Botany, 45, p. 419).

Several researchers suggested that competition between plants in a monoculture is in principal for light, rather than for other environmental resources. Cannel et al. (1984) investigated the competition within stands of *Picea sitchensis* and *Pinus contorta* grown in 50 x 50 hexagonal arrays of 14 cm spacing to ages 7 and 5 years. They concluded that "Competition was confined mostly to first-order neighbours and larger trees depressed the relative growth rates in height (RHGR) of smaller neighbours. Neighbours did not need to greatly overtop a tree to depress its RHGR, it is enough to be at least as tall and in conclusion "competitive status accounted for 25 and 38 per cent of the variation in RHGR for studied species". Cannel et al. noted that "Competition in plant monocultures implies that the supply of environmental resources (light, water and/or nutrients) falls below the combined demands of the plants, and that the environmental resources are shared unequally between plants in relation to their size. That is, the plants have unequal RGR (Relative growth rates): indeed, competition in plant monocultures can be assessed only by observing the distribution of RGR" (p. 349). In fact the competition is at the same time a spatial process in which individual performances depend on its height compared to its neighbours and its distance from them (for details see Ford and Sorrensen 1992: "Theory and models of interplant competition as a spatial process").

In 1981 Ford and Diggle analyzed the competition model for light in a plant monoculture modelled as a spatial stochastic process (a glasshouse experiment with *Tagetes patula*). This paper was mentioned here for its theoretical value and possibilities of the model to be used in forests. An important problem is to choose the index of competition. "The index may be based on the sum of the angles subtended by potential competitors of the subject tree, may include a threshold (i.e. competitor only if the angle is exceeded) and may be weighted for the size of competitors. Ford and Diggle selected competitors as those individuals taller than a 450 angle from the top of the subject plant and based their index on the angle subtended by competitors, but many others choose to include other characteristics in the index" (Vanclay 1994, p. 60).

Two core monographs refer to canopy-root system: Russell's R. (1977): Plant root system: their functions and interactions with the soil" and Russell's et al. 1989: "Plant canopies: their growth, form, and functions".

Cited authors:

Adlard 1974, Aikman and Watkinson 1980, Cannel et al. 1984, Diggle 1976, Edlin 1970, Fischer and Tippet 1928, Ford and Diggle 1981, Ford and Newbould 1970, Ford and Sorrensen 1992, Greig-Smith, P. 1964, Haftley and Schreuder 1977, Hopkins 1954, Hummel 1955, Johnson N. L. 1949, Ovington 1962, Rennolls 1978, Rennols et al. 1985, Russell R. 1977, Russel et al. 1989 (eds.), Vanclay 1994 (Denmark), Yoda et al. 1963 (Japan).

8.7. Stand volume, yield tables

In 1809 Charles Waistell drew up what were to be the first yield tables for English forest species; this work represents in fact only the first attempt to calculate the value and yield of stand growing timber. Waistell's textbook contains estimation of increment of crops of timber, data on basal area, form factors, tables giving the expected yield from seven species: thinning tables and tables for calculating volumes basal areas and heights.

The third volume of Schlich's "Manual of Forestry" (the last edition, 5th in 1925) was published in 1895 and contains yield tables for eight different species from various districts of Germany.

After a century, in 1909 Percival T. Maw published more detailed data on measurement of stands and interest tables in his "The Practice of Forestry concerning also the Financial Aspects of Afforestation".

Concerning stand volume the following works should be mentioned:

Chaturvedi - 1926 (measurement of the cubical contents of forest crops), the Forestry Commission's (1947) modifications of sample plot procedure since 1931, Christie's (1958 b) alignment charts and form height tables for determining stand volumes of conifers, oak and beech. Prance (1984) noted what to measure in a forest inventory: all trees (of all species including useless and dead stems) exceeding 10 cm dbh.

Yield tables. There is no doubt that the first yield tables for British forest species were constructed by Percival Maw and published in 1912. According to Maw the tables "were based on the adaptability of any particular area for the successful growth of timber and sites and were divided into four classes, quality I being the best and quality IV the worst." Maw's tables have been constructed for ash, beech, birch, oak, poplar, sweet chestnut, Douglas-fir, larch, Norway spruce, Scots pine, silver fir and Sitka spruce and were reviewed in the "Quarterly Journal of Forestry" by R. L. Robinson. Maw's tables were not replaced until 1920 when the Forestry Commission began to issue yield tables.

According to James (1981, p. 204) in preparation of yield tables, the Forestry Commission adopted a similar system to Maw's and the first tables were published in 1920 and 1921 (Norway spruce). In the case of Norway spruce dominant height and four classes with dominant height and the reference age of 50 years were used as a basis - the system was similar to that practiced later in the U.S.A. British yield tables were reviewed in 1926 by Gerhardt in Germany.

In 1946 the Forestry Commission issued a new set of yield tables for Scots pine and other conifers.

Hummel (1949) constructed revised yield tables for Japanese larch (in Great Britain) and in 1953 with J. Christie revised yield tables for other conifers. The methods used to construct these revised tables were summarized by Hummel and Christie in 1957. In the United Kingdom the enlarged rule of Eichhorn was in use in the case of even-aged coniferous stands.

Figure 8.7.-1. shows a scheme of site classes (five in this case) used in the United Kingdom and the U.S.A. where standard age for height is 50 years.

Provisional yield tables for oak and beech were completed in 1958 by Waters and Christie. In 1959 Hiley proposed a method for the construction of a yield table using another existent yield table for stands of similar productivity but different thinning intensities.

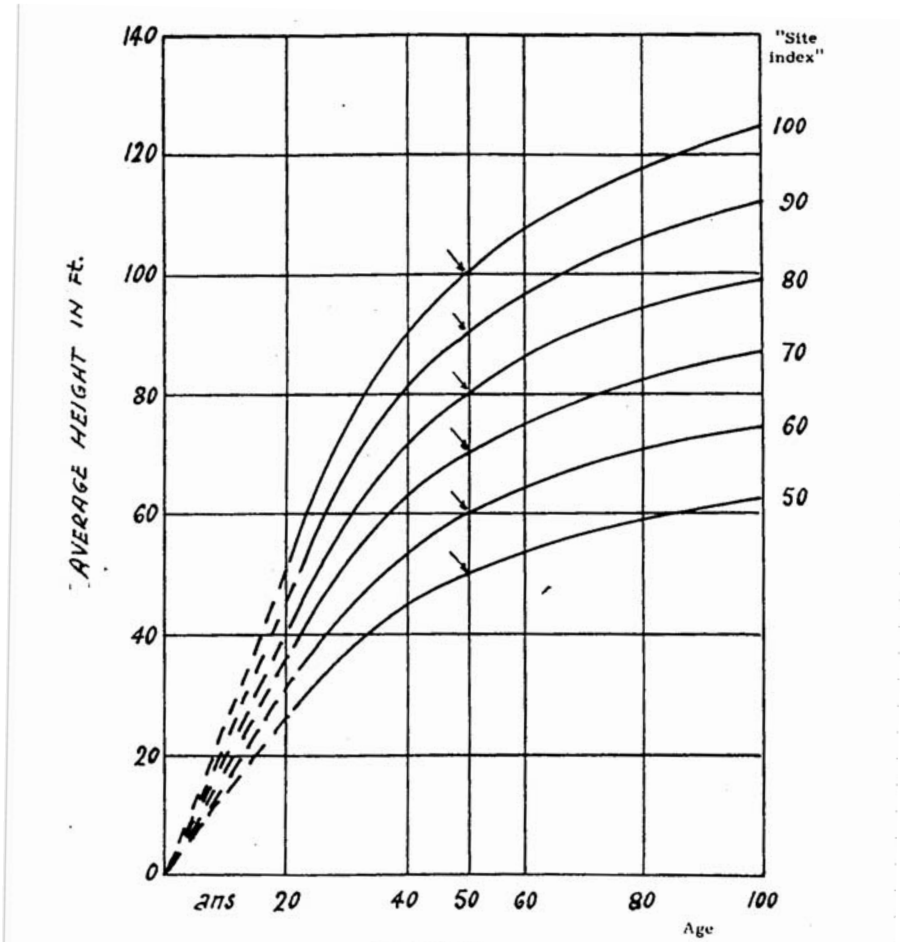


Fig. 8.7.-1. A scheme of site classes used in the U.K. Reference age 50 years.
SOURCE: Hummel and Christie 1953, "Revised yield tables for conifers in Great Britain", Forest Record no. 24, Forestry Commission, London 1953.

Bradley, Christie and Johnson (1966) advocated that mean annual increment (MAI) at culmination provides a better basis for comparison but these measures may be applied only to pure even-aged stands and difficulties become evident in mixed stands with many different species. Their yield tables are regionalized and the criterion of site classes is mean growth of all stand yields at 50 or 100 years. In the case of spruce nine classes of productivity have been adopted.

Christie (1970) characterized the relationships between basic crop parameters in yield table construction.

The first metric yield tables were constructed in 1971 by Hamilton and Christie as a result of metrication in the U.K. forestry (Table 8.7.-1.). The above authors constructed in 1973 a stand yield model which, as far as we know, is the first attempt made in the U.K. in this field.

TABLE 8.7.-1. Hamilton/Christie 1971 spruce yield table for Great Britain
SOURCE: Hamilton and Christie 1971, "Forest Management Tables (Metric). Forestry Commission, Booklet 34, London

Age	Trees that remain up to the next thinning: Stems (trees)	Dominant height	Average diameter	Basal area	Wood volume with top diameter > 7 cm	Current annual increment	MAI Mean annual increment
years	number	m	cm	m^2	m^3	m^3	m^3
				Site class 22			
10	3840	6.7	7.1	15.2	22	6.2	2.2
20	1866	11.8	11.8	20.4	93	23.7	8.6
30	786	18.3	21.4	28.4	230	31.4	15.5
40	470	23.7	31.3	36.2	392	30.5	19.5
50	329	28.1	40.2	41.7	525	26.9	21.3
60	252	31.5	48.3	46.2	627	23.3	22.0
70	212	34.3	55.5	51.2	720	19.1	21.9
80	186	36.7	61.6	55.5	794	16.1	21.3
				Site class 14			
20	3608	8.5	9.0	23.2	62	12.8	3.5
30	1614	13.7	14.2	25.4	141	19.8	8.2
40	919	18	20.6	30.6	246	20.3	11.3
50	622	21.5	26.8	35.0	345	18.8	12.9
60	463	24.4	32.2	37.8	423	16.6	13.7
70	378	26.7	37.2	41.2	497	14.4	14.0
80	324	28.6	41.4	43.7	559	12.5	13.9
				Site class 6			
30	3694	7.8	8.2	19.4	47	6.7	1.6
40	2497	10.7	10.8	22.8	87	8.9	3.2
50	1812	13.1	13.7	26.8	138	9.3	4.4
60	1349	15.2	16.6	29.2	186	8.8	5.2
70	1059	17.0	19.4	31.3	230	8.1	5.6
80	903	18.4	21.8	33.8	275	7.1	5.9
90	791	19.7	23.9	35.4	312	6.0	6.0

In 1981 Edwards and Christie presented in "Yield models for forest management" the variable density yield tables for plantations. These tables give height, number of stems per hectare, average diameter, stand basal area, mean stem volume, volume per hectare, mean annual and cumulative volume production at five year intervals for many species, site and management regime types (combinations).

In his “Forest Mensuration Handbook” Hamilton (1988) presented yield tables as alignment charts, a technique practiced in the U.S.A. many years before (1927, Reineke).

In 1991 Crockford and Savill constructed preliminary yield tables for oak coppice.

Cited authors:

Bradley et al. 1966, Chaturvedi 1926, Christie 1958, 1970; Crockford and Savill 1991, Edwards and Christie 1981, Forestry Commission 1921, 1946, 1947; Gehrhardt 1926, Hamilton 1988, Hamilton and Christie 1971, 1973; Hiley 1959, Hummel 1949, Hummel and Christie 1953, 1957; Maw 1909, 1912; Prance 1984, Reineke 1927 (U.S.A.), Schlich (vol. 3) 1895, Waistell 1809, Waters and Christie 1958.

8.8. Stand growth and yield. Conventional methods

The Forestry Commission published in 1920 the rate of growth of conifers in the British Isles, and in 1928 growth and yield of these species in a more detailed text.

Hummel and Brett (1953) used a simple method (based on heights) of estimating volume increment in stands of young conifers. Hummel (1958) proposed also methods of forecasting production from thinnings.

In 1959 Ovington and Madgwick investigated the growth and composition of natural stands of birch including dry-matter production which was a novelty. They noted: “Since natural regeneration is unreliable and difficult to control in the deforested landscape of Britain it has rarely been used by British foresters in their efforts to build up a reserve of timber. It is not surprising therefore, that the production of stemwood by forest plantation has been studied more intensively (as biomass, see 8.10 - our note) than that of woodlands originating from natural regeneration” (Ovington and Madgwick 1959, Plant and Soil 10, p. 271).

The researches on the growth of Norway spruce in the U.K. were summarized also by Kramer (1966 - Germany) and Newbould (1968) who presented methods of estimating root production.

The climate and the efficiency of crop production were analyzed by Monteith (1977) and a comparison of forest productivity in Britain and Europe in relation to climatic factors was completed by Christie and Lines in 1979.

A synthesis on the problems of planning performance and evaluation of growth and yield studies was completed by H. Wright in 1980.

The relationships between site factors and growth in the case of Sitka spruce (*Picea sitchensis*) in northeastern Scotland was investigated by Blyth and MacLeod in 1981, and in Northern Britain by Worrell (1987) and Worrell and Malcom (1990).

An interesting analysis of the components of relative growth rate (RGR) and their interrelations with 59 temperate plant species (out of which 16 woody dicotyledons) was completed in 1997 by Hunt and Cornelissen. Multiple regression showed that the leading determinants of RGR were unit leaf rate (ULR) and specific leaf area (SLA) in herbaceous species and leaf weight fraction (LWF) in woody species. The non-growth analytical characteristics most strongly correlated with RGR proved to be percentage yield at a low level of mineral nutrients, nitrogen concentration in leaves, and seed weight. The authors of this investigation - which in our opinion opens a new direction in forest physiology, growth and taxonomy - concluded that the mean RGR has a central role "in the identification of pathways of evolutionary specialization in herbaceous species". What about woody species?

Cited authors:

Blyth and MacLeod 1981, Christie and Lines 1979, Forestry Commission 1920, 1928; Hummel 1958, Hummel and Brett 1953, Hunt and Cornelissen 1997, Kramer 1966, Monteith 1977, Newbould 1968, Ovington and Madgwick 1959, Worrell 1987, Worrell and Malcom 1990, Wright, H. 1980.

8.9. Modelling

There are different model classifications proposed by different authors in different countries.

In a review of mathematical models in forestry Keith Rennolls (1992) defined the following areas of mathematical modelling and mentioned in brackets the most well-known authors who used them without mentioning the country:

(1) Spatial models (Matéin from Sweden made major early contributions): a) Point processes as models of random forests (Holgate, Ripley, Diggle): i) competition via hard or soft-cores, ii) sampling studies using geometric probability (Kendal and Moral, Miles), and introduction of point sampling methods (Bitterlich, Holgate); b) Lattice models (Besag) with competing marks (Gates).

(2) Growth models: general linear, generalized linear (Wilkinson, Nelder, McCallugh) and non-linear (Turnbull, Pienaar, Prodan) and that have a major importance in repeated- measure methods (Crowder and Hand); the stochastic growth model includes randomness in the processes rather than in the deviation from trend (Suzuki, Sloboda, Garria).

(3) Dynamic population models (spatial): involves points moving in space over time (stochastically), (Shellam, Mollinson), and link with areas 1 and 2.

(4) Multivariate state spaces – have implications for marked processes (Jeffers, Green Gates).

(5) The sampling theory with different methodologies (randomization, super-population and Bayesian, linear model prediction et al.)

(6) Sampling a multivariate process over space and time – which is an area of activity and brings together all of the above-mentioned areas; extending the early works of Cunia and Mandallaz) – After Rennolls 1992 p. 496 who underlined: "The integrated use of such models on large data sets is only now becoming feasible with the explosion of computing power. New software techniques (objects-oriented) and models (neural nets) allow a much higher degree of complexity than was conceivable a decade ago. The parallels between spatial lattice models, image-analysis algorithms and neural nets are very close; the class of 'algorithms' is a fundamentally important class of models in addition to those mathematical classes mentioned above" (Op. Cit. p. 496). According to Adlard (1995) "Growth elimination of living trees and stands is needed for: 1) yield prediction, 2) health monitoring, 3) long-term productivity monitoring, 4) socio-economic analyses of forest influences", (p. 4).

Before this classification, Jeffers analyzed in 1976 the problem of application of system analysis in forest research while Elston (1982) discussed the application of sensitivity analysis in the presence of correlated parameter estimates. In general modelling in forestry was improved by the progress in biometrics and mathematical statistics. In this respect it will be mentioned the works completed by: Leslie (1945, 1948 - the use of matrices in certain population mathematics); Gower (1967 - methods of cluster analysis); Harvey (1984 - a unified view of statistical forecasting procedures).

8.9.1. Growth and yield models

Among earlier works on growth and yield modelling Hamilton and Christi's communication on construction and application of stand yield models (1974) should be mentioned. They noted that "More recently, the availability of electronic computers has offered enormous advantages to yield table construction". ('Yield models' and 'yield tables' are substantially synonymous terms, though the former tends to reflect the greater flexibility in construction and application which is offered by computers).

In 1997 Alder et al.(from the Commonwealth Forestry Institute, Oxford University, U.K.) described a computer program GROPE (an acronym for Generalized Rainforest Out-turn Projection Evaluator) that represents a standardized growth projection method for tropical rainforest. GROPE model "was to have all its parameters estimated 'automatically' by self calibration from site specific data." It should be remembered that the GROWTH program, originally written by I.A. Andrew, a biometrician from New Zeeland, was used for this program.

In 1978 Kirkpatrick constructed growth models for Sitka spruce in Northern Ireland with log basal area increment as dependent and log transformed basal area, age, site index and their two factor interactions as predictor variables and Nokoe demonstrated the flexibility of the Gompertz function as a yield model using mature species data.

Briggs and Wickramasinghe (1990) analyzed the modelling of forest growth and environment relationships: theory and applications. They noticed that multiple-regression based models of tree growth of forest productivity can differ from region to region if environmental factors differ, but presented a universal deterministic model of the forest-environment relationship based on the observed close relationship between actual evapotranspiration during the growing season (effective evapotranspiration) and vegetation growth. Investigated species were *Pinus sylvestris* and *P. nigra* and considered parameters were potential evapotranspiration, soil available water capacity, soil moisture content, actual evapotranspiration, interception loss, drainage and runoff. Their model predicted better volume growth than basal area or diameter growth and the results were acceptable.

Rennolls (1995) constructed a forest height growth model for Sitka spruce. "The model is simple and based on the Chapman-Richards growth curve, has inhomogeneous variance structure and is calibrated by use of an interactive maximum likelihood estimation procedure" (p. 231). This model avoided the complications of correlated errors which, as a rule, arise in the analysis of longitudinal data, but avoids the complicated specifications of the stochastic models.

In an interesting paper Adlard (1995) examined "Myth and reality in growth estimation" reviewing the nature of growth data on which models have depended for their development and validation. He considered that "Tree and stand models of an empirical nature are likely to serve the needs of management in this decade, at least, but the trend to mixed "phenomenological" models (process-oriented models – our note) will increase. Adlard concluded: "Beautiful models can be made from slender data and create comforting myths like the traditional yield tables. The myth that the complex and changing shape of an individual tree can be described by a simple regression function still encourages traditional methods of growth analysis. Flexible models at all levels from the stand to leaf stomata are now available which demand new standards and controls on data.” (Op. cit., p. 8).

Vanclay (1994) underlined that the mechanistic models cannot solve the difficulties of accurate forecasts.

In a meeting of the GCTE (Global Change and Terrestrial Ecology project on the International Geosphere-Biosphere-Programme) Wheat Network compared predictions from ten different mechanistic models of wheat growth and discovered that their predictions varied between 2.5 and 8.0 t ha^{-1} in spite of the fact that dates of emergence, anthesis and maturity were prescribed (Steffen 1994). If this has happened with a species amenable to experimentation, what would happen in the case of forest species!?

Nevertheless regression models have been used and developed because in many cases they remain useful.

In 1996 Proe et al. established the assessment of the impact of climate change on growth of Sitka spruce in Scotland using a regression model developed to predict the general yield class (GYC), maximum mean annual volume increment of Sitka spruce from a range of site factors; the model has been used to express the potential impact of climate warming on the growth of Sitka spruce in Scotland.

8.9.2. Yield models for forest management

The type of models belongs to another field of modelling, but some British works will be mentioned here, being connected with diameter repartition and stand yield.

For a maximum sustained production Usher (1966) considered that “the proportions of the different size or age classes of the resource will have to be determined, and the amount of replacement by younger organisms calculated”. In this respect Usher adopted a matrix approach to the management of renewable resources, with special reference to selection forests. Some studies use the diameter class matrix advocated by Usher (1966) which are still termed Leslie matrices, but it is an evident distinction between Leslie and Usher matrices: “With a Leslie matrix of age classes all surviving individuals progress (“age”) to the next class each cycle. With an Usher matrix only some of the surviving trees grow into the next class, whereas those with little or no growth remain in the same class ... and Usher matrices have been used more widely than Markov matrices” (Vanclay 1994, p. 46).

In 1976 Usher used his matrices to estimate optimum yield and rotation length for *Pinus sylvestris* plantations in Britain: “A matrix model for a forest is extended so as not only to investigate number of trees in different site classes, but also to give expressions for the volume increment and economic increment of the forest as a whole" (Usher 1876, p. 123).

A booklet on yield models for forest management was completed in 1981 by Edwards and Christie.

Growth models were constructed for some agroforestry situations but there is a need for "a model that performs adequately across much on the forest-agroforestry-agricultural continuum" such as the Vandermeer (1989) model.

8.9.3. Process-based growth models

The uptake of nutrients by timber forest and its importance for timber production was underlined in Britain before 1960 (Rennie 1957).

The importance of process-based growth models on a stress on plant physiology has been recognized in the U.K. since the 1970s.

In 1976 Thornley published a remarkable textbook on mathematical models in plant physiology. Another textbook was written by Landsberg (1986) on "Physiological Ecology of Forest Production" and contains process models attempting to model the processes of growth, taking into account as input: the light, temperature and soil nutrient levels and modelling photosynthesis, respiration and the allocation of photosynthesis to roots, stems and leaves.

Landsberg (1986) issued a challenge to forest growth-modellers by defining a model as "a formal and precise statement or set of statements embodying our current knowledge or hypotheses about the working of a particular system and its responses to stimuli", and arguing that when such statements are made in mathematical terms, it usually becomes clear that our knowledge is incomplete and assumptions have to be made how parts of the system work. The consequences of these assumptions can be explored either algebrically or numerically, and it must be possible to test them, and the model as a whole, experimentally. By these criteria conventional forestry models scarcely qualify as models; they are not hypotheses, but descriptions of observations ..." (quotation from Vanclay 1994, p. 246).

The next year (1987) Rennolls and Blackwell published a paper on integrated forest process model, its calibration and predictive performance.

In 1990 Ludlow, Randle and Grace Jennifer from New Zealand developed a process-based growth model for Sitka spruce, constructing firstly a single-tree model. "Finally, the model's predictions were confirmed in a qualitative way with the common forestry experience that height growth is fairly independent of stocking density but much more related to site quality and to tree morphology ... The model therefore conforms to the fundamental assumption on which the United Kingdom yield tables were constructed" (Edwards and Christie 1981).

Cited authors (4.9.):

Adlard 1995, Adler et al. 1977, Briggs and Wickramasinghe 1990, Edwards and Christie 1981, Elston 1982, Hamilton and Christie 1974, Jeffers 1976, Kirkpatrick 1978, Landsberg 1986, Ludlow et al. 1990, Nokoe 1978, Proe et al. 1996, Rennie 1957, Rennolls 1992, Rennolls 1995a, 1995b; Rennolls and Blackwell 1987, Steffen 1994, Thornley 1976, Usher 1966, 1976; Vanclay 1994 (Denmark), Vandermeer 1989.

8.10. Weight and biomass studies

The first extensive studies on dry matter production in the UK have been carried out by J. D. Ovington in 1956, who determined the form, weights and productivity of tree species growth in closed stands in three main localities: Abbotswood in the forest of Dean, Bedgebury in Kent and West Tafts in Thetford Chase: "an account is given of the individual trees and the plantations (g/m^2) as a whole." Weight is given at 80^0C for the following species from plantations: *Abies grandis, Alnus incana, Betula alba, Castanea sativa, Chamaecyparis lawsoniana, Fagus sylvatica, Larix decidua, Larix eurolepis, Larix leptolepis, Nothofagus obligqua, Picea abies, Pinus nigra, Pinus sylvestris, Pseudotsuga menziesii, Quercus petraea, Q. robur, Q. rubra, Tsuga heterophylla* and *Thuja plicata*. The term "biomass" is not mentioned in Ovington's work. Ovington continues his works during the next 10 years in the UK: in 1957 (dry matter production by *Pinus sylvestris*), in 1959 (a) with Madgwich (distribution of organic matter and plant nutrients in a plantation of Scots pine, in southern Scotland), in 1959 (b) with Madgwich (the growth and composition of natural stands of birch: dry matter production), in 1962 (quantitative ecology and the woodland ecosystem concept), in 1963 (flower and seed production as a source of error in estimating woodland production, energy flow and mineral cycling - a paper in which Ovington mentioned for the first time the term "biomass measurements") and in 1965 (organic production, turnover and mineral cycling in woodlands mentioning explicitly in chapter IV Biological primary production: (1) Biomass, (2) Biomass change and (3) Net primary production.

The biomass and nutrient content of Scots and Corsican pines growing on sand dunes (*Pinus nigra* var. *calabria* and *P. sylvestris*) was determined by Wright and Will 1958.

Peterken and Newbould (1966) determined dry matter production of *Ilex aquifolium* L. in the New Forest.

In 1967 Rodin and Bazilievich published a notable monograph on production and mineral cycling in terrestrial vegetation containing data on biomass of some forest trees.

Methodological aspects of biomass and primary production estimation of forest were developed by Ovington et al. (1967) and Newbould (1967).

As a part of systems analysis in northern coniferous forests Satchell et al. computed in 1971 confidence limits for estimates of net primary production in coniferous forests.

Hughes (1971) determined trees biocontent, net production and litter fall in a deciduous woodland. Hughes studied energy flow and accumulation in the above parts of an alder-birch woodland in Durham County. Because these species are forest pioneers, some of the data will be mentioned: tree litter fall was approximately 1450 kcal/m^2/year, total biocontent of tree holes and branches was 50,912 Kcal/m^2 (10,679.2 g/m^2) and tree litter fall biocontent was close to 40.6 % of tree above ground net primary production.

An impressive book (982 pp.) published in 1981 (Palz et al. eds.) contains the Proceedings of the "International Conference on Biomass and Energy from Biomass" held at Brighton in 1980. In 1981 Mitchell et al. developed biomass tables for young conifer stands using regression equations. Another notable textbook belongs to Cannell (1982) and refers to "World Forest Biomass and Primary Production Data" published by the Academic Press in London.

Rollinson (1983) outlined a method for estimation of biomass for open-grown trees. The method is based on photographs and an image analyzing computer that can measure separately stemwood, large branchwood and small branchwood. Image analyzing computer could also be used for estimation of crown diameter - dbh relationships and for leaf area estimation.

The principle of the proposed technique is than an image from an elevation photograph of an open-grown tree is scanned by a television camera. The signal from the scanner is passed to a detector module and than to a television monitor to display.

Cannell (1985) discussed dry matter partitioning in tree crops.

In 1987 Hall and Overend published a book about biomass as regenerable energy. Applegate et al. (1988) examined the use of biomass estimation in the management of forests for fuelwood and fodder production.

Cannell (1989) investigated light interception, light use efficiency and assimilated partitioning in poplar and willow stands. He expressed "the total biomass" (above and below ground) as follows:

$$\mathrm{B} = \bar{\varepsilon} \int f S_0 \, dt \qquad (1)$$

where $\bar{\varepsilon}$ is the seasonal mean efficiency with which the crop uses intercepted light energy in the production of new dry matter (g MJ^{-1}), it is the fraction of incident radiation intercepted by canopy. S_0 is the daily integral to incident radiation, and the integral in the above equation is evaluated over the growing season. Because seasonal changes in S_0 are slow, the equation (1) can be simplified:

$$B=\bar{\varepsilon}\bar{f}A$$

where $\bar{f}$ is the mean intercepted fraction over the season, and $A=\int S_0 dt$, the accumulated amount of incoming solar radiation received over a season. If the aboveground woody biomass, B_w, is the mean proportion, $\bar{\eta}$, of the total dry matter, then

$$Bw=\bar{\eta}B=\bar{\eta}\bar{\varepsilon}\bar{f}A$$

Thus, woody biomass production can be analyzed into four approximately independent components, $\bar{\eta}, \bar{\varepsilon}, \bar{f}$ and A. (p. 1)

A core monograph on the utilization of residual forest biomass was written by Hakkila and published in London in 1989 by the Springer-Verlag.

A sample of data on biomass and net annual primary production in British forest ecosystems is shown in table 8.10.-1.

Cited authors:

Applegate et al. 1988, Cannell 1982, 1985, 1989; Hakkila 1989, Hall and Overend 1987, Hughes 1971, Mitchell et al. 1981, Newbould 1967, Ovington 1956, 1957, 1962, 1963, 1965; Ovington and Madgwick 1959 a, 1959 b; Ovington et al 1967, Palz et al. 1981, Peterken and Newbould 1966, Rodin and Bazilevich 1967, Rollinson 1983, Satchell 1971, Wright and Will 1958.

8.11. Tree-ring studies

8.11.1. The beginning of tree-ring studies, dating and chronologies

In 1838 was published the second edition of Babbage's text "On the age of strata, as inferred from the rings of trees embodied in them". He used the relative ring width for crossdating only five years later than Twining (1833) in the USA .

Chalk (1930) investigated the formation of spring and summer wood in ash and Douglas fir and published the results in the Oxford Forestry Memoire. In 1971 Philipson, Ward and Butterfield published a core monograph on vascular cambium, its development and activity.

TABLE 8.10.-1. A sample of data on biomass and net annual primary production in British forest ecosystems

Author(s) Species	Age	Biomass: trees, shrubs, and herbs (g/m^2)	Net primary production: trees, shrubs, and herbs (g/m^2/9yr)	Method of estimation
1	2	3	4	5
Ovington (1956)				
Abies grandis	21	35541 T, AG	1840 mns	m
Abies grandis	24	16485 T, AG	925 mns	m
Alnus incana	22	12470 T, AG	630 mns	m
Alnus incana	22	9754 T, AG	506 mns	m
Betula alba	22	6284 T, AG	286 mns	m
Betula alba	22	5881 T, AG	267 mns	m
Castanea sativa	47	11661 T, AG	375 mns	m
Chamaecyparis lawsoniana	21	20687 T, AG	1057 mns	m
Fagus sylvatica	39	13333 T, AG	505 mns	m
Larix decidua	46	18942 T, AG	598 mns	m
Larix eurolepis	23	14776 T, AG	964 mns	m
Larix leptolepsis	22	8601 T, AG	473 mns	m
Larix leptolepsis	22	7845 T, AG	439 mns	m
Nothofagus obliqua	22	8077 T, AG	431 mns	m
Picea abies	20	21832 T, AG	11295 mns	m
Picea abies	47	13980 T, AG	745 mns	m
Picea abies	47	26273 T, AG	939 mns	m
Pinus nigra	18	17387 T, AG	1033 mns	m
Pinus nigra	22	12238 T, AG	587 mns	m
Pinus nigra	22	14187 T, AG	676 mns	m
Pinus sylvestris	47	15655 T, AG	787 mns	m
Pseudotsuga mensiesii	21	11475 T, AG	720 mns	m
Pseudotsuga mensiesii	22	16821 T, AG	864 mns	m
Pseudotsuga mensiesii	22	18144 T, AG	924 mns	m
Pseudotsuga mensiesii	47	25242 T, AG	977 mns	m
Quercus	44	9238 T, AG	324 mns	m
Quercus petraea	21	4243 T, AG	202 mns	m

TABLE 8.10.-1. (continuation)

Author(s) Species	Age	Biomass: trees, shrubs, and herbs (g/m^2)		Net primary production: trees, shrubs, and herbs ($g/m^2/9yr$)	Method o estimatio
1	2	3		4	5
Quercus robur	47	12830	T, AG	394 mns	m
Quercus rubra	21	4306	T, AG	205 mns	m
Tsuga heterophylla	23	24960	T, AG	1294 mns	m
Thuja plicata	22	6832	T, AG	311 mns	m
Ovington (1957)					
Pinus sylvestris	3	4	T	2200 mns	m
Pinus sylvestris	7	746	T	2200 mns	m
Pinus sylvestris	11	2598	T	2200 mns	m
Pinus sylvestris	14	3331	T	2200 mns	m
Pinus sylvestris	17	4811	T	2200 mns	m
Pinus sylvestris	20	6535	T	2200 mns	m
Pinus sylvestris	23	9170	T	2200 mns	m
Pinus sylvestris	31	12720	T	2200 mns	m
Pinus sylvestris	31	12720	T	2200 mns	m
Pinus sylvestris	35	16336	T	2200 mns	m
Pinus sylvestris	55	15072	T	2200 mns	m
Pinus sylvestris	11	5163	T	n	m
Pinus sylvestris	14	4939	T	n	m
Pinus sylvestris	11	5163	T	n	m
Pinus sylvestris	14	4939	T	n	m
Wright and Will (1958)					
Pinus nigra var. Calabrica	18	2576	T, AG	n	M
Pinus nigra var. Calabrica	18	2576	T, AG	n	M
Pinus nigra var. Calabrica	28	6832	T, AG	n	M
Pinus nigra var. Calabrica	48	11200	T, AG	n	m
Pinus sylvestris	18	5488	T, AG	n	m
Pinus sylvestris	28	9408	T, AG	n	m
Pinus sylvestris	64	11872	T, AG	n	m

TABLE 8.10.-1. (continuation)

Author(s) Species	Age	Biomass: trees, shrubs, and herbs (g/m^2)	Net primary production: trees, shrubs, and herbs ($g/m^2/yr$)	Method of estimation
1	2	3	4	5
Ovington and Madgwick (1959)				
Pinus sylvestris	33	18591	n	s
Betula verrucosa	6	170	n	m
Betula verrucosa	24	7990	n	m
Betula verrucosa	27	7830 AG	n	m
Betula verrucosa	32	6380 AG	n	m
Betula verrucosa	38	7050 AG	n	m
Betula verrucosa	42	9450	n	m
Betula verrucosa	46	12080 AG	n	m
Betula verrucosa	53	17270	n	m
Betula verrucosa	55	21380	n	m
Peterken and Newbould (1966)				
Ilex aquifolium	82	21000 AG	1540 mns	s
Ilex aquifolium	100	13100 AG	970 mns	s
Ilex aquifolium	92	3800 AG	220 mns	s
Ilex aquifolium	94	7200 AG	380 mns	s
Ilex aquifolium	80	6000 AG	360 mns	s

Key to table: T = trees only, AG = above ground mass only, mns = method of estimating production not specified, m = mean tree technique, n = data not given, s = stratified tree techniques.
ORIGINAL SOURCES: Ovington 1956, Ovington 1957, Wright and Will 1958, Ovington and Madgwick 1959.
Reproduced after: H. W. Art and P. L. Marks "A summary table of biomass and net annual primary production in forest ecosystems of the world" pp. 6, 8, 9, 11, 16. In:Forest Biomass studies, IUFRO, XV IUFRO Congress, Univ. of Florida, Gainsvill, USA, March 15-20, 1971.

In 1943 Gwyneth Harrington, an American researcher, analyzed from dendrochronological point of view (dating first of all) the material removed from Ballinderry Crannog No. 1 excavated by Henken in the 1930s. Harrington noted: "The most important result at present is that even this small sequence (50 years) and correlations show that dating from tree rings in Ireland (northern I., author's note) can be done, though not as easily and clearly as is more favourable regions" and according to Baillie (1973) they led to the generally accepted belief that tree-ring dating would not work in Ireland. It is likely that the real reason for the total disinterest in tree ring dating as a tool for the Irish archaeologist and historian was founded on the short staffing in those disciplines and the lack of any financial support for a research project to fully investigate the possibilities" (Baillie, Tree-Ring Bull. 1933, vol. 33, p. 15).

In fact tree-ring dating and the development of English dendrochronology proved to be possible in spite of Britain's very temperate climate and the fact that Britain has no trees that can attain very great ages (Jennifer Hillam 1980). A comparison of three tree-ring chronologies is shown in figure 8.11.-1.

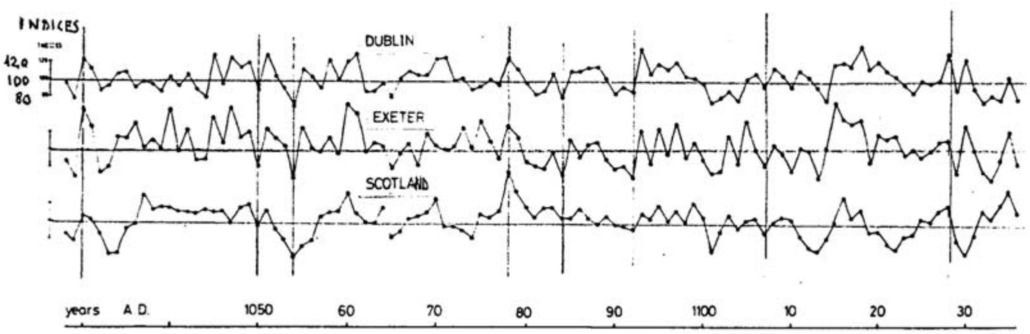


Fig. 8.11.-1. Comparison of the Exeter index chronology with the Dublin and Scotland index chronologies for the period A.D. 1028-1136.
SOURCE: Hirlam, J. 1980, Tree-Ring Bulletin, vol. 40, p. 18, "A medieval oak chronology"

In 1957 Schore and Lowther used dendrochronological research (dating) in medieval archaeology.

In his review Eckstein (1972) mentioned the above quoted work and Fletcher and Switzur (1973) papers on dendrochronological research in British archaeology and the chronologies constructed by Baillie (1973). He also mentioned the existence in the U.K. of two dendrochronological laboratories: Belfast and Oxford; other European laboratories of this kind were located in Caen, Louvain, Cologne, Trier, Oslo, Hamburg, Göttingen, Stuttgart, Munich, Lund (Sweden), East Berlin, Zbraslaw, Rome, Stockholm, Helsinki, Kaunas, Warsaw and Moscow.

A sustainable development of British dendrochronology commenced after 1968 and was concentrated at Palaeoecology Laboratory at the Queen's University, Belfast. In the early studies was used sub-fossil material. "Good crossdating over a wide area was then established for both oaks and pines, demonstrating an overriding climatic influence on tree growth even under log conditions. A number of floating sequences in excess of 500 years length have been constructed, timbers have been found from every half millennium back to 8,000 radiocarbon years before present" (Information from Tree-Ring Bulletin, vol. 33, 1973, p. 1). The first purpose of the beginning years was a modern standard chronology.

Baillie (1973) established the validity of the dendrochronological methods in Ireland and developed a standard chronology from A.D. 1649 to 1970 using timber from post-medieval constructions.

A cross-correlation of tree-ring patterns is presented in Fig. 8.11.-2. where the key year is A.D. 1580 and is arrowed in each of the three compared samples of different provenance.

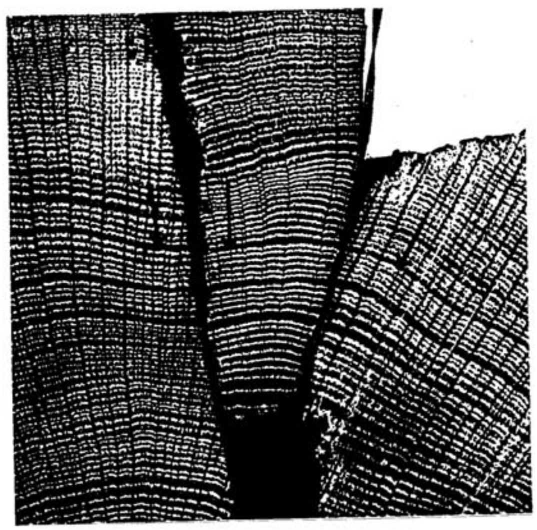


Fig. 8.11.-2. Visual crossdating between Q.U.B. 1122 (Dublin), Q.U.B. 29 (Coagh) and Q.U.B. 536 (Hillsborough). The year DATUM (A.D. 1580) is arrowed in each case.
SOURCE: M.G.I. Baillie 1973, "A recently developed Irish tree-ring chronology", Tree-Ring Bulletin, vol. 33, p. 19, Fig. 2.

As far as we know the first replicated modern tree-ring site chronology (using living trees) from the U.K. was published by Pilcher in 1976 (based on statistical methods) and the first response function was completed in 1978 (Hughes et al. 1978).

A sample of tree ring chronologies from U.K. is presented in table 8.11.-1.

Among other dendrochronologies ought to be mentioned a dendrochronology for Winchester (Barefoot et al. 1974), tree-ring chronologies for the 6th century for oaks on southern and eastern England (Fletcher 1977), a modern oak chronology form North Wales (Leggett et al. 1978), a 7272 year European tree-ring chronology (Pilcher et al. 1984) and woodland change and the dendrochronology of *Fagus sylvatica* in a plateau of beechwood of the Weald (Kent).

TABLE 8.11.-1. A sample of tree-ring chronologies from the United Kingdom

Year	Author(s)	Chronology years	Material, species	Area
1973	M.G.L. Baillie	1970-1380 A.D.	Medieval and post medieval timber	Northern Ireland
1973	M.G.L. Baillie	1972-1649 extended till 1380 A.D.	Recently filled oak trees and timbers from post medieval buildings	Northern Ireland
1975	A. C. Barefoot	1635-1972 A.D.		Winchester
1977	M. G. L. Baillie	1970-1001 A.D.	oak	Belfast
1977	M. G. L. Baillie	1030	oak (living)	South central Scotland
1977	J. R. Pilcher J. Hillman M. G. L. Baillie G. W. Pearson	a 2990 floating chronology covering approximately the period 1000 to 4000 BC	subfossil oak	Northern Ireland
1978	M. K. Hughes P. Leggett S. J. Milsom F.A. Hibbert	265 years modern oak chronology	sessile oak (*Q. petraea*) living trees	North Wales
1978	Donals W. Brett	1971-1840 1971-1900	Elm (*Ulmus* spp.)	London parks and Kew
1980	Jennifer Hilam	1216-799 A.D.	medieval waterlogged oak timbers	Exeter, southwest
1980	J. R. Pilcher M. G. L. Baillie	Six chronologies none extends before A.D. 1800	living *Quercus petraea* trees	Northern Ireland
1980	J. R. Pilcher M. G. L. Baillie	Eight modern tree-ring chronologies in index form	living oak	England and Scotland
1987	R. A. Morgan C. D. Litton C. R. Salisbury	a long tree-ring chronology spanning approximately 4500-3900 B.C. (calibrated radiocarbon dates)	material from submerged forest; neolitic oaks. The submerged forest was probably killed by sea-level raising	Midlands and South-west of England

It is useful to underline that in the U.K. as well as in the United States the dendrochronology was born by analyzing wood from old medieval buildings.

8.11.2. Methods of dendrochronology

Baillie and Pilcher developed in 1973 a simple crossdating program for tree-ring research, called CROSS, an algorithm which was improved for crossdating tree ring series proved to be useful and the improved algorithm should help any dendrochronologist who dates oak timber. CROSS has been widely used especially by the dendrochronologists working with oak and other species that do not have usually missing or multiple rings.

Pilcher (1976) developed in 1976 a statistical oak chronology in the northern Ireland.

In the field of tree-ring responses functions a review and intercomparison program was published in 1981 by Wigley and Laugh.

For testing the statistical significance of the summary response function Pilcher and Gray (1983) proposed a simple method which was applied to European oak data; this method should assist in determining which months are indicated for the reconstruction of climatic data from tree-ring chronologies.

Some aspects of chronology development and analysis were examined by Graybill (1982).

"Statistical dendrochronology" was the subject of Steward's M.Sc. thesis (1983) in the University of Sheffield. Statistical methods were in general use in the 1980s and some examples are given here: the use of Student's "t" test for matching tree-ring pattern (Orton, 1983), information theory and dendrochronology (Laxton and Litton 1982, 1983).

In 1969, in the United States, Ferguson used radiocarbon (C_{14}) to establish a 7104 year annual tree-ring chronology for bristlecone pine (*Pinus aristata*) from the White Mountain in California. This 14C method proved to have a high precision and was applied for dating Irish oaks and to show the natural 14C variations from 200 B.C. to 4000 B.C. (Pearson et al. 1983) and from AD 1840 to 5210 B.C. (Pearson et al. 1986). It is interesting that similar studies on ice core record of the C^{13}/C^{12} ratio of atmospheric CO_2, in the past two centuries, have been developed during the same year-period (Firedli et al. 1986). Other studies based on radiocarbon calibration have been performed by Wigley (1982), Becker (1983) and Baillie (1985).

In connection with an objective approach to standardization in dendrochronology should be mentioned the work of Briffa et al. (1987).

In 1995 Loader et al. used high resolution stable isotope analysis of tree rings and its implications in "microdendroclimatology" for palaeoenvironmental research. They used the *Quercus petraea* sample and attempted to reconstruct short-term climatic changes during the growing season and discovered a surprising clarity of signal that suggests a significant relationship between $\delta^{13}C_3$ and relative humidity and in a smaller intensity with temperature. This work may be considered as valuable for a future value of intra-ring isotope studies that can be named "microdendroclimatology".

8.11.3. Dendroclimatology

Schove (1950) underlined the relationship between tree-rings and summer temperatures.

Pilcher's statistical oak chronology (1976) was considered by the author as "a preliminary stage of the dendroclimatic research" ("trees show a positive response to rainfall making the site unusual in this respect"). For the oak in North Wales, Hughes (1978) developed a response function using rainfall data from a station very close to the investigated trees and established that 45 % of the chronology variance is due to climate and 73 % to climate plus prior growth.

Hughes et al. (1978) presented climatic signals in British Isles tree-ring chronologies.

Pilcher and Baillie (1980) tested their six modern oak (*Q. petraea*) chronologies from Ireland for climatic aspects using the response function method and observed that the results range from 5 % to 52 % of the chronology variance and explained by temperature and precipitation during and prior to the growing periods, and considered northern Ireland "as a single tree-ring area from a dating viewpoint" (p. 23, Tree-Ring Bull. vol. 40, 1980). Short considerations on response functions have been published by Guiot et al. in the comprehensive textbook "Climate from tree rings" based on the 2nd International Workshop on Global Dendroclimatology held in Norwich, U.K., July 1980, and published by the Cambridge University Press in 1982 (Hughes et al. eds.). This text may be considered as a core monograph for dendroclimatology.

The relationships between growth of oak trees and climate in Britain were examined by Pilcher and Gray (1982).

Briffa's et al. (1983) work in the field of climate reconstruction from tree rings presented the basic methodology and preliminary results for England, and in the next year (1984) Briffa completed his Ph.D. thesis on "Tree-climate relationships and dendroclimatological reconstruction in the British Isles".

More recently Bridge et al. (1996) published their dendroclimatological observations on trees at Kew and Wakehurst Place: event and pointer years (years with severe storms such as 1987 and 1990 or 1958 coincides with a marine wet summer) were identified for all investigated species and related to weather records.

Loader et al. (1996) reconstructed past environmental change using stable isotopes (carbon) in tree-rings. The authors considered that conventional dendroclimatological techniques often fail to reconstruct climatic variations and in such cases more parameters than ring width are required, and the stable isotope variations within the growth ring could provide other parameters.

8.11.4. Dendrochronological researches in archaeology

Shove and Lowther (1957) used dendrochronological research in British archaeology centers on Roman and Saxon remains by developing relative chronologies for the period between the 2nd century B.C. and the 4th century A.D., and for the 8th and 9th centuries, in the case of the Saxon period, respectively.

During the 1970s were completed the works of re-dating of the English art-historical tree-ring chronologies (Baillie et al. 1973), dating planks of a Middle Saxon cistern (Fletcher and Switzur 1973), dating of Cullyhanna hunting lodge in northern Ireland (Hillam 1976), Winchester excavation (Barefoot et al. 1978), dating of vernacular buildings from Yorkshire (Hillam and Ryder) and Baillie's text on "Tree ring dating and archaeology" published in 1982 by Croom Helm in London.

8.11.5. Other areas in which dendrochronology was involved

Dendrochronological dating was used in the U.K. for dating submerged forests around the British Isles which represented indicators of postglacial land and sea-level changes (Heyworth 1978).

Another interesting problem was dating of the geographical migration of *Quercus petraea* and *Quercus robur* in Halocene times (Fletcher 1978). According to Fletcher "the two species appear to have persisted in separate locations during the last ice age. Such analysis of the numerous Halocene oaks in Europe now being dated by dendrochronology offers the possibility of studying the separate migration of the species" (p. 45, TRB, 1978). The mentioned methods refer to the differences in wood structure and were determined in Germany by Huber et al. in 1941 (Huber selected four properties as characterizing each species: "the number of rows of vessels in the early wood and the fraction of annual growth formed by early wood are quantitative and the shape of the vessels in the early wood and the shape of the flames in the late wood, are qualitative" (after Fletcher, 1978, p. 45 op. cit.).

In A.D. 536 in the Mediterranean and eastern Asia a dust-veil and its effects were historically recorded. Dendrochronology raises questions about the nature of this dust-veil event because tree-ring evidence (especially that from European oaks) “shows a two state response and from this question if the veil was determined by a single great eruption or more eruptions” (Baillie 1994).

Widdicombe (1996) used dendrochronology of *Fagus sylvatica* in a plateau in Weald for the investigation of post-windthrow sections of beech to put into evidence woodland change.

Cited authors:

Babbage 1838, Baillie 1973 a, 1973 b, 1977 a, 1977 b, 1977 c, 1982, 1985, 1994; Baillie and Pilcher 1973, Baillie et al. 1973, Barefoot 1975, Barefoot et al. 1978, Barefoot et al. 1974, Becker 1983, Brett 1978, Bridge 1996, Briffa 1984, Briffa et al. 1983, Briffa et al. 1987, Chalk 1930, Eckstein 1972 (Germany), Ferguson 1969 (USA), Fletcher 1977, 1978; Fletcher and Switzur 1973, Friedli 1986, Gower 1967, Guiot et al. 1982, Graybill 1982, Gray and Pilcher 1983, Harrington 1943, Harvey 1984, Heyworth 1978, Hillam 1976, 1980; Hillam and Ryder 1980, Hughes et al. 1978, Hughes et al. 1978, Hughes et al. 1982, Laxton and Litton 1982, 1983; Legget 1978, Leslie 1945, 1948; Loader and Switsur 1996, Loarder et al. 1995, Morgan et al. 1987, Munro M.A.R. 1984, Orton 1983, Philipson et al. 1971, Pearson et al. 1983, Pearson et al. 1986, Pilcher 1976, Pilcher and Baillie 1980 a, 1980 b; Pilcher and Gray 1982, Pilcher et al. 1984, Pilcher et al. 1977, Schove 1950, Schove and Lowther 1957, Steward 1983, Widdicombe 1986, Wigley 1982, Wigley and Lough 1981.

8.12. Forest inventory: sampling, remote sensing and GIS

The first two woodland censuses were completed by Forestry Commission in 1924 and 1947-1949 (the lost is based on a complete field survey). A census woodlands of five acres and over carried out by different authors was published in London by Forestry Commission under the title “Census/Report” No.1 (264 pp.).

Macdonald (1931, 1932) presented sample plot method in Great Britain, procedure which was modified by Forestry Commission in 1947. In 1984 Yates published a detailed presentation of systematic sampling.

The problem of sample surveys on a large scale was examined by Mahalanobis (1944).

Hummel (1949) detailed the methods employed in the national forest survey of Great Britain performed during 1947-1949 period.

A code of sample plot procedure was published by Hummel et al. in 1959. For elementary statistical calculations, Dawkins (1968) proposed STATFORMS, predesigned forms for hand calculations in statistical techniques indicating the different computational steps. There was not yet the time for computerized processing of data for forest inventories in U. K. and Dawkins forms were very useful for small manual calculations.

In 1977-1978 was developed the Northern Ireland state forest inventory (Kilpatrick and Savill 1978.).

In 1983 and 1984 Forestry Commission published the results of the 1979-1982 Census of woodlands and trees: Warwickshire, Leicestershire, South Scotland, East Scotland, West Scotland, and Great Britain.

Watkins (1984) examined the results of 1924 and 1947-1949 censuses of Forestry Commission for investigation of past planting trends, the history of individual woods, and post-war changes in woodland type and species (For. Abs. 1321/1988).

Prance (1984), in connection with current in plant taxonomy, suggested how an inventory should be completed.

A discussion of the origins and ecological characteristics of ancient semi-natural Scottish woodlands, in connection with nature conservation is presented by Walker and Kirby (1989).

Dawkings (1985) suggested that sampling errors in extensive forest inventory can be estimated by the Poisson distribution - in essence, this is a nomogram procedure based on data from Nigerian inventories an was not tried in the conditions of temperate forests.

A critical analysis of growth estimation using sample plots of a forest inventory was performed by Adlard (1993) in this "Myth and reality in growth estimation" paper.

A handbook for national inventory was completed by Wright D. and J. Gilbert (1996) but, at least in 1996, it remained in the stage of unpublished document at the Forestry Commission Headquarters in Edinburgh.

Information and information technology. Landis and Hummel (1996) proposed to bridge the information gap in forestry in general and in forest inventory in special.

In connection with the use of the three dimensional visualization of normal photos (bidimensional) photography in forestry deserve we mention that for a stereoscopic visualization it is necessary a device called stereoscope which is a device " by which two photographs of something taken from slightly different angles are seen as if united and with the effect of depth and solidity" and "The first stereoscope was exhibited by Wheatstone in Great Britain in 1838 (Brewstes 1856), while the daguerreotype - the first practical photograph - was announced to the French Academy of Art and Sciences in 1839 (Spurr 1960, USA).

In 1947 Sisam discussed the use of aerial survey in forestry and agriculture and three years later Trorey (1950) published a handbook of aerial mapping and photogrammetry. A very clear and useful book about the utilization of aerial photography with special reference to vegetation (including forest) appeared in 1970 (Hovard J. A.), under the title "Aerial photo-ecology".

New information on the use of photogrammetry and remote sensing for forestry in Great Britain was presented by Thallon (1984).

In 1986 D. J. Carter published a valuable guide (175 pp.), as a source - book, to remote sensing products, services facilities, publications and other materials. This book covers the history of remote sensing and provides also a list of text-books and a guide to technical literature discussing in the same time the organizational structure of remote sensing activities in the U. K.

Dury, Collins and Hedges (1986) described a successful method for identification of different species and different age classes using the simulation of SPOT satellite data.

The advantages of satellite imagery compared with aircraft-borne cameras or sensors like radar were discussed by Allan (1986) with reference to the US Landsat satellite which was able to supply every 16 days with a resolution of 30 m compared with the lower resolution data of 1 km every half hour from the European Space Agency's Meteostat. Reability of results was examined in the case of monitoring devegetation and detection of grazing resources at a continental and global level.

Preliminary evaluation of the relationships between SPOT - 1 HVR and forest stand parameters have been presented in 1987 by Danson. Satellite data were compared with ground data in the case of mean percentage canopy cover, tree density, mean tree dbh and height, and compartment age (Danson investigated 28 sub-compartments of *Pinus nigra* var. *maritima* ages from 13 to 79 years near Mansfield, UK). Correlation coefficients for near Infra-Red (IR) wave-band (S3) were highly significant (99%) for all parameters except the percentage of canopy cover) (For. Abs. 1139/1989).

A short critical evaluation of spatial resolution for remote sensing of forest plantations was presented by Atkison and Danson (1988).

In 1997 Wright and Morrice used Landsat TM spectral information to enhance the land cover of Scotland 1988 data set but the obtained results indicated that the overall accuracy comparison with the LCS 88 (Land cover of Scotland 1988 survey) cover features was limited. "However, the opportunistic mapping of important agricultural crops and primary cover types, such as oilseeds rape and forestry cover features, or the interpretation of some of the considerable confusion between semi natural grassland and improved grassland cover features, provide for an enhanced LCS 88 dataset" (For. Abs. 2730/1997).

Imagery from a Compact Airborne Spectrographic Imager (CASI) was used by Blackburn and Milton (1996) to produce a vegetation cover map for five types of deciduous woodlands in the New Forest, Hampshire, UK. "A raster based GIS was used to derive a range of measures to describe the spatial characteristics of canopy gaps, in order to infer the relative ecological status of different types of deciduous woodland…It is concluded that the combination of airborne remotely sensed data and GIS technology holds great potential for ecological studies of woodlands" (For. Abs. 3605/1997).

Harris (1996) advocated the use of automated fire monitoring from space using the Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar orbiting satellites. This technique make possible a rapid production of fire maps.

Gerard and North (1997) developed a geometric-optical reflectance model that can estimates the bidirectional reflectance distribution function (BRDF) of forest canopies.

A remarkable work (2 volumes) on Geographical Information System (GIS) principles and applications was completed in 1991 by Maguire, Goodchild and Rhind (eds.). In this book Coppock and Rhind presented "The History of GIS" (vol. I, pp. 21-43).

During the last decade of 20th century the trend toward multi - resource forest inventories became more evident in many countries. Updating of timber inventories is not new but monitoring the forest status as an ecosystem is a more complex activity in which ecology is highly implicated. MRI and the assesssment of biodiversity (plants and animals) are evidently interconnected.

Since 1980 some works have been published in UK in connection with animals, plants and biodiversity: Corbet and Hill (1980) - a world list of mammalian species; Seber (1982, 1986 and 1992) - estimation of animal abundance; Kent and Coker (1992) - vegetation description and analysis: Hawksworth (1995) - measurement and estimation of biodiversity; Groombridge and Jenkins (1996) - assessing biodiversity status and sustainability.

In 1997, Mack et. al. compared remotely sensed and ground-based habitat data using species-area models and concluded that the remotely sensed data are of sufficient resolution (Land Cover Map derived from Landsat TM (thematic mapper) data having a pixel size of 25x25 m) for coarse estimates of the relationships between species and area.

Cited authors:

Adlard 1993. Allan 1986, Atkinson and Danson 1988, Blackburn and Milton 1996, Brewster 1856, Carter 1896, Coppock and Rhind 1991, Corbet and Hill, Danson 1987, Dawkins 1968, 1985; Dury et. al. 1986, (U.K.) Forestry Commission 1983, Gerard and North 1997, Groombridge and Jenkins 1996, Harris 1996, Hawksworth 1995, Howard 1970, Hummel 1949, Hummel et al. 1959, Kent and Coker 1992, Kilpatrick and Savill 1978, Landis and Hummel 1996, Macdonald 1931, 1932; Mack et. al. 1997, Maguire et al. 1991, Mahalanobis 1944, Prance 1984, Seber 1982, 1986, 1992; Sisam 1947, Thallon 1984, Trorey 1950, Walker and Kirby 1989, Watkins 1984, Weight D. and J. Gilbert 1996, Wright G. G. and J. G. Morrice 1907, Yates 1948.

8.13. Chronology of selected events

1553: Regulation of the measurement of fuel wood (An Act for the Assize of Fuel).

1633 (reprinted 1893): Duodecimals system in the measurement of logs (Samuel Pepys).

1736: Edward Hoppus' log rule and tables.

1809: First data on yield of English Forests (Charles Waistell).

1838: The exhibition of the first stereoscope by Wheatstone (D. Brewster 1856).

1893: Early data on the size, age and growth of the main trees in the United Kingdon (D. Christison).

1895: Manual of forestry vol. III - the first forest mensuration textbook, based on German data (William Schlich).

1911: A very useful handbook: "Forestry for Woodmen (C. O. Hanson).

1911: The first form factors of various British conifers (L. R. Robinson).

1912: The first complete yield tables for British forests (Percival T. Maw).

1912 (1988 - 11th edn): Soil conditions and plant growth (Edwards W. Russell).

Since 1920: Yield tables prepared by the Forestry Commission.

1926: Measurement of the cubical contents of forest crop (M. D. Chaturvedi).

1927: The first British expression of stem form (M. L. Anderson).

1928: Growth and yield of conifers in Great Britain (Great Britain Forestry Commission).

1931, 1932: The description of sample plot method in U.K. - modified in 1947 (J. Macdonald).

1932-1934: The form of the stem in coniferous trees (James Macdonald).

1939: Elementary forest mensuration (M. R. K. Jerram).

1944: Determination of site quality class by top height instead of mean height for conifers in Great Britain (A. Foggie).

1946: Yield tables for Scots pine and other conifers (Great Britain Forestry Commission).

1947-1949: The second woodland census on country level based on a complete field survey (Forestry Commision).

1948: F. Yates published a detailed presentation of systematic sampling.

1950: General volume tables for beach, birch, oak, European larch and Scots pine (F. C. Hummel and W. T. Waters).

Since the late 1940s and early 1950: The use of aerial photography in the U. K. (Sisam 1947, Trorey (1950).

1950: Introduction of relascope in the U. K. (E. A. Keen).

1951: Principles of log measurements (C. F. Laver).

1953: Revised yield tables for conifers in Great Britain - the use of top height (F. C. Hummel and J. Christie).

1956: Form and taper of forest tree stems (H. R. Gray).

1956: Tariff tables for conifers in Great Britain (F. C. Hummel).

1956: Recording caliper using punched paper tapes to be processed by computer (J. N. R. Jeffres).

1956: The first study on form, weights and productivity of the tree species grown in close stands (J. D. Ovington).

1957, 1959: Dry weight of some trees grown in the United Kingdom (J. D. Ovington - 1957, J. D. Ovington and H. A. J. Madgwick - 1959).

1957: First British dendrochronological researches in medieval archaeology (D. J. Schowe and A. W. G. Lauther).

1958: Alignment charts and form height tables for determining stand volumes of conifers, oak and beech (J. M. Christie).

1959, 1961: Chapman-Richards growth equation (F. J. Richards - 1959 and D. G. Chapman - 1961).

1962: Development of the quantitative ecology and the woodland ecosystem concept (D. J. Ovington).

1967: Methods for estimating the primary production of forests (P. J. Newbould).

1970: Metric volume ready reckoner for round timber (British Forestry Commission).

1971: Metric forest management tables (G. J. Hamilton and J. M. Christie).

1971: First metric yield tables (G. J. Hamilton and J. M. Christie).

1972: A balanced qualitative model for root-shoot ratios in vegetative plants (J. H. M. Thornley).

1973: Validity of the dendrochronological methods in Northern Ireland and development of a standard Chronology (M. G. L. Baillie).

1973: A crossdating program for tree ring research based on statistical methods (M. G. L. Baillie and J. P. Pilcher).

1976: A preliminary stage of the dendroclimatic research Statistical oak chronology (J. R. Pilcher).

1976: The first replicated modern tree-ring site chronology using living trees (J. R. Pilcher).

1978: Growth models for Sitka spruce in Northern Ireland (D. J. Kirkpatrick).

1980: A model for growth self thinning in even-aged monocultures of plants of different densities using computer simulation of the growth and survival of plants (D. P. Aikman and A. R. Watkinson.

1980: A computer modelling of individual tree growth (J. C. Grace).

1980: Modern oak chronologies and climatic aspects (J. R. Pilcher and M. G. L. Baillie).

1981: The relationships between site factors and growth in the case of Sitka spruce in northeastern Scotland (J. F. Blyth and D. A. MacLeod).

1981: First British variable density yield tables (P. N. Edwards and J. M. Chrostie).

1981: Ways for evaluation of forest site productivity (B. Häggland).

1981: Proceedings of "International Conference on Biomass and Energy from Biomass"- Brighton 1980 U. K. (W. Palz, P. Charter, D. O. Hall eds.).

1982: World Forest Biomass and Primary Production Data (M. G. R. Cannell).

1983: Forest mensuration textbook: "Measuring Trees and Forests (M. S. Philip).

1983, 1984: Forestry Commission published the results of the 1979-1982 census of woodlands and trees.

1985: H. C. Dawkins proposed the use of Poisson distribution for estimation of sampling errors in extensive forest inventory.

1986: Publication of a valuable guide on remote sensing (RS) in U.K. (D.J. Carter).

1986: Development of a successful method for identification of different species and age classes using SPOT satellite data (S.J. Dury, W. G. Collins, P. D. Hedges).

1986: Physiological Ecology of Forest Production-Process models (J. J. Landsberg).

1987: An integrated forest process model, its calibration and predictive performance (K. Rennolls and P. Blackwell).

1987: Preliminary evaluation of the relationship between SPOT - 1 HRV satellite imagery and forest stand parameters (F. M. Danson).

1990: Modelling forest growth and environment relationships: theory and applications (D. I. Briggs and A. Wickramasinghe).

1990s: The use of GIS techniques and its history (D. J. Maguire, M. F. Goodchild and D. W. Rhind (eds.) 1991; J. T. Coppack and D. W. Rhind 1991; Blackburn and Milton 1996).

1992: Theory and models of inter-plant competition as a spatial process (E. D. Ford and K. A. Sorrensen).

1992: A review of mathematical models in forestry (Keith Rennolls).

1995: High resolution stable isotope analysis of tree-rings an its implications in “microdendroclimatology” (N. J. Loader and V. R. Switur).

1995-1996: Assessing biodiversity in connection with potential multi - resources inventories (D. L. Hawsworld 1995 (ed.); B. Groombridge and M. D. Jenkins 1996).

1996: Reconstruction of past environmental change using stable carbon isotopes in tree-ring (N. J. Loader, V. R. Switsar, E. M. Field).

1997: Components of relative growth rate and their interrelations in 59 temperate plant species (R. Hunt and J. H. C. Cornelissen).

8.14. Selected contributors

Author	Printing years	Field
Edward Hoppus	1736	1
Charles Waistell	1809	01, 4
C. Babbage	1838	6
William Schlich	1880s→5th edn. 1925	01
E. A. P. Burt	1888, 1898	1
John Nisbet	1890s, 1900s, 1910s	1, 4
Percival T. Maw	1909, 1912	01, 4
R. L. Robinson	1911	1
Edward W. Russell	1912, edn. 11: 1988	01, 4
M. D. Chaturvedi	1920s	01, 4
M. R. K. Jerramm	1930s, 1940s	01
James Macdonald	1930s	1, 7
F. C. Hummel	1940s, 1950s	1, 4, 7
J. M. Christie	1950s, 1970s	4
J. N. Jeffers	1950s, 1970s	4
J. F. Laver	1950s	01, 1
L. G. Trorey	1950s	7
J. D. Ovington	1950s, 1960s	5
D. R. Johnson	1960s	01
P. J. Newbould	1960s	4, 5
M. B. Usher	1960s	4
H. C. Dawkins	1960s-1980s	7
M. G. L. Baillie	1970s-1990	6
J. Fletcher	1970s	6
J. A. Howard	1970s	7
E. D. Ford	1970s-1990s	3
G. J. Hamilton	1970s, 1980s	01, 4, 1
Jennifer Hillam	1970s, 1980s	6

Author	Printing years	Field
Malcolm K. Hughes	1970s, 1980s	6
J. R. Pilcher	1970s, 1980s	6
K. D. Rennolls	1970s, 1980s	3, 4
J. H. M. Thornley	1970s	1, 4
M. G. R. Cannell	1980s	5, 3
D. J. Carter	1980s	7
P. N. Edwards	1980s	4, 1
J. J. Landsberg	1980s	01
M. S. Philip	1980s	01
P. G. Adlard	1990s	4, 7
N. J. Loader	1990s	6
T. L. M. Wigley	1990s	4, 6
F. M. Danson	1990s	7
E. Landis	1990s	7

01 = books and textbook, 1 = tree and primary product measurements, 2 = forest site evaluation, 3 = stand structure, 4 = stand growth and yield, 5 = weight and biomass, 6 = tree-ring studies, 7 = forest inventory.

8.15. Comments

Features of the British timber mensuration history were determined first of all by a very large area of man made forests (two million acres = 809372 ha planted tree in 1975) especially conifer plantation as a result of depletion of natural productive forests rich in oak trees. As mentioned before (8.1) the destruction of natural forest was determined by the development of industry, navy construction and later the blockade during the Second World War.

Early English works on forest mensuration (Hoppus, Waistell, Christison) were scarce and contain a few data on natural forests.

Extension of conifer plantation after 1850 determined the existence of a large area covered with even-aged, pure stands for which the use of classical yield tables (existing in other countries) became very suitable for stand volume determination. Except for Maw's (1912) yield tables for British forests the forest mensuration in Britain was since the end of the 10th century till the 1920s under a strong influence of the German literature (Schlich's Manual of Forestry volume III whose 5th edition appeared in 1925). William Schlich, an outstanding German educated forester organized and directed Indian Forest Service under British rule later became Sir W. Schlich as a reward for his contribution to the development of British forestry and re-creation of forest in the British Isles. In his honour a special medal was issued, and one of the leaders awarded with this medal was the American president Franklin Roosevelt.

Maw (1909, 1912) was the first English forester who constructed yield tables for species grown in Great Britain and his tables were in use until 1920 when the Forestry Commission began to issue its own yield tables.

In the 1930s the form and volume of trees were relatively well-known but improvements in this area continued during the next two decades.

Introduction of metric system in the U. K. determined a revision and transformation of all volume and yield tables during the 1970s.

A remarkable development of tree ring studies began in 1968 and the number of titles in this area selected by us seems to be very large (20 %) in comparison with other fields, affecting the representativity of general sample of the selected work but we considered that it is better to keep available information on tree-ring studies and to improve the information on other fields in the future.

British foresters have been involved since the 1960s in modelling, taking into account biological aspects. The work of outstanding British statisticians like Fisher had a considerable influence on the development of forest mensuration (tree-ring studies included).

In the field of biomass studies the earliest works in U.K. were completed in the 1950s by Ovington, who seems to have used for the first time the term “biomass” in forestry.

The last decade of the 20th century remains dominated by the use of modelling in different fields of forest mensuration and extension of remote sensing and GIS techniques in forest inventory.

Out of 328 papers cited in this chapter 36 % were published after 1980 and 11 % after 1990. The most representative subjects of forest mensuration during the investigated period (1553-1999) were represented by tree mensuration (19 %), stand grow and yield-including modelling (19 %) and forest inventory (13 %).

Discussing the future of biometrics in forestry J. N. R. Jeffers (1992, Tampere IUFRO Congress, Proc. p. 495) noted that "The past hundred years of IUFRO's existence have seen an almost incredible development of mathematical representation and logical manipulation within the broad framework of forestry...Today, we stand at same sort of cross-roads where many of our preconceptions about the boundaries of scientific disciplines are being challenged. What kinds of knowledge will the forester of the future be required to have to meet the day-to-day challenges of his work?" And Jeffres concluded that "The modelling of the complex interactions between management and ecosystems, linked to decision support systems by concepts of artificial intelligence, will deliniate a new kind of biometrics as we enter the second century of IUFRO".

We consider that forest mensuration in U. K. is developing in this direction and the investigation of tree or stand growth will be based on strong relationship between biometrics and ecology and more than that, between biometrics and ecophysiology on tree level.

In our opinion the following aspects will have a notable impact on the future development of the different forest mensuration branches: (1) commercial availability of higher resolution of satellite imagery (this will permit the expansion of multi-resource inventories, updating of inventories and forest ecosystem monitoring), (2) sustainable development of ecophysiology (needed for the construction of reliable process-based growth models), and (3) concentration of tree-ring studies on annual ring level (from dendrochronology to “microdendrochronology”). We presume that this short list should not be closed because there are more methods and techniques which deserve to be taken into account for the progress in the field of forest mensuration.

References

ADLARD, P. G. 1974. Development of the empirical competition model for individual tree within a stand. pp. 22 - 27 in : "Growth Models for Tree and Stand Simulation" IUFRO Working party S 4.01-4. Proceedings of meetings in 1973, edited by Jöran Fries Institutionen for Skogsproduktion - Department of forest yield Research. Rapporter och Uppsoter/Research Notes nr. 30, 1974. Skogshögskolan Royal College of Forestry S - 10405 - Stockholm, Sweden, 379 pp.

ADLARD, P. G. 1990. Procedures for monitoring tree growth and site change. Oxford Forestry Institute, Tropical Forestry Papers 23, 188 pp.

ADLARD, P. G. 1995. Myth and reality in growth estimation. In Growth and Yield estimation from successive forest inventories. Selected papers from the IUFRO Conference, held in Copenhagen, 14 – 17 June 1993 (edited by Vanclay, J. K. et. al.). Forestry Ecology and Management (1995) 71 (3): 171-176.

AIKMAN, D. P.; WATKINSON, A. R. 1980. A model for growth and self-thinning in even-aged monocultures of plants. Annals of Botany 45: 419-427.

AITKIN, M.; ANDERSON, D.; FRANCIS, B.; HINDE, J. 1989. Statistical Modelling in GLIM. Oxford statistical Science Serves 4, Oxford Science publications, Clarendon Press, Oxford, 374 pp.

ALLAN, J. A. 1986. Remote sensing of agricultural and forest resources from space. Outlook on Agriculture 15(2): 65-69.

ALDER, D.; SYNNOTT, T. J.; SMITH, J. P. 1977. GROPE; a Standardized growth projection method for tropical rain forest. In E. F. Brünig (ed.) Transactions of the International MAB-IUFRO Workshop on Tropical Rainforest Ecosystem Research. Hamburg-Reinbeck 12-17 May 1977. Chair of World Forestry, Special Report No. 1, pp. 170-175.

AN. ACT....1553. An Act for the Assize of Fuel. 7 Edw. 6, C8.

ANDERSSON, M. L. 1927. The Expression of Stem Form. Scottish Forestry Journal, Vol. 4.

APPLEGATE G. B.; GILMORE, D. A.; MOHNS, B. 1988. The use of biomass estimation in the management of forests for fuelwood and fodder production. Commonwealth Forestry Review 67 (2): 141-147.

ATKINSON, P. M.; DANSON, .F. M. 1988. Spatial resolution for remote sensing of forest plantations. In: Proceeding, IGARSS '88 Symposium, Edinburgh, Scotland, 13-16 September 1988, ESA Publ. Division, pp. 221-223.

AYHAN, H. O. 1977. A crown radius instrument. Scottish Forestry 31 (2): 67-70.

BABBAGE, C. 1938. On the age of strata as inferred from the rings of trees embedded in them. In: The Ninth Bridgewater Treatise, a Fragment, 2nd edn., John Murray, London.

BAILEY G. R. 1970. A simplified method of sampling logging residences. Forestry Chronicle 46 (4): 288-294. Can.

BAILLIE, M. G. L. 1973 a. A dendrochronological study in Ireland with reference to the dating of medieval and post medieval timbers. Ph.D. Thesis, Queens University Belfast.

BAILLIE, M. G. L. 1973 b. A recently developed Irish tree-ring Chronology Tree-ring Bulletin 33: 15-28.

BAILLIE, MICHAEL G. L. 1977 a. Dublin medieval dendrochronology. Tree-Ring Bulletin 37: 13-20.

BAILLIE, MICHAEL G. L. 1977 b. The Belfast oak chronology to A. D. 1001. Tree-Ring Bulletin Vol. 37: 1-12.

BAILLIE, MICHAEL, G. L. 1977 c. An oak chronology for south-central Scotland Tree-Ring Bulletin Vol. 37: 33-44.

BAILLIE, M. G. L. 1982. Tree-ring dating and Arhaeology. Croom Helm - London.

BAILLIE, M. G. L. 1985. Irish dendrochronology and radiocarbon calibration. Ulster Journal of Arhaeology 48: 11-23.

BAILLIE, M. G. L. 1994. Dendrochronology raises questions about the nature of the A. D. 536 dust-veil event. Halocene 2 (4): 212-217.

BAILLIE, M. G. L.; J. R. PILCHER 1973. A simple crossdating program for tree-ring research. Tree-ring Bulletin 33: 7-14.

BAILLIE, M. G. L.; J. HILLAM; K. R. BRIFFA; D. M. BROWN. 1973. Re-dating the English art-historic tree-ring chronologies. Nature 315: 317-319.

BARNETT, V.; T. LEWIS. 1978. Outliers in statistical data. John Wiley, Chichester.

BARR and STRAUD Ltd. 1956 (?). The Barr and Straud dendrometer, description and method of use. Barr and Straud Ltd. Anniesland. Glasgow, Pamphl., no. 1216.

BAREFOOT, A.C. 1975. A Winchester dendrochronology for 1635 to 1572, A.D.: Its validity and possible extension. Journal of the Institute of Wood Science 7: 25-32.

BAREFOOT, A. C.; WOODHOUSE, L. B.; HAFLEY, W. L.; WILSON, E. H. 1974. Developing a dendrochronology for Winchester. England. Journal of the Institute of Wood Science 6 (5): 34-40.

BAREFOOT, A. C.; HAFLEY, W. L.; HUGES, J. F., 1978. Dendrochronology and the Winchester excavation. In: "Dendrochronology in Europe" (British Archaeological Reports. International Series 51, edited by J. M. Fletcher, pp. 162-171. B.A.R., Oxford.

BECKER, B. 1983. Dendrochronology and calibration of the radiocarbon timescale. In: Dendrochronology and Archaeology in Europe, eds.Eckstein, Wrobel and Aniol. Mitt. Bund. Forst. und Holzwirtschaft 141: 61-78.

BENNET, R. J. 1979. Spatial time series. Pion Ltd. London.

BERTALANFFY, L. VON 1941. Untersuchungen über die Gesetzlichkeit des Wachstums VII. Stoffwechseltypen und Wachstumstypen. (Researches on the laws of growth). Biol., Zbl. 61: 510-535.

BLACKBURN, G. A.; MILTON, E. J. 1996. Filling the gaps: remote sensing and GIS in the service of ecology and biogeography: a series of case studies. A special issue based on a meeting of the Biogeography Research Group of the Institute of British Geographer held at Newcastle, U. K., in May 1993. Global Ecology and Biogeography Letters (1996) 5 (5/4): 175-191.

BRADLEY, R.T.; CHRISTIE, J. M.; JOHNSON, D. R. 1966. Forest management tables. HMSO, For. Comm., Broklet no. 16 London.

BRETT, D. W. 1978. Elm tree rings as a rainfall record. Weather 33: 87-94.

BREWSTER, DAVID. 1856. The Stereoscope. John Murray, Publisher, London, 235 pp.

BRIDGE, M. C.; GASSON, P. E.; CUTLER, D. F. 1996. Dendroclimatological observations on trees of Kew and Wakehurst Place: event and pointer years. Forestry (Oxford) 19 (3): 263-269.

BRIFFA, K. R. 1984. Tree-Climate relationships and dendroclimatological reconstruction in the British Isles. Ph.D. thesis, University of East Anglia, Norwich, England, U.K.

BRIFFA, K. R.; JONES, P. D.; WIGLEY, T. M. L; PILCHER, J. R.; BAILIE, M. G. L. . 1983. Climate reconstruction from tree rings: Part I, Basis methodology and preliminary results for England Journal of Climatology 3: 233-242.

BRIFFA, K. R; WINGLEY, T. M. L.; JONES, P. D. 1987. Towards an objective approach to standardization. L. Kairiuktis, Z. Bednarz and E. Feliksik (eds). In: Proceedings of: Methods of Dendrochronology 1. International Institute for Applied Systems Analysis/Polish Akademy of Sciences-Systems Research Institute Warschaw, Poland pp. 69-86.

BRIGGS, D. I.; WICKRAMASINGHE, A. 1990. Modelling forest growth-environment relationships theory and applications. Applied Geography 10 (3): 187-204.

BRITISH FORESTRY COMMISSION. 1970. Metric volume ready reckoner for round timber. British Forest Commission Booklet 26, Her Majesty's Stationery Office, London, England, 80 pp.

BURT, E. A. P. 1888. The railway rates, standard timber measurer. London.

BURT, E. A. P. 1898. Guide to round timber cubing rule. London.

BUSGEN, M.; MÜNCH, E.; THOMSON,T. 1929. The structure and life of forest trees. London.

BLYTH, J. F. 1974. The importance of initial check and tree form in the estimation of yield class as a growth index for site assessment. Scottish Forestry 28 (3): 198-210.

BLYTH J. F.; MACLEOD, D. A. 1981. Sitka spruce. (*Picea sitchensis*) in northeast Scotland. I. Relationships between site factors and growth. Forestry 54: 41-62.

CANNELL, M. G. R. 1982. World forest biomass and primary production data. Academic Press, London, 391 pp.

CANNELL, M. G. R. 1985. Dry matter partitioning in tree corps. In: Cannell, M. G. R., and J. E. Jackson, eds. "Attributes of Trees As Crop Plants". Institute of Terrestrial Ecology, Huntingdon, England, U. K., pp. 160-188.

CANNELL, M. G. R. 1989. Light interruption, light use efficiency and assimilate partitioning in poplar and willow stands, pp. 1-12. In: "Biomass production by Fast Growing Trees", J. S. Pereira and J. J. Landsberg eds., © Kluwer Academic Publishers Dordrecht/Boston/London, printed in the Netherlands, 285 pp.

CANNELL, M. G. R.; ROTHERY, P., FORD, E. D. 1984. Competition within stands of *Picea sitchensis* and *Pinus contorta*. Annals of Botany 53: 349-362.

CARTER, D. J. 1986. The remote sensing source-book: a guide to remote sensing products, services, facilities, publication and other materials. McCarta 1986, 175 pp.

CHALK, L. 1930. Formation of spring summer wood in ash and Douglas-fir. Oxford Forestry Memoir 10, 48 pp.

CHAPMAN, D. G. 1961. Statistical problems in dynamics of exploited fisheries population. In Proc. 4th Berkeley Symp. Mth. Stat. and Prob., Univ. Calif. Press, Berkeley pp. 153-168.

CHAPMAN, HERNAN H.; DWIGHT B; DEMERITT. 1936. Elements of Forest Mensuration 2nd edn. (revised), Albany, New York, J. B. Lyon Company, Publishers, 451 pp.

CHATURVEDI, M. D. 1926. Measurements of the cubical contents of forest crop. Oxford Forestry, Mem. 4, 142 pp.

CHRISTIE, J. M. 1958. Alignment charts and form height tables for determining stand volumes of conifers, oak and beech. Forestry Commission. Forest Record no. 37, 20 pp., London.

CHRISTIE, J. M. 1970. The characterisation of the relationships between basic crop parameters in yield table construction. In: Proceedings of the 3rd Conference of the Advisory Group of Forest Statisticians. IUFRO, Jouy-en-Josas, France.

CHRISTIE, J. M.; R. LINES. 1979. A comparison of forest productivity in Britain and Europe in relation to climatic factors. Forest Ecology and Management 2: 75-102.

CHRISTISON, D. 1893. The size, age, and rate of girth-increase attained by trees of the chief species in Britain, particularly in Scotland. Trans. Bot. Soc. Edinburg 19: 455-535.

COPPOCK, J. T.; RHIND, D. W. 1991. "The History of GIS". In Geographical Information Systems: Principles and Applications, edited by D. J. Maguire, M. F. Goodchild and Rhind, D. W. vol. I, pp. 21-43. London: Longman Scientific and Technical, 1991.

CORBET, G. B.; HILL, J. E. 1980. A world list of mammalian species. London: British Museum of Natural History.

CRAWLEY, M. I. 1993. GLIM for Ecologists. Blackwell, Oxford, 379 pp.

CREE, GAVIN. 1851. Essays on the Scientific Management of Forest Trees. Lanark, Engl.; Printed by R. Wood, 1851.

CROCKFORD, K. J.; P. S. SAVILL. 1991. Preliminary yield tables for oak coppice. Forestry (Oxford), 64 (1): 29-49.

DALLIMORE, WILLIAM; A. BRUCE JACKSON. 1923. A Handbook of Conifers and Ginkgoaceae, 570 pp. 1st edn. The 4th edn. revised by S. G. Harrison ed. London, E. Arnold, 1966, 729 pp.

DANSON, F. M. 1987. Preliminary evaluation of the relationship between SPOT-1 HRV data and forest stand parameters. International Journal of Remote Sensing 8(10): 1571-1575.

DAVEY, R. 1941. Measurement of Trees.

DAWKINS, H. C. 1968. STATFORMS - Formats for elementary statistical calculation. Commonwealth Forestry Institute, Oxford. Institute paper No. 41.

DAWKINS, H. C.; D. R. B. FIELD. 1978. A long-term surveillance system for British woodland vegetation. Commonwealth. For. Institute, Occasional Paper 1.

DAY, A. C. 1972. FORTRAN Technique. Cambridge University Press. 96 pp.

DENT J. B.; M. J. BLACKIE. 1979. Systems simulation in agriculture. Applied Science Publishers, London.

DIGGLE, P. J. 1976. A spatial stochastic model of interplant competition. Journal of Applied Probability 13: 662-671.

DIGGLE, P. 1983. Statistical Analysis of Spatial Point Patterns. Academic Press.

DURY, S. J.; COLLINS, W. G.; HEGDGES, P. D. 1986. The use of SPOT simulation data in forestry mapping (Forest of Dean, U. K.). In Remote sensing for resources development and environmental management. Proc. 7th Int. Symp. ISPRS (International Society for Photogrammetry and Remote Sensing) Commission VII, Enschede, Aug. 1986 (edited by Damen, M. C. J.; Smit, G. S.; Verstappen, H. T.) Rotterdam, Netherlands; A. A. Balkema (1986) vol. I, 425-428.

ECKSTEIN, D. 1972. Tree-ring research in Europe. Tree-Ring Bulletin Vol. 32: 1-18.

EDLIN, H. L. 1953. The Forester's Handbook, London.

EDLIN, H. L., 1970. Trees, woods and man. New Naturalist Series 32, Collins, London.

EDWARDS, P. N. 1983. Timber Measurement. A Field Guide. Forestry Commission, Booklet no. 19, HMSO, London.

EDWARDS, P. N.; J. M. CHRISTIE. 1981. Yield models for forest management. Forestry Commission, Booklet 48, 32 pp.

ELDERTON, W. P. 1906. Frequency curves and correlation. C. and E. Layton, London.

ELSTON, D. A. 1982. Sensitivity analysis in the presence of correlated parameter estimates. Ecol. Modelling 64: 11-22.

EVELYN, JOHN 1664. Sylva or a Discourse of Forest-Trees. 2nd edn. 1670, 3rd edn. 1679, 4th edn. 1706, 5th edn. 1729. In the forth and subsequent editions the "sylva" is spelt "Silva". In 1776 A. Hunter published: "A John Evelyn’s Silva or A Discourse of Forest-Trees". 2nd edn. 1786, 3rd 1801, 4th edn. 1812, 5th edn. 1825.

EZEKIEL, M. 1930. Methods of Correlation Analysis. New-York-London.

FERGUSON, C. W. 1969. A 7104 year annual tree-ring chronology for bristlecone pine, *Pinus aristata* from the White Mountains, California. Tree-Ring Bulletin 29: 3-29.

FINCH, H. D. S. 1957. New ways of using the general tariff tables for conifers. For. Comm. For. Rec. no. 32, London.

FINNEY, D. J. 1952a. Statistical Method in Biological Assay. London.

FINNEY, D. J. 1952b. Probit Analysis. A Statistical Treatment of the Sigmoid response curve. Cambridge University Press.

FISHER, R. A. 1948. Statistical methods for research workers. Oliver and Boyd, Ltd. 10th edn., Edinburgh and London, 354 pp.

FISHER, R. A. 1949. The design of experiments. 5th edn. Edinburgh.

FISHER, R. A.; H. C. TIPPET. 1928. Limiting forms of the frequency distributions of the largest or smallest members of a sample. In 24th Camb. Philos. Soc. Proc. 1927: 180-190.

FISHER, R. A.; F. YATES. 1957. Statistical Tables. Edinburgh: Oliver and Boyd.

FLETCHER, J. 1977. Tree-ring chronologies for the 6th centuries for oaks on southern and eastern England. Journal of Archaeological Science 4: 335-352.

FLETCHER, JOHN. 1978. Dating the geographical migration of *Quercus petraea* and *Q. robur* in holocene times. London.

FLETCHER, J. M.; R. SWITZUR.1973. North Elmham: the dating. Current Archaeology Vol. 4, 1: 25-28.

FOGGIE, A. 1944. On the determination of quality class by top height instead of mean height for conifers in Great Britain. Forestry 18: 28-39.

FORD, E. P.; P. J. NEWBOULD. 1970. Stand structure and dry weight production through the sweet chestnut (*Castanea sativa* Mill.) coppice cycle. J. Ecol. 58: 275-296.

FORD, E. D.; P. J. DIGGLE. 1981. Competition for light in a plant monoculture modelled as a spatial stochastic process, Annals of Botany 48: 481-500.

FORD, E. D.; K. A. SORRENSEN. 1992. Theory and models of inter-plant competition as a spatial process. In P. L. De Angelis and L. J. Grass (eds.): "Individual based Models and Approaches in Ecology". Chapman and Hall, N. Y., pp. 363-407.

FORESTRY COMMISSION. 1920. Rate of growth of conifers in the British Isles. Bulletin no. 3, G. B.

FORESTRY COMMISSION. 1921. British yield tables, G. B.

FORESTRY COMMISSION. 1928. Growth and yield of conifers in Great Britain. Bull. 10, 187 pp, G.B.

FORESTRY COMMISSION. 1946. Yield tables for Scots pine and other conifers. 23 pp, G.B.

FORESTRY COMMISSION. 1947. Modification of sample plot procedure since 1931. For. Comm. (Great Britain). Mimeo, 16 pp.

FORESTRY COMMISSION. 1960. Conversion tables for forest research workers. For. Comm. Booklet no. 5, 64 pp.

FORESTRY COMMISSION. 1969. Metric guide for forestry. A. guide to the introduction of the metric system in British forestry. For. Comm. Booklet no. 27, 12 pp.

FORESTRY COMMISSION 1983. Census of woodlands and trees 1979-82: 1983: Warwickshire, Leicestershire; 1984: South Scotland, East Scotland, West Scotland, Great Britain. Edinburgh, U. K. Forestry Commission.

FORESTRY COMMISSION. 1987. Top diameter sawlog tables. For. Comm. Field Book, no. 1, 2nd edn., 25 pp.

FRIEDLI, H. L.; H. OESCHAER; U. SIEGENTHALER; B. STAUFER. 1986. Ice core record of the C^{13}/C^{12} ratio of atmospheric CO_2, in the past two centuries. Nature 324: 237-238.

GEHRHARDT, E. 1926. Britische Ertragstafeln. (British yield tables. Allg. Forst.-u. Jagdztg. 102: 142-147.

GERARD, F. F.; NORTH, P. R. J. 1997. Analyzing the effect of structural variability and canopy gaps on forest BRDF using a geometric - optical model. Remote sensing of Environment 62 (1): 46-62.

GOMPERTZ, B. 1825. On the nature of the function expressive of the law of human mortality and on a new mode of determining, the value of life contingencies. Phil. Transac. Royal Society, London, 115: 513-585.

GROOMBRIDGE, B.; JENKINS, M. D. 1996. Assessing biodiversity - status and sustainability. WCML Biodiversity Series 5. Cambridge, U. K.: World Conservation Press. 104 pp.

GRACE, J. C. 1980. Computer modelling of individual tree growth. Ph.D. Thesis, Oxford University, Oxford, England, U.K.

GRAY, H. R. 1956. The form and taper of forest-tree stems, Oxford Univ. Imp. For. Inst. Paper 32: 1-74.

GRAY, B. M.; J. R. PILCHER. 1983. Testing the significance of summary response functions. Tree-Ring Bull. Vol. 43: 31-38.

GRAYBILL, D. A. 1982. Chronology development and analysis. In: Hughes, M. K.; Kelley, J. R. Pilcher, and V. C. Lamarche, Jr. eds. "Climate from Tree Rings". Cambridge University Press, Cambridge, England, U.K., pp. 21-28.

GREENHILL, A. G. 1883. Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and of the greatest height to which a tree of given proportions can grow pp. 65-73; 7 February 1881 Proceedings of the Cambridge Philosophical Society volume IV October 25, 1980-May 28, 1983, Cambridge. Printed at the University Press, and sold by Deighton, Bell and Co. and Macmillan and Co. Cambridge; Bell and Sons. London 1883.

GREIG-SMITH, P. 1964. Quantitative plant ecology. Sevenoaks, U. K.

GOWER, J. C. 1967. A comparison of some methods of cluster analysis. Biometrics 23: 626-637.

GUIOT, J.; A. I. BERGER; A. V. MUNAUT. 1982. Response functions. In: "Climate from tree-rings", M. K. Hughes et al. (eds.), pp. 3845, Cambridge University Press.

HAFLEY, W. L.; H. T. SCHREUDER. 1977. Statistical distributions for fitting diameter and height data in even-aged stands. Can. J. For. Research 7: 481-487.

HÄGGLUND, B. 1981. Evaluation of forest site productivity. Commonwealth Forestry. Bureau, Forest Abstracts Review Article 42 (11): 515-527.

HAKILLA, P. 1989. Utilization of Residual Forest Biomass. London, Springer-Verlag, 568 pp (Core monograph).

HALL, D. O.; R. P. OVEREND. 1987. Biomass: Regenerable Energy. Chichester, U. K. Wiley (Core monograph).

HAMILTON, G. J. 1971. Timber measurement for standing sales. Forestry Commission, Booklet no. 36, HMSO, London.

HAMILTON, G. J. 1974. Metrication in British Forestry. Jour. Forestry 72: 749-752.

HAMILTON, G. J. 1985. Forest mensuration handbook. Forestry Commission Booklet no. 39, 274 pp.

HAMILTON, G. J.; J. M. CHRISTIE. 1971. Forest management tables (Metric) Forestry Commission Booklet 34. London.

HAMILTON, G. J.; J. M. CHRISTIE 1973. Construction and application of stand yield models. Forestry Commission Research and Development Paper 96, Edinburgh. Published in 1974 in Growth Models for Tree and Stand Simulation IUFRO working party S4.01-4. Proceedings of meetings in 1973. Edited by Jörah - Fries Research Notes no. 30, Royal College of Forestry S-10405 Stockholm, Sweden, 379 pp.

HAMILTON, G. J.; J. M. CHRISTIE; J. EDWARDS. 1981. Yield models for forest management. Forestry Commission Booklet, no. 48, 32 pp. + tables.

HAMMERSLY, J. M.; C. D. HAMDSCOMB. 1964. Monte Carlo Methods. Chapman and Hall, London.

HAMMINGS, R. W. 1977. Digital filters. Prentice Hall, Englewood Cliffs.

HANSON, C. O. 1911. Forestry for Woodmen. Oxford: Clavendon Press, 2nd edn. 1921.

HARPER, J. L. 1977. Population Biology of Plants. Academic Press. London England, U. K.

HARRINGTON, G. 1943. The wood from Bellindery Crannog No.1. Proceedings of the Royal Irish Academy 43: 235-238.

HARRINSON, P. J.; C. F. STEVENS. 1976. Bayesian forecasting (with discussion). Journal of the Royal Statistical Society, Series B; 38: 205-247.

HARRIS, A. J. L. 1996. Towards automated fire monitoring from space: semi-automated mapping of the January 1994 New South Wales wildfires using AVHRR data. International Jourrnal of Wildland Fire 6 (3): 107-116.

HARVEY, A. C. 1981. Time Series Models. Philip Allan Publishers Ltd., England, U. K.

HARVEY, A. C. 1984. A unified view of statistical forecasting procedures. Journal of Forecasting 3: 245-275.

HASSALL, R. B.; D. C. MacMILLAN; H. G. MILLER. 1994. Predicting Sitka spruce yield in the Buchan area of north-east Scotland. Forestry (Oxford) 67 (3): 219-235.

HAWKINS, D. M. 1980. Identification of Outliers. Chapman and Hall, London.

HAWKSWORTH, D. L. (ed.) 1995. Biodiversity mensurement and estimation. London, U. K.: Chapman and Hall 144 pp.

HAYES, SAMUEL 1794. A practical Treatise on Planting and the Management of Woods and Coppices 2nd edn. 1822.

HELLIWELL, D. R. 1986. The extent of tree roots. Arboricultural Journal (1896) 10 (4): 341-347.

HEYWORTH, A. 1978. Submerged forests around the British Isles: their dating and relevance as indicators of postglacial land and sea-level changes. In: Dendrochronology in Europe ed. J. M. Fletcher. British Archaeological Reports S 51: 279-288.

HIDE, R. H. 1950. Squaring the circle or the forester and his escapes from π Empire. Forestry Rev. 29: 146-151.

HILEY, W. E. 1954. Woodland Management. 2nd edn. 1967 revised by C. W. Scott and R. W. V. Palmer.

HILEY, W. E. 1959. Economics of Plantation, London.

HILEY, W. E.; N. CUNLIFFE. 1922. An investigation into the relation between height growth of trees and meteorological conditions. Oxf. For. Mem. no. 1.

HILEY W. E.; N. CUNLIFFE. 1923. Further observations of the relation of the height growth of trees to meteorological conditions. Ann. Appl. Biol. 10: 442-452.

HILLAM, J. 1976. The dating of Cullyhanna hunting lodge. Irish Archaeological Forum 3: 17-20.

HILLAM, JENNIFER. 1980. A medieval oak tree-ring chronology from southwest England. Tree-Ring Bull. 40: 13-22.

HILLAM, J.; P. F. RYDER 1980.Tree-ring dating of vernacular buildings from Yorkshire. Vernacular Architecture 11: 23-31.

HIORNS, R. W. 1965. The fitting of growth and allied curves of the asymptotic regression type by Steven's method, Tract for computors, No. XXVIII, Cambridge University.

HOPKINS, B. 1954. A new method of determining the type of distribution of plant individuals. Ann. Bot. London: 213-227.

HOPPUS, EDWARD. 1736. Practical Measuring made easy to the Meanest Capacity by A new Set of Tables which upon a Bare Inspection show... The solid or Superficial Content (and consequently the Value of all kinds of Squared or Round Timber, whether it be Standing or Felled, 2nd edn. 1738 which was followed by a further, 19 numbered edition, the 21st being dated 1834. In 1837 a “New" edition was published and then all editions were either described as "New" or simply dated. Modern copies of these tables which were widely used until metrication (1971) were adopted in about 1972, and frequently undated.

HOWARD, J. A. 1970. Aerial photo-ecology. Faber and Faber, London, 325 pp.

HUDSON, W. F. A. 1913. A Handbook of Forestry. U. K.

HUGHES, M. K. 1971. Tree biocontent, net production and litter fall in a deciduous woodland. Oikos, vol. 22, pp. 62-73.

HUGHES, M. K. (ed) 1982. Climate from Tree-Rings: Based on the 2nd International Workshop on Global Dendroclimatology. Univ. of East England, Norwich, U. K. July 1980. Cambridge, U. K. and New York; Cambridge University Press, 233 pp (Core monograph).

HUGHES, M. K.; P. LEGGETT; S. J. MILSON; F. A. HUBERT. 1978. Dendrochronology of oak in North Wales. Tree-Ring Bull. 38: 15-21.

HUGHES, M. K.; B. GRAY; J. PILCHER; M. BAILLIE; P. LEGGETT. 1978. Climatic signals in British Isles tree-ring chronologies. Nature 272: 605-606.

HUGHES, M. K; P. M. KELLY; J. R. PILCHER; V. C. LaMARCHE, Jr. (eds). 1982. Climate from Tree-Rings. Cambridge University Press, Cambridge, England, U. K. 223 pp.

HUMMEL, F. C. 1949a. Revised yield tables for Japanese larch in Great Britain. Forestry Commission, Forest Record no. 1, 14 pp.

HUMMEL, F. C. 1949b. The methods employed in the national forest survey of Great Britain. Act. 3 Congr. Forest. Mond. Helsinki Nr. 1.S. 39-52.

HUMMEL, F. C. 1951. Instruments for the measurement of height diameter and taper on standing trees. For. Abstr. 12 (3): 261-269.

HUMMEL, F. C. 1955. The volume-basal area line a study in Forest Mensuration. Bulletin nr.24, For. Commission, 84 pp.

HUMMEL, F. C. 1956. Tariff tables for conifers in Great Britain. Forestry Commission, Forest Record no. 31, 16 pp., London.

HUMMEL, F. C. 1958. Methods of forecasting productions from thinnings. Unasylva, no. 2: 67-71.

HUMMEL, F. C.; J. BRETT. 1950. A simple method of estimating volume increment in stands of young conifers. Empire Forestry Rev. 29: 58-59.

HUMMEL, F. C.; J. CHRISTIE. 1953.Revised yield tables for conifers in Great Britain, Forest Record no. 24, 1953 24 pp.

HUMMEL, F. C.; J. M. CHRISTIE. 1957. Methods used to construct the revised yield tables for conifers in Great Britain, 5 pp in "Forest Research 1957", London.

HUMMEL, F. C.; W. T. WATERS 1950 a. General volume table for oak in Great Britain. Forestry Commission. Forest Record no. 5, 11 pp.

HUMMEL. F. C.; W. T. WATERS. 1950 b. General volume table for beech in Great Britain. Forestry Commission, Forest record no. 6, 11 pp.

HUMMEL, F. C.; W. T. WATERS. 1950 c. General volume table for beech birch, oak, European larch, Scots pine in Great Britain. For. Commission. Forest Record no. 5-9.

HUMMEL F. C.; T. W. IRVINE; J. JEFFERS. 1950. General volume tables for European larch in great Britain. Forestry Commission. Forest Record no. 9, 24 pp.

HUMMEL, F. C.; LOCKE, G. M. L.; JEFFERS, J. N. R.; CHRISTIE, J. M. 1959. Code of sample plot procedure. London. Her Majesty's Stationari Office, 1959, V, Bulletin Nr. 31

HUNT, R.; J. H. C. CORNELISSEN. 1997. Components of relative growth rate and their interrelations in 59 temperate plant species. New Phytologist 135 (3): 395-417, U.K.

JAMES, N. D. G. 1981. A history of English forestry. Basil Blackwell. Oxford, U. K.

JEFFRES, J. N. R. Barr and Stroud dendrometer type FP 7. Report on Forest Research for the Year ended March 1955, London 1956, pp. 127-136.

JEFFERS, J. N. R. 1972. Mathematical Models in Ecology: The 12th Symposium of the British Ecological Society March 23-26, 1971, Grange-over-Sands, Lancashire, England, Blackwell Scientific Publications, Oxford, England U.K., 398 pp.

JEFFERS, J. N. R. 1976. Systems analysis in forest research. IUFRO XVI World Congress, Norway, Division VI.

JEFFRES. J. N. R. 1978. An Introduction to Systems Analysis: with ecological applications Edward Arnold, London, 198 pp.

JEFFRES, J. N. R. 1992. The future of biometrics in forestry. IUFRO Centennial, p. 495.

JERRAM, M. R. K. 1939. Elementary Forest mensuration. (with a chapter on the measurement of forests by R. Bourne. London, Thomas Murby and Company, 124 pp. Second impression: 1949.

JOHNSON, N. L. 1949. Bivariate distributions based on simple transformation systems. Biometrika 36: 297-309.

JOHNSTON, D. R.; A. J. GRAYSON; R. T. BRADLEY. 1967. Forest Planning. Faber and Faber, London. 541 pp.

KEEN, E. A. 1950. The Relascope. Empire Forest Rev. 29: 253-264.

KENDALL, M. G. 1947. The Advanced of Statistics. London.

KENT, M.; COKER, P. 1992. Vegetation description and analysis: A practical approach. London: Belhaven Press.

KILPATRICK, D. J.; SAVILL, P. S. 1978.Northern Ireland state forest inventory. Proceedings of IUFRO meeting in Bucharest, Romania, pp. 551-558.

KIRKPATRICK, D. J. 1978. Growth models for Sitka spruce in Northern Ireland. Forestry 51 (1): 46-56.

KIRCKPATRICK, D. J.; R. S. SAVILL. 1981. Top height curves for Sitka spruce in Northern Ireland. Forestry 54 (1): 31-40.

KRAMER, H. 1966. Zum Wachstum der Fichte (*Picea abies*) in Grossbritannien. (About the growth of spruce (*Picea abies*) in Germany. Allg. Forst-u. Jagdztg. 137: 53-67.

LANDIS, E.; HUMMEL, R. 1996. Information and information technology - a proposal to bridge the information gap in forestry. In: Päivinen - Vanklay - Miina (eds), see references chapter 1, Finland.

LANDSBERG, J. J. 1986. Physiological Ecology of Forest Production. Academic Press, London. 198 pp.

LAVER. C. F. 1951. Principles of log measurement, Publ. London Ernest Benn Ltd. 200 pp.

LAXTON, R. R.; C. D. LITTON. 1982. Information theory and dendrochronology. Science and Archaeology 24: 9-24.

LAXTON, R. R.; C. D. LITTON. 1983. Information theory and dendrochronology: the effect of pre-whitening. University of Nottingham Statistics Group Research Report also published in Computer Applications in Archaeology. 1983.

LEGGETT, P.; M. K. HUGHES; F. A. HIBBERT. 1978. A modern oak chronology from North Wales and its interpretation. In "Dendrochronology in Europe" edited by John Fletcher,pp. 187-194. British Archaeological Reports, International Series S1.

LESLIE, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika 33: 183-212.

LESLIE, P. H. 1948. Some further notes on the use of matrices in population mathematics. Biometrika 35: 213-245.

LOADER, N. J.; V. R. SWITSUR. 1996. Reconstructing past environmental change using stable isotopes in tree-rings. In "Environmental history of the Cairngorms". Special issue of papers from the Botanical Society of Scotland symposium held at the Department of Geography, University of Edinburgh, 31 March 1995, (edited by McConnell J.; J. W. H. Conroy. Botanical Journal of Scotland 48 (1): 65-78.

LOADER N. J.; V. R. SWITSUR; E. M. FIELD. 1995. High-resolution stable isotope analysis of tree-rings: implications of "microdendroclimatology" for paleoenvironmental research Halocene 5 (4): 457-460, U. K.

LUDLOW, ANTHONY R.; TIMOTHY J. RANDLE; JENNIFER C. GRACE. 1990. Developing a process-based growth model for Sitka Spruce. pp. 249-262 in: "Process Modelling of Forest growth Responses to Environmental Stress". Dixon, Robert K.; Ralph S. Meldahl; Gregory A. Ruark; G. William Warren (eds.), (c) Timber press Portland Oregon 441 pp.

MACDONALD, JAMES. 1931a. The measurement of Standing trees. Scottish Forestry Journal Vol. 45.

MACDONALD, JAMES. 1931b. Sample plot method in Great Britain. Empire Forestry Journal 10: 241-258.

MACDONALD, JAMES, 1932-1934. The form of the stem in coniferous trees. Forestry 6: 53-62, 141-153, 7: 32-42, 121-129, 8: 56-63.

MACDONALD, JAMES, 1932. Sample plot method in Great Britain. In Proceedings of IUFRO Congress, Nancy, 10 pp.

MACK, E. L.; FIRBANK, L. G. ; BELLAMY, P. E. ; HINSLEY, S. A. ; VEITCH, N. 1997. The comparison of remotely sensed and ground-based habitat area data using species-area models. Journal of Applied Ecology 34(5): 1222-1228.

MAGUIRE, D. J.; RHIND, D. W. (EDS.). 1991. Geographical Information Systems: Principles and Applications. London: Langman Scientific and Technical, 1991, 2 vols.

MAHALANOBIS, P. C. 1944. On large scale sample surveys. Phil. Trans. Royal Society London, Genès 231 (B584): 329-451.

MATHER, K. 1949. Statistical Analysis in Biology. 3rd ed., London.

MAW, PERCIVAL T. 1909. The Practice of Forestry Concerning also the Financial Aspects of Afforestation, Brockenhurst: Hants Walter and Walter.

MAW. PERCHIVAL T. 1912. Complete Yield Tables for British Woodlands and the Finance of British Forestry. London: C. Lackwood and Son.

McGREGOR, J. L. L. 1883. Organization and Valuation of Forests. London, Wyman and Sons.

MITCHELL, C. P.; PROE, M. F.; MACBRAYNE, C. G. 1981. Biomass tables for young conifer stands in Britain. Proc. S 4-1, Kyoto: 45-50.

MITCHELL, J. 1827. Dendrochronologia or A Treatise of Forest Trees with Evelyn's Silva Revised, Corrected and Abridged, U.K.

MITSCHERLICH, E. A. (Problems of plant growth). Landwirtschaftliche Jahrbücher 53: 167-182, (In German).

MONTEITH, J. L. 1997. Climate and the efficiency of crop production in Britain. Phil. Trans. Royal Soc. (London), Series B 281: 277-294.

MORGAN, R. A. 1987. Trackways and tree trunks-dating neolithic oaks in the British Isles. Tree-Ring Bulletin Vol. 47: 61-69.

MUNRO, MARTIN A. P. 1984. An improved algorithm for crossdating tree-ring series. Tree-Ring Bull. Vol. 44: 17-28.

NEWBOULD, P. J. 1967. Methods for estimating the primary production of forests. I B P Handbook No. 2 Blackwell Scientific Publications. Oxford and Edinburgh 62 pp.

NEWBOULD, P. J. 1968. Methods of estimating root production pp. 187-190. In: Eckhardt, F. E. ed., "Functioning of Terrestrial ecosystems at the primary production level. (UNESCO Copenhagen Symposium).

NEWTON, G. W. 1859. A Treatise on the Growth and Future Management of Timber Trees. U.K.

NISBET, JOHN. 1893. British Forest Trees and their Silvicultural Characteristics and Treatment. London and New York: Macmillan.

NISBET, JOHN. 1894. Studies in Forestry. Oxford, Clarendon Press.

NISBET, JOHN. 1905. The Forester, A Practical Treatise on British Forestry and Arboriculture for Landowners, Land Agents and Foresters, Edinburgh and London: W. Blackwood.

NISBET, JOHN. 1911. The Elements of British Forestry: A. Handbook for Forest Apprentices and Students of Forestry. Edinburgh and London W. Blackwood and Sons.

NOKOE, SAGARY. 1978. Demonstrating the flexibility of the Gompertz function as a yield model using mature species data. Forestry Review 57 (1): 35-42.

OSMANSTON, F. C. 1968. The Management of Forests. U. K.

ORTON, C. R. 1983. The use of Student's t-test for matching tree-ring pattern. Bulletin of the University of London Institute of Archaeology 20: 101-105.

OVINGTON, J. D. 1956. The form weights and productivity of tree species grown in class stands. New Phytol. 55: 289-304.

OVINGTON, J. D. 1957. Dry matter production by Pinus sylvestris. Ann. Bot. (N. S.) 21: 287-314, London and New York.

OVINGTON, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1: 103-192, U. K.

OVINGTON, J. D, 1963. Flower and seed production. A source of error in estimating woodland production, energy flow, and mineral cycling. Oikos 14: 148-153.

OVINGTON, J. D. 1965. Organic production, turnover and mineral cycling in woodlands. Biol. Rev. 40: 295-336.

OVINGTON, J. D.; MADGWICK, H. A. I. 1959 a. Distribution of organic matter and plant nutrients in a plantation of Scots pine. Forest Science 5: 344-355.

OVINGTON, J. D.; MADGWICK, H. A. I. 1959b. The growth and composition of natural stands of birch I. Dry matter production. Plant and Soil 10: 271-283.

OVINGTON, J. D.; FORREST, W. G.; ARMSTRONG, J.S. . 1967. Tree biomass estimation pp. 4-31 in Young, H. E. ed. Symposium on primary Productivity and Mineral Cycling in Natural Ecosystems (Ecol. Soc. Amer.).

PALZ, W.; CHARTIER, P.; HALL, D. O.. 1981. International Conference on Biomass, 1st, Brighton, East Sussex, Eng. 1980 Energy from Biomass. Proceedings edited by Palz Ch. Hol. London; Applied Science Publishers 1981, 982 pp.

PEARL, R. 1924. Introduction to medical biometry and statistics. London.

PEARSON, KARL. 1930. Tables for statisticians and biometricians. Part I. Biometric Laboratory Univ. College, London, 3rd edn.

PEARSON, G. W.; PILCHER, J. R.; BAILLIE, M. G. L. 1983. High precision 14C measurement of Irish oaks to show the natural 14C variations from 200 BC to 4000 BC. Radiocarbon 25: 179-186.

PEARSON, G. W.; PILCHER, J. R.; BAILLIE, M. G. L; CORBETT, D. M.; QUA, F. 1986. High precision 14 C measurement of Irish oaks to show the natural 14C variations from A. D. 1840 to 5210 B. C. Radiocarbon 28: 911-934.

PEPYS, SAMUEL. 1663 (1893). The Diary of Samuel Pepys, M. A., F. R. S. (with Lord Braybrooke's Notes) Edited by Henry B Wheatley, F. S. A. George Bell and Sons, London, 1893.

PETERKEN, G. F.; P. S. NEWBOULD. 1966. Dry matter production by *Ilex aquifolium* L. in the New Forest. J. Ecol. 54: 143-150.

PHILIP, M. S. 1983. Measuring trees and forests Aberdeen University, Press Aberdeen, Scotland, 388 pp. 2nd edn. 1994, CAB International, Wallingford, U.K. 310 pp.

PHILIPSON, WILLIAM R.; JOSEPHINE M. WARD; B. G. BUTTERFIELD. 1971. The Vascular Cambium; its Development and Activity. London: Chapman and Hall, 182 pp. (Core monograph).

PILCHER, J. R. 1976. A statistical oak chronology from the north of Ireland. Tree-Ring Bulletin 36: 21-27.

PILCHER, J. R.; BAILIE, M. G. L. 1980 a. Six modern oak chronologies from Ireland. Tree-Ring Bulletin 40: 23-34.

PILCHER, Jon R.; MICHAEL G. L. BAILLIE. 1980 b. Eight modern oak from England and Scotland. Tree-Ring Bull. 40: 45-58.

PILCHER, J. R.; GRAY, B. M. 1982. The relationship between oak tree growth and climate in Britain. J. Ecology 70: 297-304.

PILCHER, J. R.; BAILIE, M. G. L.; SCHMIDT, B.; BECKER, B. 1984. A 7272 year European tree-ring chronology. Nature 312: 150-152, U.K.

PILCHER, J. R.; HILLMAN, J.; BAILLIE, M. G. L.; PEARSON, G. W. 1977. A long sub-fosil oak-ring chronology from the north of Ireland. New Phytologist 79: 713-729.

POPPER, K. R. 1958. The logic of Scientific Discovery. Hutchinson, London.

PRANCE, G. T. 1984. Completing the Inventory. In: V. H. Heywood and D. M. Moore (eds.): " Current concepts in plant taxonomy". Academic Press, London, pp. 365-397.

PROE, M. F.; ALLISON, S. M.; MATTHEVS, K. B. 1996. Assessment of the impact of climate change on the growth of Sitka spruce in Scotland. Canad. Jour. of Forest Research 26 (11) 1914-1921.

QUENOUILLE, M. H. 1952. Associated Measurement. London.

QUENOUILLE, M. H. 1953. The design and analysis of experiment. London.

RENNIE, P. J. 1957. The uptake of nutrients by timber forest and its importance to timber production in Britain. Quart. Jour. For. 51: 101-115.

RENNIE, P. J. 1963. Methods of assessing site capacity. Comm. For. Rev. 42 (4): 306-317.

RENNOLLS, K. D. 1978 "Top height", its definition and estimation. Common. For. Rev. 57 (3): 219-255.

RENNOLLS, KEITH. 1992. A review of mathematical models in forestry: links and projections. IUFRO Centennial Symposium, Eberswalde, Germany, Proceedings, p. 496. (Summary).

RENNOLLS, K. 1995 a. Forest height growth modelling. In: "Growth and yield estimation from successive forest inventories" Selected papers from the IUFRO Conference, held in Copenhagen, 14-17 June 1993 (edited by Vanclay, J. K. et al.), Forest Ecology and Management (1995) 71 (3): 217-225.

RENNOLLS, KEITH. 1995 b. Mis-specification and over-parametrization in Forest Growth Modelling. IUFRO XX World Congress, Tampere, Finland, Inviting papers, p. 293 (summary).

RENNOLLS, K.; BLACKWELL, P. 1987. An integrated forest process model: its calibration and predictive performance Forestry Commission Research and Development Paper 148. Great Britain Forestry Commission. London, England, U.K., 31 pp.

RENNOLLS, K.; GEARY, D. N.; ROLLINSON, T. J. D. 1985. Characterizing diameter distributions by the use of the Weibull distribution. Forestry 58 (1): 57-66.

RICHARDS, F. J. 1959. A flexible growth function for empirical use. Jour. Exp. Botany 10: 290-300.

ROBINSON, R. L. 1911. Form factors of various conifers. Quarterly Journal of Forestry, Vol. V.

RODIN, L. E.; BAZILEVICH, N. I. 1967. Production and Mineral Cycling in Terrestrial Vegetation. Oliver and Boyd, London, 288 pp.

ROLLINSON, T. J. D. 1983. Biomass estimation for open-grown trees. INRA-Biom., pp. 31-36.

RUSSEL, ROBERT S. 1977. Plant Root Systems: Their Functions and Interactions with the Soil. London and New York, McGraw-Hill, 298 pp. (Core monograph).

RUSSELL, EDWARD W. 1912. Russell's Soil Conditions and Plant Growth... Edited by Alan Wild in 1988, 11th edition Harlow, Longmans 991 pp, 1st edn. as Soil Conditions and Plant Growth, London and New York; Longman's, Green, 1912, 168 pp. (Core monograph).

RUSSELL, G.; MARSHALL, B.; JARVIS, P. G. (eds.). 1989. Plant Canopies: Their Growth, Form and Functions. Cambridge, U. K. and New York; Cambridge University Press. 178 pp. (Society for Experimental Biology Seminar) Series no. 31.

SATCHELL. J. F.; LINDLEY, D. K.; HIBBARD, J. K. 1971: Computation of confidence limits for estimates of net primary production. In: "Systems analysis in northern coniferous forests", T. Rosswall (ed.). Swed. Natl. Sci.

Counc. Bull. 14: 75-82.

SCHLICH WILLIAM. 1889. Manual of Forestry. (Schlich's Manual of Forestry)). Vol. I, London. 2nd edn. 1896, 3rd edn. 1906, 4th edn. 1922.

SCHLICH, WILLIAM. 1895. Manual of Forestry. Vol. III., London. 3rd edn. 1905, 4th edn. 1911, 5 edn. 1925.

SCHOVE, D. J. 1950. Tree-rings and summer temperatures. The Scottish Geographical Magazine, vol. 66, pp. 37-42.

SCHOVE, D. J.; LOWTHER, A. W. G. 1957. Tree-rings and medieval archaeology. Medieval Archaeology Vol. I, pp. 78-95.

SEBER, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd edn. London: Charles Griffin and Company, Ltd.

SEBER, G. A. F. 1996. A review of estimating animal abundance. Biometrics 42: 267-292.

SEBER, G. A. F. 1992. A review of estimating animal abundance II. Intl. Stat. Rev. 60: 129-166.

SERRY, VICTOR. 1970. Metrication in the timber and allied building trades. Ernest Benn, Ltd., London, England, 188 pp.

SISAM, J. W. B. 1947. The use of aerial survey in forestry and agriculture. Imperial Agricultural Bureaux (Great Britain) Joint Rebl. 9, 59 pp.

SMITH, J. R. 1970. Optical distance measurement. London: Crosby Lockwood and Sons.

SPRENT, PETER. 1969. Models in Regression and Related Topics. Methuen's Monographs on Applied Probability and Statistics Methuen and Co. Ltd. 11 New Fetter Lone, London EC4.

STEFFEN, W. 1994. GCTE News No. 6, march 1994. GCTE = Global Change and Terrestrial Ecology, project of the International Geosphere-Biosphere Programme).

STEWARD. S. 1983. Statistical dendrochronology M. Sc. Thesis, University of Sheffield.

THALLON, K. P.; HORNE, A. I. D. 1984. The use of photogrammetry and remote sensing for forestry in Great Britain. Photogrametric Record 11(64); 359-370.

THOMPSON, JAS. 1805. Complete Treatise on the Mensuration of Timber. Troy, N. Y. (U.S.A.).

THORNLEY, J. H. M. 1972. A balanced quantitative model for root-shoot rations in vegetative plants. Annals of Botany 36: 341-441.

THORNLEY, J. 1976. Mathematical Models in Plant Physiology. Academic Press, London, England, U.K. 318 pp.

THORNLEY, J. H. M. 1999. Modelling stem height and diameter growth in plants. Annals of Botany (1999) 84(2): 195-205.

TROREY, LYLE G. 1950. Handbbook of Aerial Mapping and Photogrammetry. Cambridge University Press, London. 178 pp.

TUFTE, E. 1983. The Visual Display of Quantitative Information. Graphics Press, Chesire CT. 197 pp.

TUFTE, E. 1990. Envisioning Information. Graphics Press, Chestire CT, 126 pp.

USHER, M. B. 1966. A matrix approach to the management of renewable resources, with special reference to selection forests. Journal of Applied Ecology 3: 355-367 (U.K. Oxford).

USHER, M. B. 1976. Extensions to models, used in renewable resource management, which incorporate an arbitrary structure. J. Environment Management. 4: 123-140.

VANCLAY, JEROME K. 1994. Modelling Forest Growth and Yield. CAB International Wallingford Oxon, U. K.

VANDERMEER, J. 1989. The Ecology of Intercropping. Cambridge Univ. Press, U. K. 237 pp.

WAISTELL, CHARLES. 1809. The Method of Ascertaining the value of Growing Timber Trees of Different and Distant periods of time with Observations on the Growth of Timber, U. K.

WALKER, BRIAN; WILL STEFFEN (eds.) 1996. Global Change and Terrestrial Ecosystems. (c) International Geosphere-Biosphere programme 1996. Cambridge University Press.

WALKER, G. J.; KIRBY, K. J. 1989. Inventories of ancient, long-established and semi-natural woodland for Scotland. Research and Survey in Nature Conservation No. 22, 63 pp.

WAREING, P. F.; PHILLIPS, D. J. 1981. Growth and Differentiation in Plants. 3rd edn. Oxford, U. K. and New York; Pergamon Press 1981, 343 pp. (Originally titled: The Control of Growth and Differentiation in Plants. 1st. edn. 1970, 303 pp.

WATERS, W. T.; CHRISTIE, J. M. 1958. Provisional yield tables for oak and beech in Great Britain. Forestry Commission. Forest Record no. 36, 32 pp.

WATKINS, C. 1984. The use of Forestry Commission censuses for study of woodland change. Journal of Historical Geography 10 (4): 396-406.

WATKINS, C. 1990. Britain's ancient Woodlands. Woodland management and conservation. London, David and Charles, 160 pp.

WATKINS, WILLIAM. 1753. A Treatise on Forest-Trees. U.K.

WECK, J. 1951. Wachstumsdiagnosen. (Growth diagnosis). Forstarchiv 22: 135-138.

WIDDICOMBE, R. C. 1996. Woodland change and the dendrochronology of *Fagus sylvatica* in a plateau of beechwood of the Weald. Arboricultural Journal 20 (1): 79-93.

WIGLEY, T. M. K. 1982. Oxigen-18, Carbon-13 and Carbon-14 in tree rings. In Climate from tree rings, M. K. Hughes et al. eds., pp. 18-21.

WIGLEY, T. M. L. 1993. Climate change and forestry. Commonw. For.. Rev. 72: 256-264.

WIGLEY, T. M. L.; LOUGH, M. 1981. Tree-Ring Responses Functions: a Review and Program Intercomparison. Climatic Research Unit. University of East Anglia, Norwich, England.

WORELL, R. 1987. Predicting the productivity of Sitka spruce on Upland Sites in Northern Britain. Forestry Commission Bulletin no. 72, HMSO, London.

WORRELL, R.; MALCON, D. C. 1990. Productivity of Sitka spruce in northern Britain, Forestry 63(2): 105-128.

WRIGHT, DOUGLAS; GILBERT JUSTIN. 1996. National inventory handbook. Unpublished document. Edinburgh, UK; Forestry Commission Headquarters. 59 pp. plus appendices.

WRIGHT, G. G.; MORRICE, J. G. 1997. Landsat TM spectral information to enhance the land cover of Scotland 1988 dataset. International Journal of Remote Sensing 18(18): 3811-3834.

WRIGHT, H. 1980. Planning, Performance and Evaluation of Growth and Yield Studies. Commonwealth Forestry Institute, Oxford, Great Britain.

WRIGHT, T. W.; WILL, .G. M. 1958. The nutrient content of Scots and Corsican pines growing on sand dunes. Forestry 31: 13-25.

YATES, F. 1946. A review of recent statistical developments in sampling and sampling surveys. Jour. Royal Stat. Soc. 109: 12-30.

YATES, FRANK. 1948. Systematic sampling. Royal Soc. of London Philos. Trans. 241 (A 834): 345-377.

YODA, K.; KIRA, T.; OGAWA, H.; HOZAMI, K. 1963. Self thinning in overcrowded pure stands under cultivated and natural conditions. J. Biol. Osaka City Univ. 14: 107-129.

YULE, G. U. 1919. An Introduction to the Theory of Statistics. C. Giffin and Co., London.

YULE, G. U.; KENDALL, M. G. . 1937. An Introduction to the Theory of Statistics. Charles Giffin and Co. Ltd. London. Reprinted in 1950.

FERGUSON, C. W. 1969. A 7104 year annual tree-ring chronology for bristlecone pine, *Pinus aristata* from the White Mountains, California. Tree-Ring Bulletin 29: 3-29.

FINCH, H. D. S. 1957. New ways of using the general tariff tables for conifers. For. Comm. For. Rec. no. 32, London.

FINNEY, D. J. 1952a. Statistical Method in Biological Assay. London.

FINNEY, D. J. 1952b. Probit Analysis. A Statistical Treatment of the Sigmoid response curve. Cambridge University Press.

FISHER, R. A. 1948. Statistical methods for research workers. Oliver and Boyd, Ltd. 10th edn., Edinburgh and London, 354 pp.

FISHER, R. A. 1949. The design of experiments. 5th edn. Edinburgh.

FISHER, R. A.; H. C. TIPPET. 1928. Limiting forms of the frequency distributions of the largest or smallest members of a sample. In 24th Camb. Philos. Soc. Proc. 1927: 180-190.

FISHER, R. A.; F. YATES. 1957. Statistical Tables. Edinburgh: Oliver and Boyd.

FLETCHER, J. 1977. Tree-ring chronologies for the 6th centuries for oaks on southern and eastern England. Journal of Archaeological Science 4: 335-352.

FLETCHER, JOHN. 1978. Dating the geographical migration of *Quercus petraea* and *Q. robur* in holocene times. London.

FLETCHER, J. M.; R. SWITZUR.1973. North Elmham: the dating. Current Archaeology Vol. 4, 1: 25-28.

FOGGIE, A. 1944. On the determination of quality class by top height instead of mean height for conifers in Great Britain. Forestry 18: 28-39.

FORD, E. P.; P. J. NEWBOULD. 1970. Stand structure and dry weight production through the sweet chestnut (*Castanea sativa* Mill.) coppice cycle. J. Ecol. 58: 275-296.

FORD, E. D.; P. J. DIGGLE. 1981. Competition for light in a plant monoculture modelled as a spatial stochastic process, Annals of Botany 48: 481-500.

FORD, E. D.; K. A. SORRENSEN. 1992. Theory and models of inter-plant competition as a spatial process. In P. L. De Angelis and L. J. Grass (eds.): "Individual based Models and Approaches in Ecology". Chapman and Hall, N. Y., pp. 363-407.

FORESTRY COMMISSION. 1920. Rate of growth of conifers in the British Isles. Bulletin no. 3, G. B.

FORESTRY COMMISSION. 1921. British yield tables, G. B.

FORESTRY COMMISSION. 1928. Growth and yield of conifers in Great Britain. Bull. 10, 187 pp, G.B.

FORESTRY COMMISSION. 1946. Yield tables for Scots pine and other conifers. 23 pp, G.B.

FORESTRY COMMISSION. 1947. Modification of sample plot procedure since 1931. For. Comm. (Great Britain). Mimeo, 16 pp.

FORESTRY COMMISSION. 1960. Conversion tables for forest research workers. For. Comm. Booklet no. 5, 64 pp.

FORESTRY COMMISSION. 1969. Metric guide for forestry. A. guide to the introduction of the metric system in British forestry. For. Comm. Booklet no. 27, 12 pp.

FORESTRY COMMISSION 1983. Census of woodlands and trees 1979-82: 1983: Warwickshire, Leicestershire; 1984: South Scotland, East Scotland, West Scotland, Great Britain. Edinburgh, U. K. Forestry Commission.

FORESTRY COMMISSION. 1987. Top diameter sawlog tables. For. Comm. Field Book, no. 1, 2nd edn., 25 pp.

FRIEDLI, H. L.; H. OESCHAER; U. SIEGENTHALER; B. STAUFER. 1986. Ice core record of the C13/C12 ratio of atmospheric CO2, in the past two centuries. Nature 324: 237-238.

GEHRHARDT, E. 1926. Britische Ertragstafeln. (British yield tables. Allg. Forst.-u. Jagdztg. 102: 142-147.

GERARD, F. F.; NORTH, P. R. J. 1997. Analyzing the effect of structural varialility and canopy gaps on forest BRDF using a geometric - optical model. Remote sensing of Enviroment 62 (1): 46-62.

GOMPERTZ, B. 1825. On the nature of the function expressive of the law of human mortality and on a new mode of determining, the value of life contingencies. Phil. Transac. Royal Society, London, 115: 513-585.

GROOMBRIDGE, B.; JENKINS, M. D. 1996. Assessing biodiversity - status and sustainability. WCML Biodiversity Series 5. Cambridge, U. K.: World Conservation Press. 104 pp.

GRACE, J. C. 1980. Computer modelling of individual tree growth. Ph.D. Thesis, Oxford University, Oxford, England, U.K.

GRAY, H. R. 1956. The form and taper of forest-tree stems, Oxford Univ. Imp. For. Inst. Paper 32: 1-74.

GRAY, B. M.; J. R. PILCHER. 1983. Testing the significance of summary response functions. Tree-Ring Bull. Vol. 43: 31-38.

GRAYBILL, D. A. 1982. Chronology development and analysis. In: Hughes, M. K.; Kelley, J. R. Pilcher, and V. C. Lamarche, Jr. eds. "Climate from Tree Rings". Cambridge University Press, Cambridge, England, U.K., pp. 21-28.

GREENHILL, A. G. 1883. Determination of the greatest height consistent with stability that a vertical pole or mast can be made, and of the greatest height to which a tree of given proportions can growth. pp. 65-73; 7 February 1881 Proceedings of the Cambridge Philosophical Society volume IV October 25, 1980-May 28, 1983, Cambridge. Printed at the University Press, and sold by Deighton, Bell and Co. and Macmillan and Co. Cambridge; Bell and Sons. London 1883.

GREIG-SMITH, P. 1964. Quantitative plant ecology. Sevenoaks, U. K.

GOWER, J. C. 1967. A comparison of some methods of cluster analysis. Biometrics 23: 626-637.

GUIOT, J.; A. I. BERGER; A. V. MUNAUT. 1982. Response functions. In: "Climate from tree-rings", M. K. Hughes et al. (eds.), pp. 3845, Cambridge University Press.

HAFLEY, W. L.; H. T. SCHREUDER. 1977. Statistical distributions for fitting diameter and height data in even-aged stands. Can. J. For. Research 7: 481-487.

HÄGGLUND, B. 1981. Evaluation of forest site productivity. Commonwealth Forestry. Bureau, Forest Abstracts Review Article 42 (11): 515-527.

HAKILLA, P. 1989. Utilization of Residual Forest Biomass. London, Springer-Verlag, 568 pp (Core monograph).

HALL, D. O.; R. P. OVEREND. 1987. Biomass: Regenerable Energy. Chichester, U. K. Wiley (Core monograph).

HAMILTON, G. J. 1971. Timber measurement for standing sales. Forestry Commission, Booklet no. 36, HMSO, London.

HAMILTON, G. J. 1974. Metrication in British Forestry. Jour. Forestry 72: 749-752.

HAMILTON, G. J. 1985. Forest mensuration handbook. Forestry Commission Booklet no. 39, 274 pp.

HAMILTON, G. J.; J. M. CHRISTIE. 1971. Forest management tables (Metric) Forestry Commission Booklet 34. London.

HAMILTON, G. J.; J. M. CHRISTIE 1973. Construction and application of stand yield models. Forestry Commission Research and Development Paper 96, Edinburgh. Published in 1974 in Growth Models for Tree and Stand Simulation IUFRO working party S4.01-4. Proceedings of meetings in 1973. Edited by Jörah - Fries Research Notes no. 30, Royal College of Forestry S-10405 Stockholm, Sweden, 379 pp.

HAMILTON, G. J.; J. M. CHRISTIE; J. EDWARDS. 1981. Yield models for forest management. Forestry Commission Booklet, no. 48, 32 pp. + tables.

HAMMERSLY, J. M.; C. D. HAMDSCOMB. 1964. Monte Carlo Methods. Chapman and Hall, London.

HAMMINGS, R. W. 1977. Digital filters. Prentice Hall, Englewood Cliffs.

HANSON, C. O. 1911. Forestry for Woodmen. Oxford: Clavendon Press, 2nd edn. 1921.

HARPER, J. L. 1977. Population Biology of Plants. Academic Press. London England, U. K.

HARRINGTON, G. 1943. The wood from Bellindery Crannog No.1. Proceedings of the Royal Irish Academy 43: 235-238.

HARRINSON, P. J.; C. F. STEVENS. 1976. Bayesian forecasting (with discussion). Journal of the Royal Statistical Society, Series B; 38: 205-247.

HARRIS, A. J. L. 1996. Towards automated fire monitoring from space: semi-automated mapping of the January 1994 New South Wales wildfires using AVHRR data. International Jourrnal of Wildland Fire 6 (3): 107-116.

HARVEY, A. C. 1981. Time Series Models. Philip Allan Publishers Ltd., England, U. K.

HARVEY, A. C. 1984. A unified view of statistical forecasting procedures. Journal of Forecasting 3: 245-275.

HASSALL, R. B.; D. C. MacMILLAN; H. G. MILLER. 1994. Predicting Sitka spruce yield in the Buchan area of north-east Scotland. Forestry (Oxford) 67 (3): 219-235.

HAWKINS, D. M. 1980. Identification of Outliers. Chapman and Hall, London.

HAWKSWORTH, D. L. (ed.) 1995. Biodiversity mensurement and estimation. London, U. K.: Chapman and Hall 144 pp.

HAYES, SAMUEL 1794. A practical Treatise on Planting and the Management of Woods and Coppices 2nd edn. 1822.

HELLIWELL, D. R. 1986. The extent of tree roots. Arboricultural Journal (1896) 10 (4): 341-347.

HEYWORTH, A. 1978. Submerged forests around the British Isles: their dating and relevance as indicators of postglacial land and sea-level changes. In: Dendrochronology in Europe ed. J. M. Fletcher. British Archaeological Reports S 51: 279-288.

HIDE, R. H. 1950. Squaring the circle or the forester and his escapes from ✓ Empire. Forestry Rev. 29: 146-151.

HILEY, W. E. 1954. Woodland Management. 2nd edn. 1967 revised by C. W. Scott and R. W. V. Palmer.

HILEY, W. E. 1959. Economics of Plantation, London.

HILEY, W. E.; N. CUNLIFFE. 1922. An investigation into the relation between height growth of trees and meteorological conditions. Oxf. For. Mem. no. 1.

HILEY W. E.; N. CUNLIFFE. 1923. Further observations of the relation of the height growth of trees to meteorological conditions. Ann. Appl. Biol. 10: 442-452.

HILLAM, J. 1976. The dating of Cullyhanna hunting lodge. Irish Archaeological Forum 3: 17-20.

HILLAM, JENNIFER. 1980. A medieval oak tree-ring chronology from southwest England. Tree-Ring Bull. 40: 13-22.

HILLAM, J.; P. F. RYDER 1980.Tree-ring dating of vernacular buildings from Yorkshire. Vernacular Architecture 11: 23-31.

HIORNS, R. W. 1965. The fitting of growth and allied curves of the asymptotic regression type by Steven's method, Tract for computors, No. XXVIII, Cambridge University.

HOPKINS, B. 1954. A new method of determining the type of distribution of plant individuals. Ann. Bot. London: 213-227.

HOPPUS, EDWARD. 1736. Practical Measuring made easy to the Meanest Capacity by A new Set of Tables which upon a Bare Inspection show... The solid or Superficial Content (and consequently the Value of all kinds of Squared or Round Timber, whether it be Standing or Felled, 2nd edn. 1738 which was followed by a further, 19 numbered edition, the 21st being dated 1834. In 1837 a “New" edition was published and there after all editions were either described as "New" or simply dated. Modern copies of these tables which were widely used until metrication (1971) was adopted in about 1972, were frequently undated.

HOWARD, J. A. 1970. Aerial photo-ecology. Faber and Faber, London, 325 pp.

HUDSON, W. F. A. 1913. A Handbook of Forestry. U. K.

HUGHES, M. K. 1971. Tree biocontent, net production and litter fall in a deciduous woodland. Oikos, vol. 22, pp. 62-73.

HUGHES, M. K. (ed) 1982. Climate from Tree Rings: Based on the 2nd International Workshop on Global Dendroclimatology. Univ. of East England, Norwich, U. K. July 1980. Cambridge, U. K. and New York; Cambridge University Press, 233 pp (Core monograph).

HUGHES, M. K.; P. LEGGETT; S. J. MILSON; F. A. HUBERT. 1978. Dendrochronology of oak in North Wales. Tree-Ring Bull. 38: 15-21.

HUGHES, M. K.; B. GRAY; J. PILCHER; M. BAILLIE; P. LEGGETT. 1978. Climatic signals in British Isles tree-ring chronologies. Nature 272: 605-606.

HUGHES, M. K; P. M. KELLY; J. R. PILCHER; V. C. LaMARCHE, Jr. (eds). 1982. Climate from Tree Rings. Cambridge University Press, Cambridge, England, U. K. 223 pp.

HUMMEL, F. C. 1949a. Revised yield tables for Japanese larch in Great Britain. Forestry Commission, Forest Record no. 1, 14 pp.

HUMMEL, F. C. 1949b. The methods employed in the national forest survey of Great Britain. Act. 3 Congr. Forest. Mond. Helsinki Nr. 1.S. 39-52.

HUMMEL, F. C. 1951. Instruments for the measurement of height diameter and taper on standing trees. For. Abstr. 12 (3): 261-269.

HUMMEL, F. C. 1955. The volume-basal area line-a study in Forest Mensuration. Bulletin nr.24, For. Commission, 84 pp.

HUMMEL, F. C. 1956. Tariff tables for conifers in Great Britain. Forestry Commission, Forest Record no. 31, 16 pp., London.

HUMMEL, F. C. 1958. Methods of forecasting productions from thinnings. Unasylva, no. 2: 67-71.

HUMMEL, F. C.; J. BRETT. 1950. A simple method of estimating volume increment in stands of young conifers. Empire Forestry Rev. 29: 58-59.

HUMMEL, F. C.; J. CHRISTIE. 1953.Revised yield tables for conifers in Great Britain, Forest Record no. 24, 1953 24 pp.

HUMMEL, F. C.; J. M. CHRISTIE. 1957. Methods used to construct the revised yield tables for conifers in Great Britain, 5 pp in "Forest Research 1957", London.

HUMMEL, F. C.; W. T. WATERS 1950 a. General volume table for oak in Great Britain. Forestry Commission. Forest Record no. 5, 11 pp.

HUMMEL. F. C.; W. T. WATERS. 1950 b. General volume table for beech in Great Britain. Forestry Commission, Forest record no. 6, 11 pp.

HUMMEL, F. C.; W. T. WATERS. 1950 c. General volume table for beech birch, oak, European larch, Scots pine in Great Britain. For. Commission. Forest Record no. 5-9.

HUMMEL F. C.; T. W. IRVINE; J. JEFFERS. 1950. General volume tables for European larch in great Britain. Forestry Commission. Forest Record no. 9, 24 pp.

HUMMEL, F. C.; LOCKE, G. M. L.; JEFFERS, J. N. R.; CHRISTIE, J. M. 1959. Code of sample plot procedure. London. Her Majesty's Stationari Office, 1959, V, Bulletin Nr. 31

HUNT, R.; J. H. C. CORNELISSEN. 1997. Components of relative growth rate and their interrelations in 59 temperate plant species. New Phytologist 135 (3): 395-417, U.K.

JAMES, N. D. G. 1981. A history of English forestry. Basil Blackwell. Oxford, U. K.

JEFFRES, J. N. R. Barr and Stroud dendrometer type FP 7. Report on Forest Research for the Year ended March 1955, London 1956, pp. 127-136.

JEFFERS, J. N. R. 1972. Mathematical Models in Ecology: The 12th Symposium of the British Ecological Society March 23-26, 1971, Grange-over-Sands, Lancashire, England, Blackwell Scientific Publications, Oxford, England U.K., 398 pp.

JEFFERS, J. N. R. 1976. Systems analysis in forest research. IUFRO XVI World Congress, Norway, Division VI.

JEFFRES. J. N. R. 1978. An Introduction to Systems Analysis: with ecological applications Edward Arnold, London, 198 pp.

JEFFRES, J. N. R. 1992. The future of biometrics in forestry. IUFRO Centennial, p. 495.

JERRAM, M. R. K. 1939. Elementary Forest mensuration. (with a chapter on the measurement of forests by R. Bourne. London, Thomas Murby and Company, 124 pp. Second impression: 1949.

JOHNSON, N. L. 1949. Bivariate distributions based on simple transformation systems. Biometrika 36: 297-309.

JOHNSTON, D. R.; A. J. GRAYSON; R. T. BRADLEY. 1967. Forest Planning. Faber and Faber, London. 541 pp.

KEEN, E. A. 1950. The Relascope. Empire Forest Rev. 29: 253-264.

KENDALL, M. G. 1947. The Advanced of Statistics. London.

KENT, M.; COKER, P. 1992. Vegetation description and analysis: A practical approach. London: Belhaven Press.

KILPATRICK, D. J.; SAVILL, P. S. 1978.Northern Irleand state forest inventory. Proceedings of IUFRO meeting in Bucharest, Romania, pp. 551-558.

KIRKPATRICK, D. J. 1978. Growth models for Sitka spruce in Northern Ireland. Forestry 51 (1): 46-56.

KIRCKPATRICK, D. J.; R. S. SAVILL. 1981. Top height curves for Sitka spruce in Northern Ireland. Forestry 54 (1): 31-40.

KRAMER, H. 1966. Zum Wachstum der Fichte (*Picea abies*) in Grossbritannien. (About the growth of spruce (*Picea abie*s) in Germany. Allg. Forst-u. Jagdztg. 137: 53-67.

LANDIS, E.; HUMMEL, R. 1996. Information and information technology - a proposal to bridge the information gap in forestry. In: Päivinen - Vanklay - Miina (eds), see references chapter 1, Finland.

LANDSBERG, J. J. 1986. Physiological Ecology of Forest Production. Academic Press, London. 198 pp.

LAVER. C. F. 1951. Principles of log measurement, Publ. London Ernest Benn Ltd. 200 pp.

LAXTON, R. R.; C. D. LITTON. 1982. Information theory and dendrochronology. Science and Archaeology 24: 9-24.

LAXTON, R. R.; C. D. LITTON. 1983. Information theory and dendrochronology: the effect of pre-whitening. University of Nottingham Statistics Group Research Report also published in Computer Applications in Archaeology. 1983.

LEGGETT, P.; M. K. HUGHES; F. A. HIBBERT. 1978. A modern oak chronology from North Wales and its interpretation. In "Dendrochronology in Europe" edited by John Fletcher,pp. 187-194. British Archaeological Reports, International Series S1.

LESLIE, P. H. 1945. On the use of matrices in certain population mathematics. Biometrika 33: 183-212.

LESLIE, P. H. 1948. Some further notes on the use of matrices in population mathematics. Biometrika 35: 213-245.

LOADER, N. J.; V. R. SWITSUR. 1996. Reconstructing past environmental change using stable isotopes in tree-rings. In "Environmental history of the Cairngorms". Special issue of papers from the Botanical Society of Scotland symposium held at the Department of Geography, University of Edinburgh, 31 March 1995, (edited by McConnell J.; J. W. H. Conroy. Botanical Journal of Scotland 48 (1): 65-78.

LOADER N. J.; V. R. SWITSUR; E. M. FIELD. 1995. High-resolution stable isotope analysis of tree rings: implications of "microdendroclimatology" for paleoenvironmental research Halocene 5 (4): 457-460, U. K.

LUDLOW, ANTHONY R.; TIMOTHY J. RANDLE; JENNIFER C. GRACE. 1990. Developing a process-based growth model for Sitka Spruce. pp. 249-262 in: "Process Modelling of Forest growth Responses to Environmental Stress". Dixon, Robert K.; Ralph S. Meldahl; Gregory A. Ruark; G. William Warren (eds.), (c) Timber press Portland Oregon 441 pp.

MACDONALD, JAMES. 1931a. The measurement of Standing trees. Scottish Forestry Journal Vol. 45.

MACDONALD, JAMES. 1931b. Sample plot method in Great Britain. Empire Forestry Journal 10: 241-258.

MACDONALD, JAMES, 1932-1934. The form of the stem in coniferous trees. Forestry 6: 53-62, 141-153, 7: 32-42, 121-129, 8: 56-63.

MACDONALD, JAMES, 1932. Sample plot method in Great Britain. In proceedings of IUFRO Congress, Nancy, 10 pp.

MACK, E. L.; FIRBANK, L. G. ; BELLAMY, P. E. ; HINSLEY, S. A. ; VEITCH, N. 1997. The comparison of remotely sensed and ground-based habitat area data using species-area models. Journal of Applied Ecology 34(5): 1222-1228.

MAGUIRE, D. J. ; RHIND, D. W. (EDS.). 1991. Geographical Information Systems: Principles and Applications. London: Langman Scientific and Technical, 1991, 2 vols.

MAHALANOBIS, P. C. 1944. On large scale sample surveys. Phil. Trans. Royal Society London, Genès 231 (B584): 329-451.

MATHER, K. 1949. Statistical Analysis in Biology. 3rd ed., London.

MAW, PERCIVAL T. 1909. The Practice of Forestry Concerning also the Financial Aspects of Afforestation, Brockenhurst: Hants Walter and Walter.

MAW. PERCHIVAL T. 1912. Complete Yield Tables for British Woodlands and the Finance of British Forestry. London: C. Lackwood and Son.

McGREGOR, j. l. l. 1883. Organization and Valuation of Forests. London, Wyman and Sons.

MITCHELL, C. P.; M. F. PROE; C. G. MACBRAYNE. 1981. Biomass tables for young conifer stands in Britain. Proc. S 4-1, Kyoto: 45-50.

MITCHELL, J. 1827. Dendrochronologia or A Treatise of Forest Trees with Evelyn's Silva Revised, Corrected and Abridged, U.K.

MITSCHERLICH, E. A. (Problems of plant growth). Landwirtschaftliche Jahrbücher 53: 167-182, (In German).

MONTEITH, J. L. 1997. Climate and the efficiency of crop production in Britain. Phil. Trans. Royal Soc. (London), Series B 281: 277-294.

MORGAN, R. A. 1987. Trackways and tree trunks-dating neolithic oaks in the British Isles. Tree-Ring Bulletin Vol. 47: 61-69.

MUNRO, MARTIN A. P. 1984. An improved algorithm for crossdating tree-ring series. Tree-Ring Bull. Vol. 44: 17-28.

NEWBOULD, P. J. 1967. Methods for estimating the primary production of forests. I B P Handbook No. 2 Blackwell Scientific Publications. Oxford and Edinburgh 62 pp.

NEWBOULD, P. J. 1968. Methods of estimating root production pp. 187-190. In: Eckhardt, F. E. ed., "Functioning of Terrestrial ecosystems at the primary production level. (UNESCO Copenhagen Symposium).

NEWTON, G. W. 1859. A Treatise on the Growth and Future Management of Timber Trees. U.K.

NISBET, JOHN. 1893. British Forest Trees and their Silvicultural Characteristics and Treatment. London and New York: Macmillan.

NISBET, JOHN. 1894. Studies in Forestry. Oxford, Clarendon Press.

NISBET, JOHN. 1905. The Forester, a Practical Treatise on British Forestry and Arboriculture for Landowners, Land Agents and Foresters, Edinburgh and London: W. Blackwood.

NISBET, JOHN. 1911. The Elements of British Forestry: A. Handbook for Forest Apprentices and Students of Forestry Edinburgh and London W. Blackwood and Sons.

NOKOE, SAGARY. 1978. Demonstrating the flexibility of the Gompertz function as a yield model using mature species data. Forestry Review 57 (1): 35-42.

OSMANSTON, F. C. 1968. The Management of Forests. U. K.

ORTON, C. R. 1983. The use of Student's t-test for matching tree-ring pattern. Bulletin of the University of London Institute of Archaeology 20: 101-105.

OVINGTON, J. D. 1956. The form weights and productivity of tree species grown in class stands. New Phytol. 55: 289-304.

OVINGTON, J. D. 1957. Dry matter production by *Pinus sylvestri*s. Ann. Bot. (N. S.) 21: 287-314, London and New York.

OVINGTON, J. D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1: 103-192, U. K.

OVINGTON, J. D, 1963. Flower and seed production. A source of error in estimating woodland production, energy flow, and mineral cycling. Oikos 14: 148-153.

OVINGTON, J. D. 1965. organic production, turnover and mineral cycling in woodlands. Biol. Rev. 40: 295-336.

OVINGTON, J. D.; H. A. I. MADGWICK. 1959 a. Distribution of organic matter and plant nutrients in a plantation of Scots pine Forest Science 5: 344-355.

OVINGTON, J. D.; H. A. I. MADGWICK. 1959b. The growth and composition of natural stands of birch I. Dry matter production. Plant and Soil 10: 271-283.

OVINGTON, J. D.; W. G. FORREST; J.S. ARMSTRONG. 1967. Tree biomass estimation pp. 4-31 in Young, H. E. ed. Symposium on primary Productivity and Mineral Cycling in Natural Ecosystems (Ecol. Soc. Amer.).

PALZ, W.; P. CHARTIER; D. O. HALL. 1981. International Conference on Biomass, 1st, Brghton, East Sussex, Eng. 1980 Energy from Biomass.

Proceedings edited by Palz Ch. Hol. London; Applied Science Publishers 1981, 982 pp.

PEARL, R. 1924. Introduction to medical biometry and statistics. London.

PEARSON, KARL. 1930. Tables for statisticians and biometricians. Part I. Biometric Laboratory Univ. College, London, 3rd edn.

PEARSON, G. W.; J. R. PILCHER; M. G. L. BAILLIE. 1983. High precision 14C measurement of Irish oaks to show the natural 14C variations from 200 BC to 4000 BC. Radiocarbon 25: 179-186.

PEARSON, G. W.; J. R. PILCHER; M. G. L. BAILLIE; D. M. CORBETT; F. QUA. 1986. High precision 14 C measurement of Irish oaks to show the natural 14 C variations from A. D. 1840 to 5210 B. C. Radiocarbon 28: 911-934.

PEPYS, SAMUEL. 1663 (1893). The Diary of Samuel Pepys, M. A., F. R. S. (with Lord Braybrooke's Notes) Edited by Henry B Wheatley, F. S. A. George Bell and Sons, London, 1893.

PETERKEN, G. F.; P. S. NEWBOULD. 1966. Dry matter production by *Ilex aquifolium* L. in the New Forest. J. Ecol. 54: 143-150.

PHILIP, M. S. 1983. Measuring trees and forests Aberdeen University, Press Aberdeen, Scotland, 388 pp. 2nd edn. 1994, CAB International, Wallingford, U.K. 310 pp.

PHILIPSON, WILLIAM R.; JOSEPHINE M. WARD; B. G. BUTTER-FIELD. 1971. The Vascular Cambium; its Development and Activity. London: Chapman and Hall, 182 pp. (Core monograph).

PILCHER, J. R. 1976. A statistical oak chronology from the north of Ireland. Tree-Ring Bulletin 36: 21-27.

PILCHER, J. R.; M. G. L. BAILIE 1980 a. Six modern oak chronologies from Ireland. Tree-Ring Bulletin 40: 23-34.

PILCHER, Jon R.; MICHAEL G. L. BAILLIE. 1980 b. Eight modern oak from England and Scotland. Tree-Ring Bull. 40: 45-58.

PILCHER, J. R.; B. M. GRAY 1982. The relationship between oak tree growth and climate in Britain. J. Ecology 70: 297-304.

PILCHER, J. R.; M. G. L. BAILIE; B. SCHMIDT; B. BECKER 1984. A 7272 year European tree-ring chronology. Nature 312: 150-152, U.K.

PILCHER, J. R.; J. HILLMAN; M. G. L. BAILLIE; G. W. PEARSON. 1977. A long sub-fosil oak-ring chronology from the north of Ireland. New Phytologist 79: 713-729.

POPPER, K. R. 1958. The logic of Scientific Discovery. Hutchinson, London.

PRANCE, G. T. 1984. Completing the Inventory. In: V. H. Heywood and D. M. Moore (eds.): "Current concepts in plant taxonomy". Academic press, London, pp. 365-397.

PROE, M. F.; S. M. ALLISON; K. B. MATTHEVS. 1996. Assessment of the impact of climate change on the growth of Sitka spruce in Scotland. Canad. Jour. of Forest Research 26 (11) 1914-1921.

QUENOUILLE, M. H. 1952. Associated Measurement. London.

QUENOUILLE, M. H. 1953. The design and analysis of experiment. London.

RENNIE, P. J. 1957. The uptake of nutrients by timber forest and its importance to timber production in Britain. Quart. Jour. For. 51: 101-115.

RENNIE, P. J. 1963. Methods of assessing site capacity. Comm. For. Rev. 42 (4): 306-317.

RENNOLLS, K. D. 1978 "Top height", its definition and estimation. Common. For. Rev. 57 (3): 219-255.

RENNOLLS, KEITH. 1992. A review of mathematical models in forestry: links and projections. IUFRO Centennial Symposium, Eberswalde, Germany, Proceedings, p. 496. (Summary).

RENNOLLS, K. 1995 a. Forest height growth modelling. In: "Growth and yield estimation from successive forest inventories" Selected papers from the IUFRO Conference, held in Copenhagen, 14-17 June 1993 (edited by Vanclay, J. K. et al.), Forest Ecology and Management (1995) 71 (3): 217-225.

RENNOLLS, KEITH. 1995 b. Mis-specification and over-parametrization in Forest Growth Modelling. IUFRO XX World Congress, Tampere, Finland, Inviting papers, p. 293 (summary).

RENNOLLS, K.; P. BLACKWELL. 1987. An integrated forest process model: its calibration and predictive performance Forestry Commission Research and Development Paper 148. Great Britain Forestry Commission. London, England, U.K., 31 pp.

RENNOLLS, K.; D. N. GEARY; T. J. D. ROLLINSON. 1985. characterizing diameter distributions by the use of the Weibull distribution. Forestry 58 (1): 57-66.

RICHARDS, F. J. 1959. A flexible growth function for empirical use. Jour. Exp. Botany 10: 290-300.

ROBINSON, R. L. 1911. Form factors of various conifers. Quarterly Journal of Forestry, Vol. V.

RODIN, L. E.; N. I. BAZILEVICH. 1967. Production and Mineral Cycling in Terrestrial Vegetation. Oliver and Boyd, London, 288 pp.

ROLLINSON, T. J. D. 1983. Biomass estimation for open-grown trees. INRA-Biom., pp. 31-36.

RUSSEL, ROBERT S. 1977. Plant Root Systems: Their Functions and Interactions with the Soil. London and New York, McGraw-Hill, 298 pp. (Core monograph).

RUSSELL, EDWARD W. 1912. Russell's Soil Conditions and Plant Growth... Edited by Alan Wild in 1988, 11th edition Harlow, Longmans 991 pp, 1st edn. as Soil Conditions and Plant Growth, London and New York; Longman;s, Green, 1912, 168 pp. (Core monograph).

RUSSELL, G.; B. MARSHALL; P. G. JARVIS (eds.). 1989. Plant Canopies: Their Growth, Form and Functions. Cambridge, U. K. and New York; Cambridge University Press. 178 pp. (Society for Experimental Biology Seminar) Series no. 31.

SATCHELL. J. F.; D. K. LINDLEY; J. K. HIBBARD. 1971: Computation of confidence limits for estimates of net primary production. In: "Systems analysis in northern coniferous forests", T. Rosswall (ed.). Swed. Natl. Sci. Counc. Bull. 14: 75-82.

SCHLICH WILLIAM. 1889. Manual of Forestry. (Schlich's Manual of Forestry)). Vol. I, London. 2nd edn. 1896, 3rd edn. 1906, 4th edn. 1922.

SCHLICH, WILLIAM. 1895. Manual of Forestry. Vol. III., London. 3rd edn. 1905, 4th edn. 1911, 5 edn. 1925.

SCHOVE, D. J. 1950. Tree rings and summer temperatures. The Scottish Geographical Magazine, vol. 66, pp. 37-42.

SCHOVE, D. J.; A. W. G. LOWTHER. 1957. Tree-rings and medieval archaeology. Medieval Archaeology Vol. I, pp. 78-95.

SEBER, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd edn. London: Charles Griffin and Company, Ltd.

SEBER, G. A. F. 1996. A review of estimating animal abundance. Biometrics 42: 267-292.

SEBER, G. A. F. 1992. A review of estimating animal abundance II. Intl. Stat. Rev. 60: 129-166.

SERRY, VICTOR. 1970. Metrication in the timber and allied building trades. Ernest Benn, Ltd., London, England, 188 pp.

SISAM, J. W. B. 1947. The use of aerial survey in forestry and agriculture. Imperial Agricultural Bureaux (Great Britain) Joint Rebl. 9, 59 pp.

SMITH, J. R. 1970. Optical distance measurement. London: Crosby Lockwood and Sons.

SPRENT, PETER. 1969. Models in Regression and Related Topics. Methuen's Monographs on Applied Probability and Statistics Methuen and Co. Ltd. 11 New Fetter Lone, London EC4.

STEFFEN, W. 1994. GCTE News No. 6, march 1994. GCTE = Global Change and Terrestrial Ecology, project of the International Geosphere-Biosphere Programme).

STEWARD. S. 1983. Statistical dendrochronology M. Sc. Thesis, University of Sheffield.

THALLON, K. P.; HORNE, A. I. D. 1984. The use of photogrammetry and remote sensing for forestry in Great Britain. Photogrametric Record 11(64); 359-370.

THOMPSON, JAS. 1805. Complete Treatise on the Mensuration of Timber. Troy, N. Y. (U.S.A.).

THORNLEY, J. H. M. 1972. A balanced quantitative model for rot-shoot rations in vegetative plants. Annals of Botany 36: 341-441.

THORNLEY, J. 1976. Mathematical Models in Plant Physiology. Academic Press, London, England, U.K. 318 pp.

THORNLEY, J. H. M. 1999. Modelling stem height and diameter growth in plants. Annals of Botany (1999) 84(2): 195-205.

TROREY, LYLE G. 1950. Handbbook of Aerial Mapping and Photogrammetry. Cambridge University Press, London. 178 pp.

TUFTE, E. 1983. The Visual Display of Quantitative Information. Graphics Press, Chesire CT. 197 pp.

TUFTE, E. 1990. Envisioning Information. Graphics Press, Chestire CT, 126 pp.

USHER, M. B. 1966. A matrix approach to the management of renewable resources, with special reference to selection forests. Journal of Applied Ecology 3: 355-367 (U.K. Oxford).

USHER, M. B. 1976. Extensions to models, used in renewable resource management, which incorporate an arbitrary structure. J. Environment Management. 4: 123-140.

VANCLAY, JEROME K. 1994. Modelling Forest Growth and Yield. CAB International Wallingford Oxon, U. K.

VANDERMEER, J. 1989. The Ecology of Intercropping. Cambridge Univ. Press, U. K. 237 pp.

WAISTELL, CHARLES. 1809. The Method of Ascertaining the value of Growing Timber Trees of Different and Distant periods of time with Observations on the Growth of Timber, U. K.

WALKER, BRIAN; WILL STEFFEN (eds.) 1996. Global Change and Terrestrial Ecosystems. (c) International Geosphere-Biosphere programme 1996. Cambridge University Press.

WALKER, G. J.; KIRBY, K. J. 1989. Inventories of ancient, long-established and semi-natural woodland for Scotland. Research and Survey in Nature Conservation No. 22, 63 pp.

WAREING, P. F.; D. J. PHILLIPS. 1981. Growth and Differentiation in Plants. 3rd edn. Oxford, U. K. and New York; Pergamon Press 1981, 343 pp. (Originally titled: The Control of Growth and Differentiation in Plants. 1st. edn. 1970, 303 pp.

WATERS, W. T.; J. M. CHRISTIE 1958. Provisional yield tables for oak and beech in Great Britain. Forestry Commission. Forest Record no. 36, 32 pp.

WATKINS, C. 1984. The use of Forestry Commission censuses for study of woodland change. Journal of Historical Geography 10 (4): 396-406.

WATKINS, C. 1990. Britain's ancient Woodlands. Woodland management and conservation. London, David and Charles, 160 pp.

WATKINS, WILLIAM. 1753. A Treatise on Forest-Trees. U.K.

WECK, J. 1951. Wachstumsdiagnosen. (Growth diagnosis). Forstarchiv 22: 135-138.

WIDDICOMBE, R. C. 1996. Woodland change and the dendrochronology of *Fagus sylvatica* in a plateau of beechwood of the Weald. Arboricultural Journal 20 (1): 79-93.

WIGLEY, T. M. K. 1982. Oxigen-18, Carbon-13 and Carbon-14 in tree rings. In Climate from tree rings, M. K. Hughes et al. eds., pp. 18-21.

WIGLEY, T. M. L. 1993. Climate change and forestry. Commonw. For.. Rev. 72: 256-264.

WIGLEY, T. M. L.; M. LOUGH. 1981. Tree-Ring Responses Functions: a Review and Program Intercomparison. Climatic Research Unit. University of East Anglia, Norwich, England.

WORELL, R. 1987. Predicting the productivity of Sitka spruce on Upland Sites in Northern Britain. Forestry Commission Bulletin no. 72, HMSO, London.

WORRELL, R.; D. C. MALCON. 1990. Productivity of Sitka spruce in northern Britain, Forestry 63(2): 105-128.

WRIGHT, DOUGLAS; GILBERT JUSTIN. 1996. National inventory handbook. Unpublished document. Edinburgh, UK; Forestry Commission Headquarters. 59 pp. plus appendices.

WRIGHT, G. G.; MORRICE, J. G. 1997. Landsat TM spectral information to enhance the land cover of Scotland 1988 dataset. International Journal of Remote Sensing 18(18): 3811-3834.

WRIGHT, H. 1980. Planning, Performance and Evaluation of Growth and Yield Studies. Commonwealth Forestry Institute, Oxford, Great Britain.

WRIGHT, T. W.; G. M. WILL. 1958. The nutrient content of Scots and Corsican pines growing on sand dunes. Forestry 31: 13-25.

YATES, F. 1946. A review of recent statistical developments in sampling and sampling surveys. Jour. Royal Stat. Soc. 109: 12-30.

YATES, FRANK. 1948. Systematic sampling. Royal Soc. of London Philos. Trans. 241 (A 834): 345-377.

YODA, K.; T. KIRA: H. OGAWA: K. HOZAMI. 1963. Self thinning in over-crowded pure stands under cultivated and natural conditions. J. Biol. Osaka City Univ. 14: 107-129.

YULE, G. U. 1919. An Introduction to the Theory of Statistics. C. Giffin and Co., London.

YULE, G. U.; M. G. KENDALL. 1937. An Introduction to the Theory of Statistics. Charles Giffin and Co. Ltd. London. Reprinted in 1950.