ALEXE ALEXE

WORLDWIDE FOREST MENSURATION HISTORY

II

FOREST MENSURATION HISTORY OF CENTRAL EASTERN 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

II

FOREST MENSURATION HISTORY OF CENTRAL EASTERN EUROPEAN COUNTRIES

An outline of 19th and 20th centuries in:
Austria, Former Czechoslovakia, France,
Germany, Poland, Switzerland

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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.

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PREFACE

This is the second volume of "Worldwide Forest Mensuration History" and refers to "Forest Mensuration Hystory of Central Eastern European Countries": Austria, Former Czechoslovakia, France, Germany, Poland and Switzerland. These Countries were included in this region according to FAO classification (FAO 1995:124).

Central Europe is recognized on large scale as the cradle of modern forestry, especially the Triangle: Germany-France-Switzerland.

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

The text is organized on country level 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, monitoring, and remote sensing. In countries with a reasonable 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 of every country contains "General information" referring to 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 on forestry or historical information, if available.

For all countries the methodological aspects have been 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 represents a valuable premise for elaboration of different syntheses on regional or global level. This was the first purpose of our book. The second purpose was to supply the reader with a reasonable database of information. In this volume (section) 1730 references have been included out of which 30 % refer to papers published after 1980 and 14 % to those published after 1990.

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

For the selection of cited papers we have used the following criteria: originality (at the time when the considered work was completed), methodological features, originality or/and uniqueness of the case studies, and frequency of citations in the core monographs, forest mensuration books, and articles published in the primary journals and serials in forestry or adjiacent 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 in the selection of events that cannot be totally avoided. This is the reason why we hesitated a long time to prepare this text for publication. We are not sure that we succeeded to perform the task to present the facts in a proper manner, at least acceptable as a first valid version. We are aware that the available bibliographical material may 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 that 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.

Above all we would like the present book on history of forest mensuration and its connections with the environment to be considered as an act of culture because it is dedicated to all people interested in the presentation of forests and whose profession it connected in a way with forestry and natural environment.

Alexe Alexe
Bucharest, December, 2003

TECHNICAL NOTE

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

The definition of terms regarding forest land, other wooded lands and biomass are adopted according to those 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 covers 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 brushland: "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 brushes 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

CENTRAL EASTERN EUROPE

1. Austria, 2. Former Czechoslovakia 3. France, 4. Germany, 5. Poland, 6. Switzerland

1. AUSTRIA

General information

Land area 82,540 sq. km. (31,870 sq. mi), forest and other wooded land 38,770 sq. km (14,970 sq. mi), total forest 3,877,000 ha (14,970 sq. mi) or 47 % of land area; volume 257 m^3/ha, biomass 125 tons/ha. (FAO 1995-124 Forest resources assessment).

Round wood production: industrial round wood 10.899 mil. m^3, fuel and charcoal 2.86 mil. m^3, total round wood 13.759 mil. 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 beech (*Fagus sylvatica*), fir (*Abies alba*), Austrian pine (*Pinus nigra* var. *austriaca*), European larch (*Larix decidua*), oaks (*Quercus robur, Q. cerris, Q. frainetto*).

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

• University of Soil Sciences, Faculty of Forestry, Wien (1875);
• University of Soil, Sciences, Faculty of Forestry, Institute for Forests Management and Forest Policy, Wien (1875);
• University of Soil Sciences of Forestry, Institute of Forest Growth and Yield, Wien (1963);
• Environment Data GES M. B. H., Wien (1897);
• Federal Forestry Reserch Centre (FBVA), Wien (1874);

Publications (Primary Journals and Serials):

• Centralblatt für das gesammte Forstwesen, Wien;
• Oesterreichiche Vierteljahresschrift für Forstwesen, Wien;
• Mittheilungen aus dem forstlichen Versuchswesen Oesterreichs, Wien;
• Allgemeine Forstzeitung, Wien.

1.1. Books containing information on forest mensuration

Investigations on stand volume were the early subjects of Austrian forest mensuration textbooks. One of the earliest textbooks was published in 1854 by Bohmerle and Feistmantel. Feistmantel's second edition (1876) is better known and contains yield tables. Other 19th century remarkable textbooks were written by Breymann (1868), Neumeister (1892, 1892), and Schiffel 1899.

In 1899 Schiffel published a spruce monograph and introduced the tree form quotient concept for the first time in the Austrian literature. During the next years Schiffel determined form factor for larch (1905), Scots pine (1907), and fir (1908).

At the beginning of the 20th century A. von Guttemberg published a forest management textbook (1903) and later, in 1927, the first modern Austrian forest mensuration ("Holzmesskunde").

The use of mathematical statistics was practiced in Austrian forest mensuration before the 1930s (Anderson 1935, Czuber and Burckhardt 1938, 3rd edn.).

In 1936 by the care of J. Weiss was printed a new edition (the 3rd) of Fiestmantel yield tables for oak, beech, fir, spruce, larch, Scots pine and *Pinus nigra*.

In 1949 Wodera completed his yield tables, having 12 classes and reference height at age of 50 years. An useful and remarkable textbook is that on forest terminology written by Mayer and Brüning (1980). Sterba's lecture notes (1991) improved some aspects in the development of Austrian forest mensuration.

A list of selected textbooks containing information on forest mensuration is presented in table 1.1.-1.

TABLE 1.1.-1. Book containing information on forest mensuration in Austria

Year	Author(s)	Title	Remark(s)
1854, 1899	Karl Böhmerle	Versuche über Bestandesmassenaufnahmen (Researches on inventory of stand volume)	New edn. 1899
1854, 1876	Rudolf Feistmantel	Allgemeine Waldbestandestafeln oder übersichtliche Darstellung d. vorzüglichsten Wachstums v. Holzertragsverhältnisse der Forste. 1. Aufl. Wien 1854. (General forest tables ...)	2nd edn. 1876
1863	Kerner A. von Marilaun	Das Pflanzenleben der Donau-länder (Plant longevity in the Danube region. The background of plant ecology)	2nd edn. 1929 Engl. Transl. 1951.
1868	K. Breymann	Anleitung zur Holzmesskunst, Waldertragsbestimmung und Waldwertberechnung (Manual for wood measurement, yield and estimation of forest)	
1876	Schindler	Portefeuille für Forstwirthe (Portfolio for forestry)	
1892	Max Neumeister	Anfang zu den forstlichen Kubierungstafeln von Presler-Neumeister (The early forest volume tables of Pressler and Neumeister)	
1898	Max Neumeister	Forstliche Kubierungstafeln. (Forest volume tables)	
1899 a	A. Schiffel	Die Fichte. (The spruce)	
1899 b	A. Schiffel	Form und Inhalt der Fichte (Form and volume of spruce)	
1903	A. von Guttenberg	Forstbetriebseinrichtung. (Forest management)	
1909	J. Weiss	Allgemeine Waldbestandestafeln (nach Feistmantel) (General yield tables after Feistmantel)	
1927	A. R. von Guttenberg	Holzmesskunde (Forest mensuration)	

TABLE 1.1.-1 (cont.)

Year	Author(s)	Title	Remark(s)
1935	O. Anderson	Einführung in die mathematische Statistik (Introduction into mathematical statistics)	
1936	R. Feistmantel	Allgemeine Waldbestandestafeln für Eiche, Buche, Tanne, Fichte, Lärche, Weiss- und Schwarzföhre (General stand yield tables for oak, beech, fir, spruce, larch, pines)	3rd edn. J. Weiss, Wien-Leipzig
1938	E. Czuber and F. Burckhardt	Die statistiaschen Forschungs-methoden (Statistical methods of research)	3rd edn.
1949	H. Wodera	Normal-Ertragstafeln nach Absolut-bonitäten für die Holzarten: Fichte, Tanne, Weisskiefer, Schwarzkiefer, Lärche, Rotbuche, Eiche (Normal yield tables with absolute quality classes for spruce, fir, Scots pine, *Pinus nigra*, larch, sessile oak, common oak)	
1954	R. Frauendorfer	Forstliche Hilfstafeln-Schriftenreihe der forstlichen Bundes-Versuchs-anstalt (Forest aid tables)	166 pp. Band II yield tables
1975	J. Marschall	Hilfstafeln für die Forsteinrichtung (Aid tables for forest management)	
1980	H. Mayer and E. Brüning	Waldbauliche Terminologie (Forest terminology)	
1991	H. Sterba	Forstliche Ertragslehre Lecture notes. (Forest growth science)	

Cited authors:

Anderson 1935, Böhmerle 1854, Breyman 1868, Czuber and Burckhardt 1938, Feistmantel 1854, 1936; Frauendorfer 1954, v. Guttemberg 1903, 1927; v. Marilaum 1863, Marschall 1975, Mayer and Brüning 1980, Neumeister 1892, 1898; Weiss 1909, Wodera 1949, Schiffel 1899a, 1905, 1907, 1908; Schindler 1876, Sterba 1991.

1.2. Tree

1.2.1. Tree measurement and instruments

In 1938 G. Müller studied the errors of measurement with different hypsometers. Apart from the relascope - described in 1.3. - Bitterlich (1959) constructed calipering forks ("Sektorkluppen") made of light alloys, and an original instrument (1959 b) named "Visiermerszwinkel". This device (Fig. 1.2.-1.) is metallic, 430 g. weight, 17 cm if pliable and graded in diameters and basal area according to two joint scales and it can be used quickly in the field for determination of the tree with average basal area. The improved model "Tarifmeszwinkel" is graded for 45 tariffs for volumes. Once the tariff is chosen it is possible to read directly the volume of the tree which is measured (Fig. 1.2.-2.).

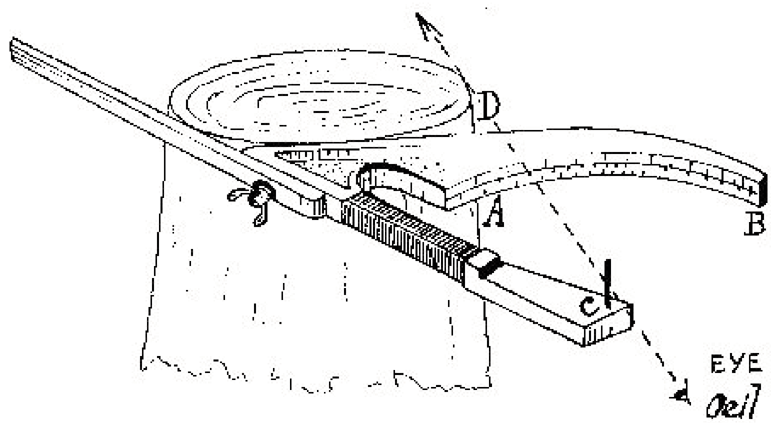


Fig. 1.2.-1. Bitterlich's "Visiermeszwunkel". Reproduced after Pardé, 1961. Dendrométrie, p. 84, fig. 34
The device was constructed by Dominicus and Co. at Remscheid-Vieringhaussen-Germany.

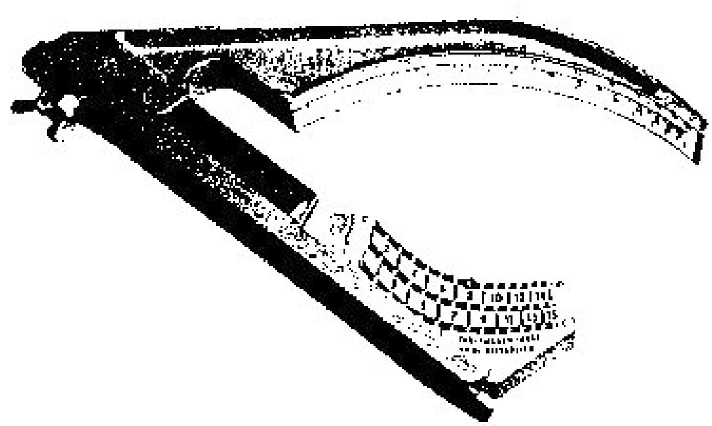


Fig. 1.2.-2. Bitterlich's Tarifmeszwinkel" Reproduced after Pardé, 1961.
Dendrométrie, p. 85, fig. photo Loc.

Before 1950 Wodera constructed an optical caliper which used a system of mirrors based on old Friedrich's principle (Germany) and can be used for measurement of upper diameters (Fig. 1.2.-3.).

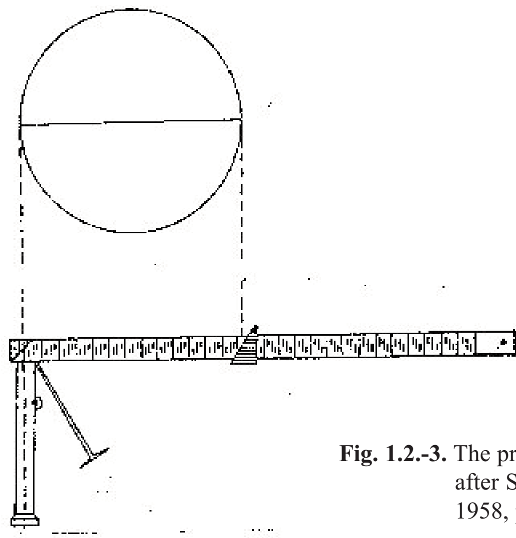


Fig. 1.2.-3. The principle of Wodera's caliper Drawing after Stinghe and Toma, Dendrometrie, 1958, p. 55, fig. 55.

1.2.2. Tree and log volume determination

Starting from the equation $y = A + Bx + Cx^2 + Dx^3$ Breymann (1868) developed for stem volume (v), the following formula which is valid for all geometrical forms a stem could have:

$$v=\frac{l}{8}\left[\left(g_0+g_n\right)+3\left(g_{1/4}+g_{3/4}\right)\right]$$

where l is the lenght of stem or log, g_0 = basal section area (larger part of stem or log), g_n = the section area at top of log (stem), $g_{1/4}$ and $g_{3/4}$ = the section area at ¼ and ¾ of length of stem or log (for the whole stem $g_n = 0$).

In 1879 Simony established a similar formula:

$$v=\frac{l}{3}\left[2\left(g_{1/4}+g_{3/4}\right)-g_{1/2}\right]$$

which gives exact results for cone shaped forms. Simony analyzed in detail the problem of stem volume considered as basis for form factor calculus and construction of volume tables.

Schiffel (1899) recommended for stem volume the empirical formula:

$$v=l\,(0.61g_{1/4}+0.62g_{3/4}-0.23g_{1/4}\cdot\frac{d_{3/4}}{d_{1/4}})$$

[d is the diameter at 1/4 or 3/4 of length (l) and g the section area at 1/4, 3/4 of length] which gives good results but is difficult for practice.

Another empirical formula was proposed by Simony (1901) and is based on Gauss's formula:

$$v=\frac{1}{2}\ g_{1/5}+g_{4/5}.$$

Simony (1901 and 1903) published a textbook on the use of geometrical solids for the calculus of stem volume (corps or solids of rotation).

Schiffel (1902, 1912) determined volume of round wood based on the measurements of two diameters.

Diameter and volume of bark were studied by Schiffel in larch (1905) and Scots pine (1907).

A critical short analysis of the work on volume determination was completed by Tischendorf in 1942.

In 1959 Bitterlich proposed application of Pressler's "Richthöhe" (Pressler director or critical point method) using the mirror relascope or telerelascope.

Pollanschutz (1965) based on several studies, proposed introduction of new variables for determination stem volume, diameter at 30 % of the tree height or at a height of 7 m.

In 1971 R. Schmidt et al. established, in their opinion, the optimal determination of the volume of standing trees.

A stem curve system for spruce was developed in 1981 for application in Austrian forests inventories (Pöytäniemi 1981).

1.2.3. Tree form

In 1893 Bohmerle determined form factors and constructed volume tables for *Pinus nigra*.

In 1899 Schiffel introduced in Austrian literature the term form quotient (k_s) defined by relation:

$$k_s=\frac{d_{0.5}}{d}$$

where $d_{0.5}$ is the diameter at the middle of the stem and d=dbh.

During the period 1899-1908 Schiffel determined form quotients and constructed volume tables with three entries (dbh, height and k_s) for spruce (1899), larch (1905), Scots pine (1907) and fir (1908). Usually form quotients are noted with q and Schiffel considered:

$$q_s=d_{0.5}/d_{1.3}=q_2$$

$$q_1=d_{1/4}/d_{1.3}$$

$$q_3=d_{3/4}/d_{1.3}$$

and established the following relationship between form factor ($f_{1.3}$) and form quotient:

$$f_{1.3}=0.88q_s-0.15+\frac{0.36}{q_s L} \qquad \text{L=length of stem}$$

the general form of Schiffel's formula is $f_{1.3} = bq_s + b_0$

For spruce Schiffel presented the relation:

$$f_f=0.66\,q_2^2+\frac{0.32}{q_2 H}+0.140$$

which can be also applied to broad-leaved species (according to Tkacenko).

In 1901 and 1903 Simony published studies on rotation corps and their use for tree volume determination. Simony developed especially the theory of volume determination of rotation corps resulted from the curves whose rotation around an axis forms a cone, an Appolonian paraboloid, a Neilian paraboloid etc., and established a great number of equations for theoretical corps of rotation and corresponding form factors completing the Schiffel's empirical formula. Simony established also a general equation for $f_{1.3}$ form factor.

Later, in 1961 Pollanschütz presented a new formula - concept of form quotient called "Pollanschütz form quotient k_p":

$$k_p=q_p=\frac{d_{0.3}}{d}$$

where $d_{0.3}$ is diameter at 3/10 of stem height and d = dbh, and established the relation between k_p and $f_{1.3}$.

$$f_{1.3}=b_0+b_1\frac{h}{d^2}+b_2 k_p^2$$

In 1965 Pollanschütz introduced a new model for estimating the form factor of Norway spruce:

$$f=b_0+b_1+\frac{d_{0.3h}}{d}+b_2\frac{h}{d^2}$$

In 1977 Bitterlich presented a regression equation of the stem form and Sloboda described the dynamics of stem form based on similitude with differential equations.

Cited authors (7.1.2.):

Bitterlich 1959 a, 1959 b, 1977; Bohmerle 1893, Breymann 1868, Müller G. 1938, Polanschütz 1961, 1965; Pöytäniemi 1981, Schiffel 1899, 1902, 1905a, 1905b, 1907a, 1907b, 1908, 1912; Schmid, P. et al. 1971, Simony 1879, 1901, 1903; Sloboda 1977, Tischendorf 1942.

1.3. Bitterlich's angle count measurements and the relascope

In 1947 and 1948 Bitterlich published his revolutionary angle count measurements of basal area per hectare ("Die Winkelzahlmessung" and "Die Winkelzahlprobe", the angle count sample plot).

Bitterlich's method represents the counting of the number of trees whose dbh appears larger than a fixed horizontal angle at a series of sampling points in a stand. A 360^0 sweep is made at each sampling point with a horizontal angle gauge with the sample points as the vertex. Bitterlich's principle (exposed almost in all forest mensuration standard books and manuals) is very simple: let G be the basal area per hectare, N the number of counted trees in a 360^0 sweep. Bitterlich demonstrated that G = K *N where K is a constant which depends on the fixed horizontal angle (see Fig. 1.3.-1.) and it is easy to make K = 1 and then G = N (If a = E = 2 cm and b = L = 100 cm than a/b = 1/50 and a = 50b by construction, than

$$G/ha=2500\ N \quad \frac{b^2}{2500\,\mathbf{b}}=N$$

In 1949 Bitterlich presented his relascope (based on above mentioned principle) and optical enumeration by the angle count method (1949b).

In 1952 (a) the Spiegel relascope (relascope with mirror) was built (Fig. 1.3.-2.) and new contributions on horizontal angle count sampling were published (1952b). The Spiegel relascope is a versatile hand-held instrument developed for point sampling and it is an universal dendrometrical device that may be used for determining: basal area per hectare (m^2/ha), measurement of upper-stem diameter, from fixed distance, tree heights, dbh, horizontal distances, measurement of slope on percent, degree and topographic scales, estimation of relative form heights to determine absolute form height, form factors and the volume of the standing tree. Sighting angles are provided for factors of 5, 10, 20 or 40 and the instrument automatically corrects each angle for slope.

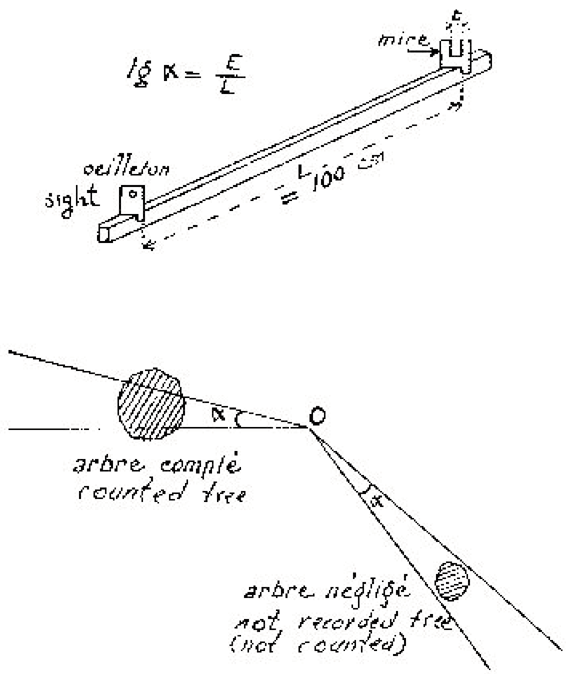


Fig. 1.3.-1. Bitterlich's principle and angle count. Redrawing from Stinghe and Toma, Dendrometrie 1958, p. 145 and Pardé 1961, Dendrometrie, p. 219, fig. 108.

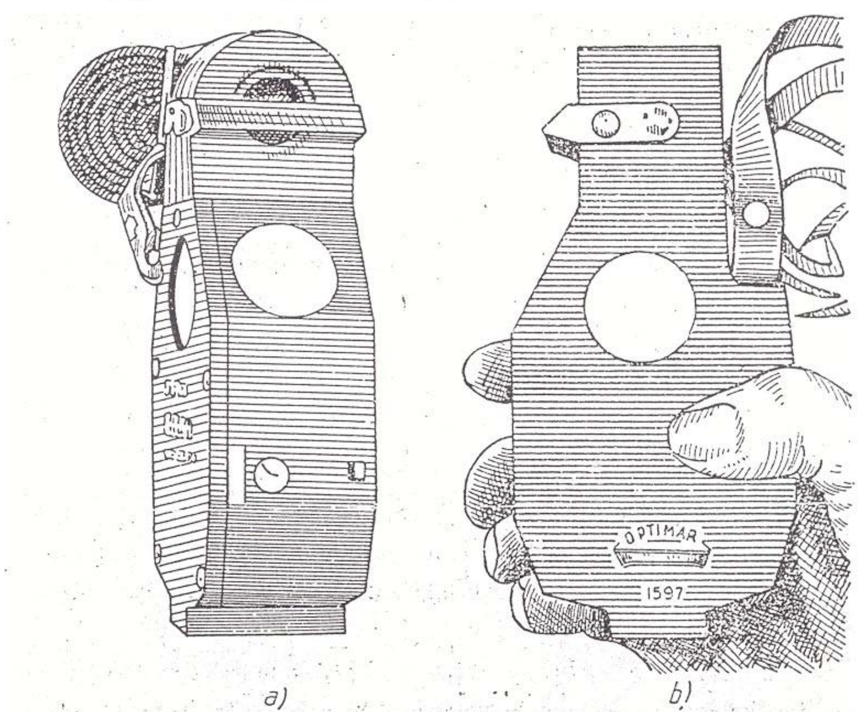
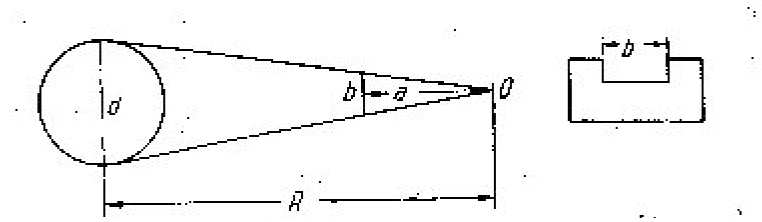


Fig. 1.3.-2. The Spiegel relascope (relascope with mirror. (a = front aspect, b = working position). Drawing from Stinghe and Toma, Dendrometrie 1958, p. 148, fig. 87

Vertical angle count sampling and height estimation through the Bitterlich method was developed in Japan by Hirata in 1955 (Bitterlich 1956 - explained what is Hirata height).

In 1957 (a) Bitterlich applied his method to stocked wood measure into solid measure establishing more accurate conversion factors by the angle count method. In the same year he discussed the harmonical average in horizontal count sampling (1957b) and improved it in 1962. A new type relascope was constructed in 1958 (Bitterlich 1958).



Bitterlich's principle (From Stinghe and Toma, Dendrometrie 1958, p. 145, fig. 85)

In 1959 Bitterlich considered relascopic technique as a rationale (fundamental) for forest mensuration. In the same year Bitterlich (1959 b) revived the old Pressler's technique for determination of stem volume based on "Richthöhe diameter" - the height at which the diameter is one half from dbh. The remarkable formula of Pressler is

$$v = S \cdot \frac{2}{3} h_1$$

where S = basic section of stem, h = tree height and h_1 the height at which the diameter D=(dbh)/2. On the other hand h_1 = 3/4 h for paraboloide, h_1 = h/2 for cone and h_1 = 0.37 h for neiloide. Determination of h_1 became very easy with the aid of relascope.

In 1959 Thomson and Dietschman published in the USA a "Bibliography of world literature on the Bitterlich method of plotless cruising".

During the next period (up to 1984) Bitterlich published new papers and improved his relascope: 1962 - relascope with width scale, 1964 - the thumb as a relascope, 1972 - the tele-relascope, 1974 - determination of stem volume using Hohenadl system and telescope, 1974, 1977, 1978 - volume determination of standing trees using the telerelascope and a minicomputer taking into account Kozak's 1969 and 1970 relation used in Canada:

$$d_i^2 = \left(b_0 + \frac{h_i}{h} + b_2 \frac{h_i^2}{h_2} \right) d^2$$

1977 - an example of program for telerelascope and “H.P. - 97", 1978 - classical and practical relascope sampling = longitudinal form of stem, 1978 - single tree measurement by the tele-relascope, 1984 - the relascope and relative measurements in forestry.

In 1976 Sterba summarized the errors involved in the estimation of stem volume with the aid of the relascope. The distance errors varied between 0,5 % and 1 % and necessitated upper-stem diameter adjustments 1-2 % while height estimates should be adjusted 20-40 cm. In case of volume the errors varied between 3 and 5 %.

In spite of the great success of Bitterlich's method it is necessary to mention the following quotation from Husch 1963 p. 155 "Grosenbaugh (1958) has shown that Bitterlich's method of stand basal area estimation (Bitterlich, 1948), Strand's method of stand height estimation (Strand, 1957) and Hirata's stand height determination method (Hirata, 1955) are but applications of the theory of sampling with probability proportional to the size of the stand variable being measured”. Grosenbaugh also showed the applicability of this sampling methods for determining average stand diameter.

Cited authors:

(1.3.): Bitterlich 1947, 1948, 1949 a, 1949 b, 1952 a, 1952 b, 1956, 1957a, 1957b, 1958, 1959a, 1959b, 1962a, 1962b, 1964, 1972, 1974, 1974-1977-1978, 1977, 1978 a, 1978 b, 1984; Grosenbaugh 1958 (U.S.A.), Hirata 1955 (Japan), Kozak et al. 1969, 1970 (Canada); Sterba 1976, Strand 1957 (Norway), Thomson and Deitschman 1959 (U.S.A.).

1.4. Stand structure and site quality

In their forest terminology H. Mayer and E. Brüning (1980) describes primary or primeval forest as "natural forests with natural forest structure, lacking anthropogenic influences from the past to the present and sets them at the same level as virgin forest”. Band (1980) also distinguishes secondary virgin forest which are nearly natural state not showing any obvious anthropogenic influence or only to minimal extent at the present. They often developed from clear out of forests used for grazing and have now characteristics that are typical for virgin forests. According to Mayer and Brüning (1980) secondary forests originate as a result of natural succession processes after either the existing natural or secondary forest cover has been removed by means or developed by natural catastrophes such as fire or insects.

In 1903 Schiffel completed the first work on percentage distribution of diameters according to the average diameter of spruce stand. (Table 1.4.-1.) Schiffel studied also volume distribution in normal spruce stands, established an interesting relation concerning the structure of even-aged spruce stands: for the same cumulated relative frequency (x) corresponds the same relative diameter independent of age or site conditions. This correlation between relative cumulated frequency (x) and relative diameter (y) was expressed by Schiffel using equation of regression $y= b_0 + b_1x+b_2x^2 + b_3x^3$ that is considered valid in the case of even-aged stands (Table 1.4.-2.).

The first tables of diameter distribution were constructed by Baker (1923) based on the curve of normal distribution. W. H. Meyer (1930), Halaj (1957) and Prodan (1953) utilized Charlier's functions, Luther-Schnur (1937) and Osumy (1961) used the curve of type III Pearson, and Osborney and Schumacher (1935) tried the Pearl's growth curve. For details on these references see Prodan et al. (1997).

Schiffel underlined the influence of thinnings and other tending measures on stand structure and proposed the creation of a science of tending forests, especially spruce forests (1910).

TABLE 1.4.-1. Distribution of relative diameters according to the average diameter of spruce stand (d_m 10-50 cm), d classes 2 cm. Distribution based on Schiffel data (1903)

d	10		15		20		25		30		35		40		45		50	
cm	Σh	h	Σh	h	Σh	h	Σh	h	Σh	h	Σh	h	Σh	h	Σh	h	Σh	H
6	2.3	2.3																
8	27.0	24.7																
10	64.0	37.0	7.0	7.0														
12	84.0	20.0	24.5	17.5	2.8	2.8												
14	93.0	9.0	50.0	25.5	10.5	7.7	0.4	0.4										
16	96.5	3.5	68.5	18.5	24.5	14.0	5.5	5.1										
18	98.8	2.3	82.6	14.1	42.5	18.0	13.0	7.5	2.7	2.7								
20			91.2	8.6	59.5	17.0	24.5	11.5	8.0	5.3	1.0	1.0						
22			95.0	3.8	73.0	13.5	38.0	13.5	15.0	7.0	4.5	3.5						
24			97.6	97.6	2.6	84.0	11.0	52.0	14.0	24.0	9.0	9.5	5.0	2.5	2.5			
26			99.5	1.9	91.2	7.2	64.2	12.2	35.0	11.0	16.1	6.6	6.5	4.0	1.1	1.1		
28					95.0	3.8	74.6	10.4	47.0	12.0	24.5	8.4	11.4	4.9	4.0	2.9	0.4	0.4
30					97.5	2.5	84.0	9.4	58.1	11.1	33.5	9.0	17.0	5.6	8.0	4.0	2.5	2.1
32					99.3	1.8	90.0	6.0	68.0	9.9	43.0	9.5	24.0	7.0	12.5	4.5	5.5	3.0
34							93.8	3.8	76.5	8.5	53.0	10.0	31.5	7.5	18.0	5.5	9.1	3.6
36							96.5	2.7	83.5	7.0	62.0	9.0	40.0	8.5	24.0	6.0	13.5	4.4
38							98.5	2.0	89.0	5.5	70.0	8.0	49.0	9.0	30.5	6.5	18.5	5.0
40							99.9	1.4	92.5	3.5	77.5	7.5	57.2	8.2	38.0	7.5	24.0	5.5
42									95.4	2.9	83.6	6.1	65.0	7.8	46.0	8.0	30.0	6.0
44									97.5	2.1	88.5	4.9	72.0	7.0	54.5	8.5	36.5	6.5
46									99.0	1.5	92.0	3.5	78.0	6.0	61.5	7.0	43.5	7.0
48											94.5	2.5	83.5	5.5	68.1	6.6	50.0	6.5
50											96.8	2.3	88.0	4.5	7.4	5.9	56.5	6.5
52											98.5	1.7	91.0	3.0	79.0	5.0	63.0	6.5
54											99.9	1.4	94.0	3.0	83.5	4.5	68.7	5.7
56													96.0	2.0	87.5	4.0	74.0	5.3
58													97.8	1.8	90.5	3.0	79.0	5.0
60													99.5	1.7	93.0	2.5	83.5	4.5
62															95.0	2.0	87.0	3.5
64															97.0	2.0	90.0	3.0
66															98.5	1.5	92.5	2.5
68															100.0	1.5	94.5	2.0
70																	96.5	2.0
72																	98.0	1.5
74																	99.5	1.5

SOURCE: Original data Schiffel, 1903. The table is reproduced after Prodan et al.1997, 'Mensura Forestal", p. 414, table 5.-1.

TABLE 1.4.-2. Percentage distribution of average diameter after Schiffel (1903) and Fekete (1939)

Diámetro medio	Σh%= 0	10	20	30	40	50	60	70	80	90	100
10	54.0	71.0	77.0	81.0	85.0	91.0	97.0	105	115	128	195
15	54.7	70.0	76.6	82.7	87.1	93.3	99.3	107	117	128	177
20	55.0	69.5	77.0	83.0	88.5	94.0	105.0	107	117	128	167
25	55.2	69.2	77.2	83.2	89.2	94.8	101.0	108	117	128	161
30	55.3	69.0	77.1	83.8	89.3	95.3	101.0	108	117	128	157
35	55.5	68.9	77.1	83.8	89.7	95.8	101.0	108	117	128	155
40	55.5	68.7	77.2	84.0	90.0	96.0	102.0	108	117	128	152
45	55.7	68.7	77.1	84.2	90.2	96.2	102.0	108	117	128	151
50	55.6	68.6	77.4	84.2	90.0	96.4	102.0	109	117	128	149
Valores medios	55.5	68.9	77.1	83.7	89.5	95.5	101.0	108	117	128	156

SOURCE: Original data from Schiffel (1903) and Fekete (1939) and reproduced by Prodan et al. Mensura Forestal" 1997, p. 414, table 5-2 ∑ h % = x = cumulated percentage frequency.

The first work on biology and forestry of larch was summarized in a paper written by Schreiber in 1921. H. Mayer analyzed in 1966 the structure of a subalpine larch and spruce selection forest in the Langau region. Zohrer (1968) investigated structure and growth of isolated mountainous subalpine larch spruce mixed stands. Sterba examined (1985) productivity level and maximum stand density index after Reineke (U.S.A.). On the other hand Suzuki (1971) considered forest transition as a stochastic process.

The effect of site factors on the yield class of Norway spruce stands in Austria using a linear regression analysis was completed in 1996 by Herzberger. He used data from 200 plots of the Austrian forest Damage Monitoring System (WBS) and concluded that "General site parameters and ecological indicator values proved to be more closely related to yield than were soil chemical analyses". Yield class was closely correlated with altitude, average temperature, nitrogen and soil pH.

Cited authors:

Herzberger 1996, Mayer H. 1966, Mayer H. and Brüning 1980, Prodan et al. 1997, Schiffel 1903, 1910, Schreiber 1921, Sterba 1985, Suzuki 1971, Zöhrer 1968.

1.5. Stand volume, growth and yield tables

1.5.1. Stand volume

In Feistmantel's (1854 and 1876) general forest tables are given data on volume and average growth per hectare for different species together with a lot of other tables for forest mensuration and management.

Böhmerle (1854 and 1899) developed researches on the inventory of stand volume.

Breymann published in 1868 a manual on wood measurement including volume of wood per unit area of the forest. He developed also the solids theory of rotation for forestry purposes.

Schiffel (1897) used in stand inventory the sample stem method for which it is necessary to know the height, dbh and $d_{1/2}$ (diameter at the middle of height). Schiffel's equations

$$k_{1/4}=0.61_s+0.41+\frac{0.41}{k_s \cdot h} \quad \text{and } k_{3/4}=0.865k_s-0.14-\frac{0.20}{k_s \cdot h}$$

allow the determination of the h, dbh and $d_{1/2}$ and the additional determination of stem form in the points 1/4 and 3/4 of height. In the next year (1838) Schiffel made critical observations on volume determination using the stand form height. Kopezki (1902) underlined the role of basal area and its use in forest mensuration. He proposed (as Gerhardt in 1901) the use of statistical relation $gh = b_o + b_1g$.

In 1948 Wodera determined stand volume after aerophotogrammes. For determination of stand volume Tischendorf (1949) used arithmetical and natural average stem procedure.

A study on stand volume in connection with stand middle height was completed by Jelem (1950). In 1956 Frauendorfer discussed the planning stages of a sampling inventory for volume determination. Braun presented in 1969 Austrian forest inventory and the methods of evaluation and classification of sites.

The problem of assortment tables was investigated in the 1980s especially by Sterba and Kleine. The functions for calculating assortment tables for Norway spruce were established by Sterba in 1983. His work is a detailed account of the stem curves (based on 1000 felled trees), and a computer program for standardized block sorting used to produce individual-stem assortment tables which were published in the same year (Sterba and Greiss 1983). Kleine calculated the assortment tables for beech valid for the whole country (1986). Tables containing volume of merchantable timber for single trees and stands, based on age, site class and stocking were constructed by Sterba et al. in 1986 for silver fir, larch, Scots pine and beech.

1.5.2. Stand growth and growth modelling

The early work and stand growth using percentage was completed by Breymann in 1868. He used the formula

$$P_y = \frac{i_y}{n \quad y_2} \; 100 \text{ or } p = \frac{i_y}{n \cdot y_1}$$

where i is the increment of an element y during a period of n years; the annual percentage is computed according to this formula which depend on final values of y_1 and y_2.

Guttemberg (1885) compared growth of beech, spruce, fir and Scots pine mixed stands in state forests. A new method of growth determination in forest stands was proposed by Kopezki in 1899.

In 1969 Zohrer studied and determined stand growth and productivity in subalpine larch - spruce mixed forests. An ecological model of production in a stand was proposed in 1973 by Baumgartner.

Agren introduced in 1983 the concept of nitrogen productivity in forest growth modelling.

Mäkelä and Hari developed in 1986 a stand growth model based on carbon uptake and allocation in individual.

The decline of growth and mortality of oak in Austria was analyzed by Marcu and Tomiczek in 1989.

In 1991 Antonovsky et al. published a booklet on "Ecophysiological models of forest stand dynamics".

Hasenauer and Monserud (1995) discussed biased statistics from height increment models developed from smoothed "data". They noted: "In the individual tree growth simulation literature many cases can be found of a surprising phenomenon: light coefficients of determination for the height increment model.... The contradictory occurrence of height coefficients of determination for height increment models that are not based on felled-tree samples can only be explained by the so-called height increment "data" that is actually predicted from same heuristic function, usually of diameter…. Because all variation has been removed when generating the smoothed "data" from the heuristic function, fit statistics are artificially high and an unreliable indicator of the true accuracy of the resulting height increment model. The authors concluded that "First that fit statistics measuring deviations about smoothed height increment "data" are misleading and strongly biased upward. Second, that measurement errors in remeasured heights on standing trees are so large that the underlying height increment signal is nearly hidden (R2 = 0,14) even with a sample as large as 7500 trees" (p. 291 Tampere IP/1995).

Klaus (1995) investigated competition and diameter increment in young beech stands and concluded that the correlation of diameter increments of selected beech trees with the competition index was found to be lower than that found for Norway spruce.

Recent analyses on growth trends of forest in Austria carried out by Schadauer (1995) showed that old spruce stands had not decreased in the last tree decades (based on 200 analysed stems). In Bohemian Massif growth trends curve based on radial-increment analyses using long increment cores from spruce and showed a continuously increasing mean radial increments of the first twenty years of trees with different germination over time.

Sterba and Monserud (1995 a) presented the validation of a diameter growth model for Austria with permanent plots and validation of the single tree stand growth simulator PROGNAUS (PROG - Nosis for Austria) designed to simulate the growth of both pure even-aged and mixed species uneven-aged stands using a distance-independent individual tree methodology. "Currently, the simulator prototype consists of a basal area increment (BAI) model, a height growth model and a crown ratio model for all major species in Austria" (p. 293: Tampere Inviting Papers, 1995 b, IUFRO XX Congress).

Golser and Hasenauer (1997) developed a model for predicting juvenile tree height growth in uneven-aged mixed species stands. It is known that the recruitment of trees after the death or filling of an overstorey tree is essential for simulation models to achieve a consistent simulation output. The model was developed for juvenile trees ($h \leq 1,3$ m) and predicts actual periodic 5-year height increments by adjusting the corresponding potential height increments using: (1) the competition of the remaining overstorey; (2) the intra- and inter species competition among the regeneration itself and; (3) a modifier for the age affected incidence of light. According to the authors who investigated the case of uneven-aged mixed stands of spruce, fir and beech "the results demonstrated that the 2 measures of competition and the modifier for the edge affected incidence of light were important for spruce and beech regeneration, while competition among regeneration for fir had no significant impact".

In 1997 Hasenauer analyzed dimensional relationship of open-grown trees in Austria. Crown width, breast height diameter, height to live crown base, and taper rates were investigated in trees which were unaffected by inter-tree competition throughout their life. These open-grown trees represents in fact the empirical maximum tree dimensions which are taken into account for developing management guidelines, modelling competition and grown closure. Hasenauer used data from 435 open - grown trees including 11 different species and developed equations for predicting the above mentioned parameters. “The result of this study makes it possible to determine maximum tree dimensions for all tree species in Austria".

1.5.3. Yield tables

The earliest yield tables (containing only stand volume and periodical volume increment) were published by Feistmantel in his "Allgemeine Waldbestandestafeln" (General forest tables) in 1854 and 1876 (2nd edn.) In 1904 Schiffel constructed yield tables for spruce taking into account age, height, number of trees and density of canopy, nine quality classes in total.

Weiss reproduced in 1909 Feistmantel's general yield tables.

A. von Guttenberg constructed in 1915 spruce volume tables for Hochgebirge and for spruce in Paneveggio (1915 b). Guttenberg used detailed stem analyses and demonstrated long time before Topçuoglu (1940, Germany), Assmann (1961, Germany) et al. that the width of annual tree ring decreased from the bottom of the tree up to a minimum located at 1-12 m (of height) and presenting a maximum in the crown zone.

The third edition of the Feistmantel textbook was published in 1936 by the care of J. Weiss and contains yield tables for oak, beech, fir spruce, larch, Scots pine, *Pinus nigra* (black pine).

In 1949 Wodera published yield tables for spruce, fir, Scots pine, Black pine, larch, sessile oak and common oak. Wodera yield tables contains 12 classes delimited according to the mean annual volume increment at the age of 100 years as that constructed by Frauendorfer in 1954 for spruce of Hochgebirge, after Guttenberg's tables.

Griess discussed in 1967 the problem of construction of yield tables for mixed stands. Marschall (1971/1981) published a set of yield tables with 11-14 classes based on mean annual volume increment.

Sterba's (1978) yield tables have 9 classes and the same criteria as that of Marschall's and refer to spruce from Sazzwald and Superior Austrian Schliergebit.

In 1990 Sterba et al. developed site index functions (based on 637 stem analysis) corresponding to the four yield tables for young spruce stands located in different regions of Austria. The functions enable site index (H_{100}) to be determined from the first five height increments above breast height (growth intercept method). Sterba considered that this method which was used to assess the site index for 22 young stands, proved to offer a greater accuracy than that obtained by age and top height (the conventional method).

Table 1.5.-1. presents comparative data for 80 years spruce stands using different yield tables. The differences are evident and depend in part on the method used for yield tables construction, and of the chosen class productivity.

TABLE 1.5.-1. Spruce stand comparative data between different yield tables in Austria

Year	Yield table Author	Type and number of classes	Ages	Height interval m	Mean annual volume increment m^3
1876	R. Feistmantel	Superior (3 classes)	20-140	-	8.8-10.7
		Middle (3 classes)	20-140	-	5.5-7.7
		Inferior (3 classes)	20-140	-	2.2-4.4
1904	A Schiffer	Quality after: age, height, number of trees, mean stem diameter as N:d			
		9 quality classes	10-130	12.6-31.1 (h_g)	3.2-16.9
		3 canopy density	10-130	13.3-32.6 (h_g)	3.9-17.0
		compact canopy	10-130	14.2-34.7 (h_g)	3.8-17.3
		middle closed canopy			
		low closed canopy			
1915	A. von Guttenberg (Fichte in Hochgebirge)	Quality after height 5 site classes	10-150	10.6-28.7	2.6-13.0
1915	A. von Guttenberg (Fichte in Panevegio)	3 site classes	10-200	11.5-21.5	2.6-7.9
1949	H. Wodera	12 classes after mean annual volume increment at the age of 100 years.	5-150	5.3-28.3 (maximum height)	0.9-11.4
1954	R. Frauendorfer	13 classes of mean annual volume increment at the age of 100 years	20-150	8.3-30.5 (hg)	1.5-14.2

TABLE 1.5.-1. (cont)

Year	Yield table Author	Type and number of classes	Ages	Height interval m	Mean annual volume increment m^3
1975/ 1981	J. Marschall (reference by Schmidt-Vogt 1991)	Abs. height quality classes after: mean annual volume increment at the age of 100 years			
		Hochgebirge (14 classes)	20-150	11.5-33.6	1.6-15.0
		Bavaria (14 classes)	20-120	17.4-35.7	4.5-17.2
		Bruck/Mur (11 classes)	20-150	18.3-35.1	4.0-14.8
		Weitra (12 classes)	20-150	20.0-35.9 (Dominant height)	4.2-15.7
1978	H. Sterba	Abs. height quality 9 classes after mean annual volume increment at the age of 100 years	15-100	26.7-36.8 (h dominant)	10.2-19.0

Cited authors:

Agren 1983, Antonovsky et al. 1991, Baumgartner 1973, Böhmerle 1854, 1899; Braun 1969, Breymann 1868, Feistmantel 1854, 1876, 1936 (c/o J. Weiss); Frauendorfer 1954a, 1954b, 1956; Guttenberg A. v. 1885, 1915a, 1915b; Galser and Hasenauer 1997, Gries 1967, Hasenauer 1997, Hasenauer and Monserud (U.S.A.) 1995, Jelem 1950, Klaus 1995, Kleine 1986, Kopezki 1899, 1902; Mäkela and Hari 1986, Marschal 1975/1981, Schadauer 1995, Schiffel 1897, 1898, 1904; Sterba 1978, 1983; Sterba and Griess 1983; Sterba et al. 1986, Sterba and Monserud 1995a, 1995b; Sterba et al. 1990, Tischendorf 1949, Weiss J. 1909, Wodera 1948, 1949; Zohrer 1969.

1.6. Other works

In 1980 Pollanschütz underlined the importance of verification and synchronization to detect missing tree-rings during dendrochronological works.

In the field of biomass studies it should be mentioned the same study (Pollanschütz 1983) which analyzed the economic necessities and ecological limits of forest biomass utilization and considered that, ecological impacts of forest soils should not be neglected especially when they are caused by special kind of biomass harvest as a result of nutrient extraction. It is taken into account the danger of erosion which is limiting and determines the harvest-methods and intensity in mountainous regions.

In 1877 J. F. Friedrich discussed the influence of weather on tree growth and was the first forester who came with the idea of an auxograph to measure diameter growth.

We have no information about tree-ring studies in Austria except the work of Wimmer and Grabner (1997) who determined the effect of climate on vertical resin duct density and radial growth of Norway spruce. They used vertical resin duct density in spruce tree-rings as a dendrochronological variable, comparing it with radial growth of trees and concluded that resin duct density is a useful variable for dendroclimatology.

1.7. Forest inventory and remote sensing

The earliest information known on forest inventory works carried out in Austria refers to Schmied communication on permanent sample plots measurements, calculation and disposition of results, presented in 1932 at the IUFRO Congress held in Nancy (Proceedings Section 1).

After the withdrawal of the occupation forces from Austria in 1955 it was decided to start a country wide forest inventory (Schieler 1933). According to Michael Kochl (1996) "the national forest inventory began in 1961 as a result of the forest survey conducted between 1952 and 1956 as a kind of large-scale forest management using the age class method, and which is not to be regarded as a mathematical or statistical assessment (p. 58)". The first National Forest Inventory began in 1961 based on regularly distributed tracts with a rotation of ten years. The second inventory was carried out between 1971 and 1980. Today the inventory area "is divided into uniform quadratic tracts, comprising four permanent angle point sample plots each and spaced at 200 m intervals (…) Trees sampled for volume determination were distributed over the four permanent point samples. For all selected trees with dbh of more than 10.4 cm, the height was measured with a relascope, the diameter at one third of the tree height with a tele-relascope, and the volume is then determined by means of volume functions. Within a circular sample plot, the height and dbh of trees with dbh between 50 and 104 mm is additionally recorded. Up to 1980 increment was determined through sample cores. The tracts of 200x200 m were distributed at regular intervals of 2.75 km all over the country and each year about 1100 tracts were surveyed over the country" (after Koehl 1996).

The first National Forest Inventory (1961/1970) based on a systematic statistical grid with temporary plots had the following as main target: forest area, gross volume of growing stock, increment, mechanical stem damage caused by man and dear.

Separation of reporting units in a forest inventory was described in 1958 by R. Braun who presented also the results of the 1952/1959 inventory of management units all over the country and published in 1961 the instructions for the

1961-1970 forest inventory and in 1969 the results of inventories and methodological aspects. Later in 1978, Haszprunar presented a summary of forest inventory works at a IUFRO meeting held in Bucharest. In 1981 FBVA published new field instructions for 1981-1985 forest inventory.

The results of the 1971-1980 forest inventory were printed in Wien in 1985 and commented in the same year by Mildner et al. who insisted on methodology presentation, changes occurred between 1961-70 and 1971-80, site and silvicultural aspects, and damage. A similar work on the results of 1986-1990 forest inventory (262 pp) was completed in 1995 by FBVA (Forstliche Bundesversuchsanstalt).

During the last two decades of 20th century like other European countries Austria developed Inventories of endangered Forests based especially on infrared color aerial photographs. In Austria sampling design (1988) consists in 4x4 km, 4x2 km, 2x2 km, assessment of defoliation/discoloration: 5 classes according to ECE, object of investigation being only stands > 60 years (Koehl 1996, p. 363). Koehl insisted that "Permanent monitoring of the forest is necessary to decide whether the foliage loss observed from the beginning of the presented decade indicates a natural, short-term fluctuation or a long-term trend" (p.362).

In 1993 Schieler presented a contribution of a permanent forest inventory to a national information system from the Austrian point of view (for the reader of his work it is not clear if he presented an official or personal point of view). Schieler underlined that "The development of the national Austrian Forest Inventory illustrates the change in the demands on inventory over the years. In the future more emphasis has to be laid on the ecological part of forest inventories in a global environmental monitoring system. Furthermore, the great advance in computer and information technology has to be taken into account". This opinion is accepted today on a large scale.

In 1983 a bioindicator grid was established - a country programme to obtain the changes in sulfur and main nutrient content in needles and leaves. Austrian Forest Condition being Inventory (AFCI), was conducted from 1984 to 1988, symptoms of crown condition being considered as an important criterion for the assessment of forest tree health.

Schieler (1993) underlined that "In the future a modern forest inventory must be a permanent information, control and planning instrument for forest policy and the forestry, not only for sustainability concerning increment and cutting observations. An inventory has to be an important part of a country-wide environmental monitoring system. A forest inventory should be an objective database to elaborate and develop practicable solutions for the compensation of different interests and demands on forest areas coming from forestry, hunting, tourism and nature conservation” (p. 70). These ideas have to be accepted but they are not new and the reader can find them in the concept of integrated forest inventories presented at the end of the 1970s in the literature of the United States of America (see also Alexe and Milescu 1983, a Romanian book on forest inventory).

In 1947 Bitterlich published a technique, considered as revolutionary, on the measurement of basal area per hectare by means of angle measurement (see 1.3, die Winkelzählmessung) followed in 1948 and 1952 by the angle count sample (die Winkelzahlprobe) and relascope technique (1959, Relascoptechnik). In 1984 Bitterlich published a comprehensive mononograph on the relascope idea and relative measurements in forestry (242 pp). The book was published in the U.K. by Commonwealth Agricultural Bureaux and refers to the Geometrical history of angle-count sampling (ACS), Significance of the term *Angle-Count Sampling*, Basic practical application of ACS; Explanations, Generalizations and innovations; Methods suggested by ACS using Steiner’s Theorem; Refinements to increase the accuracy of ACS; The development of instruments; Other relative measurements by relascopes; Continuous forest inventory (CFI); ACS in practice in various countries; Application of computers; Prospects and 6 pp of bibliography.

“A Comprehensive Concept for Future Forest Inventories” was developed by Bitterlich and presented at the symposium at Syracuse - USA in 1989 about “State of the art methodology of forest inventory” (published in 1990 by LeBau and Cunia). The following items were discussed at this symposium:

Sampling with partial replacement:

- Updating methods for forest inventory;
- Importance sampling;
- Critical height techniques;
- Multi-stage and multi-phase sampling designs;
- Point model based sampling;
- Integrating multiple value forest surveys into timber surveys;
- Error of inventory biomass or volume estimates;
- Expressing diameter distribution by mathematical functions;
- Estimation of stand ingrowth;
- Estimation of tree and stand mortality;
- Error of volume or biomass regression;

Line intersect sampling:

- Spatial analysis of inventory data;
- Objectives of forest inventory;
- Forest inventory and growth and yield models;

Permanent plots versus point sampling;
Remote sensing and its use in forestry inventory
New regression concepts
Geographic information systems

Bitterlich claimed that if his suggestions are used properly, "the topics marked by the numbers 1) to 15) can be answered or demonstrated mainly by computers using the same measurement data". It is beyond the purpose of this text to present all Bitterlich's ideas but his abstract deserve to be reproduced in his original from: "The future questions will not be Permanent plots versus point plots" or " Why and how critical height sampling?", or "What advantages will Zöhrer's suggestions about sampling with programmed probabilities bring, and how to perform them?", or even the point sampling methods by Hirata and Minova using vertical angles. All these items are not real "problems" for measurement techniques in the forests, but can be answered by computers alone if we use a comprehensive concept for point sampling shortly outlined in this article. The basic feature of it is to develop a special science and technology for getting perfectly adapted taper functions for every sample tree in question. More than ever before the Tele-Relascop and Spiegel Relascop (Wide Scale or CP-Scale) with the new micro attachment can be used for the development of taper functions as well as for controlling them occasionally and/or permanently".

The first application of terrestrial photogrammetric mapping was done in the Alps by the Austrian foresters who used a method known as Messtisch-Photogrammetrie developed in 1850s by Laussedat in France and Meydenbauer in Germany. This method was used by Wang, Kobsa, Pollack and others Austrians from the late 1880 onwards for mapping torrents and other inaccessible forest details. This old method was replaced later by stereophotogrammetry (spectroscopic measuring based on a device carried out by Pulfrich in Jena). According to Hildebrandt (1993) the first stereokomparator was built in 1901 (Zeiss in Jena) but the Zeiss Stereoautograph was based on an idea by the Austrian von Orel who was one of the pioneers in the establishment of aerial photogrammetry which was applied in Austria during the third decade of the 20th century by Dock, Wedera and Pamperl for mapping in forest management.

Photogrammetric researches in Austria were developed after 1950 at Abteilung Photogrametrie of the Österreichische Forstliche Bundesversuchsanstalt in Vienna, centre headed firstly by E. Meyer. Research was continued especially at Hochschule für Bodenkultur in Vienna under Ackerl.

"In Austria air photos provided in a countrywide Waldbestandsaufnahme (forest inventory) orientation in the field and helped to delimits (1949-1969) or describe forest stands" (Hildebrandt 1993). For instance Wodera (1948) determined volume from aerial photographs. Mark presented in 1960 the situation of photogrammetry in Austria.

After 1970 the use of orthophotomaps as forest maps increased as a result of Kraus' improvement of their production. In the same time the use of increased aerial CIR photographs in the assessment of forest damage and forest decline inventories. Different studies based on aerial Color Infra Red photographs were developed because of the rise of the "new type" of forest disease which culminated in 1970s and 1980s. This was a good opportunity to study spectral reflectance properties of plants and spectral signature analysis in remote sensing data.

Availability in the early 1970s of the satellite imagery open a new perspective for the use of remote sensing in forestry in general and forest inventory in particular.

In 1986 Stellingwerf and Sann Lwin investigated the accuracy and relative efficiency of Landsat data and orthophotos for determining area and volume of spruce for 12841 ha area of Upper Austria. Taken into account the Landsat data, classified by principal components analysis they obtained very inaccurate differentiation of species (spruce and beech), age classes and smaller non forest areas in spite of the fact that the total forest area was reasonably accurate. On the other hand, they concluded that "Landsat method required 53 % more primary (first stage sampling) units 23 % more man-days and higher extra costs than "the orthophoto method for the same accuracy" (after For. Abs. 173/1986).

A monograph on the scope for using remote sensing techniques to inventory (116 pp) and monitor forest conditions was published in 1989 by Schneider. In this monograph there are shown methods, possibilities and limits of remote sensing for the inventory of forest condition. Nothing changed till the end of 20 century because of the resolution power of the images that remained too small on the free market.

During the last decade of the 1990s Austria adopted the policy of the development of multi-resource forest inventories - MRI (Schieler 1997, Winkler 1997).

Cited authors:

Austrian Forest Inventory 1971-1980, Bitterlich 1947, 1948, 1949, 1952, 1955, 1959, 1984, 1990; Braun R. 1958, 1960, 1961, 1969; FBVA 1981, 1995; Haszprunar 1978, Hildebrandt G. 1993, Koehl 1996, Mark 1960, Mildner et al. 1985, Pelz 1993, Schieler 1993, 1997; Schmied 1932, Schneider N. 1989, Stellingwerf and Sann Lwin 1985, Sterba 1991, Winkler 1997, Wodera 1948.

1.8. Chronology of selected works

1850s-1860s: The first application of terrestrial photogrammetric mappings in the Alps by Austrian foresters who used a method known as Messtrisch-Photogrammetrie (G. Hildebrandt 1993).

1854, 1899: Researches on stand volume determination (Karl Böhmerle).

1854, 1876, 1936: General forests tables including 1876 yield tables (Rudolf Greistmantel).

1868: Manual of wood measurement, yield and estimation of forest (K. Breymann).

1877: Influence of weather on tree growth. The idea of auxograph construction (J. F. Friedrich).

1879: Determination of stem volume as basis for the calculus of form factor and volume tables (Oscar Simony).

1885: Comparison of the growth of beech, spruce, fir and Scots pine in mixed stands (A. von Guttenberg).

1892: The early volume tables of Pressler and Neumeister (Max Neumaister).

1893: Form factors and volume tables for *Pinus nigra* (Karl Böhmerle).

1897: Schiffel's equations for stem form (A. Schiffel).

1899: Kopezki's method for stand volume determination (R. Kopezki).

1899: Stem form quotient introduced first time in Austrian literature. Form and spruce volume tables (A. Schiffel).

1899: A spruce monopraph (A. Schiffel).

1902: Basal area and its use in forest mensuration (R. Kopezki).

1903: About the law of volume distribution in normal spruce stands (A. Schiffel).

1910: Proposal for creation of a science on tending spruce (A. Schiffel).

1915: Yield tables for spruce in Hochgebirge and Paneveggio (A. von Guttenberg).

1927: Holzmesskunde (Forest mensuration), (A. von Guttenberg).

1932: Early information on sample plots measurements in Austria (Schmield, IUFRO 1932 Congress).

1930s: Establishment of aerial photogrammetry (Dock, Wodera, Pamperl) for mapping in forest management.

1942: A critical paper on the works concerning volume determination. (Wilhelm Tischendorf).

1947, 1948: Measurement of basal area per hectare by the means of angle count measurement (W. Bitterlich).

1948: Volume determination after aerophotogrammes (H. Wodera).

1949: The relascope and optical enumeration by the angle count method (W. Bitterlich).

1949: Normal volume tables with 12 classes designed according to the mean annual volume increment at the age of 100 years for spruce, fir, Scots pine, *Pinus nigra*, larch, sessile oak and common oak (H. Wodera).

1952: The Spiegel relascope (relascope with mirror) (W. Bitterlich).

1952: Angle-count sampling (W. Bitterlich).

1952-1956: The first survey on country level after the Second World War. This survey was a kind of large scale forest management using the age class method without any regard to mathematical statistic assessment.

1955: The use of distance measurements by sound in forest management (W. Bitterlich).

1957, 1961: Stacked measure into solid measure. More accurate conversion factors by the angle count method (W. Bitterlich).

1959: Bibliography of world literature on the Bitterlich method of plotless cruising (G. W. Thomson and G. H. Deitschman-U.S.A.).

1960: The results of the 1952-1956 forest survey (R. Braun).

1960: About the situation of photogrammetry in Austria - a 153 pp synthesis (E. Mark).

1961: Field instructions for forest inventory in Austria (R. Braun).

1961-1970: The first National Forest Inventory based on regularly distributed tracts.

1962: Relascope with width scale (W. Bitterlich).

1965: A new method of form factor used in volume determination of standing stem (J. Pollanschütz).

1967: The problem of construction yield tables for mixed stands (D. Griess).

1969: Austrian forest inventory. Methods of evaluation and site classification (R. Braun).

1971: The optimal determination of the volume of standing trees (P. Schimd; P. Roiko-Jokela, P. Mingard and M. Zobeiri).

1971: Forest transition as a stochastic process (T. Suzuki).

1971-1980: The second National Forest Inventory.

Since 1970: Development of the use of orthophotomaps and aerial CIR photographs.

1972: The tele-relascope (W. Bitterlich).

After 1975: The use of satellite imagery.

1977: A program (H. P. - 97) for telerelascope (W. Bitterlich).

1980: Waldbauliche Terminologie: Forest terminology (H. Meyer and E. Brüning).

Since 1980: Inventories of endangered forests based especially on infra red color (CIR) aerial photographs and development of researches on spectral reflectance properties of plants and spectral analysis in remote sensing data in connexion with dieback phenomena.

1981: Field instructions for 1981-1985 forest inventory (FBVA, 173 pp.).

1983: Establishment of a bioindicator grid - a country programme to obtain the changes in sulfur and main nutrient content in needles and leaves.

1983: The concept of nitrogen productivity in forest growth modelling (G. I. Agren).

1983: The functions for calculating assortment tables for Norway Spruce. Assortment tables (H. Sterba).

1984: A comprehensive monograph (242 pp.) on relative measurements in forestry based on the relascope idea (W. Bitterlich).

1985: Austrian Forest Inventory 1971-1980. Vol. I : Ten-year results and Vol. II: Lectures on the inventory (H. Mildner et al.).

1986: Assortment tables for beech (M. Kleine).

1986: Assortment tables for silver fir, larch, Scots pine and beech (H. Sterba, M. Kleine, O. Eckmüllner Jr.).

1989: The influence of climatic factors on oak decline in Austria (Gh. Marcu and Ch. Tomiczek).

1989: A synthesis of methods, possibilities and limits of remote sensing for the inventory of forest condition - a monograph on the scope for using remote sensing techniques to inventory and monitor forest conditions (W. Schneider).

1990: A comprehensive concept for future forest inventories (Walter Bitterlich).

1991: Lecture notes on the science of forest productivity (H. Sterba, 159 pp.).

1991: Ecophysiological Models of forest stand dynamics (M. Ya. Antonovsky, F. S. Berezovskaya, G. P. Karev, A. Z. Shividenko and H. H. Shugart).

1993: Contribution of permanent forest inventory to a national information system (Karl Schieler).

1995: The results of the Austrian 1986-1990 national forest inventory.

1995: Trends of forest growth in Austria (K. Schadauer).

1995: Validation of the single tree stand growth simulator PROGNAUS (Hubert Sterba and Robert A. Monserud).

1996: National inventories and inventories of endangered forests in Europe. (Michael Koehl).

1997: Dimensional relationships of open-grown trees in Austria (H. Hasenauer).

1997: Effects of climate on vertical resin duct density and radial growth of Norway spruce (R. Wimmer and M. Grabner).

1997: The trend towards the multi resource forest inventories - MRI (Karl Schieler, Norbert Winkler).

1.9. Selected contributors

Author	Printing years	Field
Karl Böhmerle	1850s-1890s	01, 1, 4
Rudolf Feistmantel	1850s-1870s (1936 reprint)	01, 4
K. Breymann	1860s	01, 4
J. F. Friedrich	1870s	1, 6
Oscar Simony	1870s-1900s	1
A. von Guttenberg	1880s-1920s	1, 4, 01
Max Neumeister	1890s	01
A. Schiffel	1890s-1910s	1, 4, 01, 3
A. Kope	1890s-1900s	4
W. Bitterlich	1940s-1990s	1, 4, 7
W. Tischendorf	1940s	1, 4
H. Wodera	1940s	3, 4,7
R. Frauendorfer	1950s	4
J. Pollanschutz	1960s-1980s	1, 5
R.Braun	1960s	2, 7
F. Zohrer	1960s	3, 4
E. Mark	1960s	7
W. Schneider	1980s	7
H. Sterba	1970s-1990s	4, 7
K. Schieler	1990	7
H. Hasenauer	1990s	4

01 = textbooks, 1 = tree, 2 = site evaluation and stand productivity 3 = stand structure, 4 = stand volume, growth and yield, 5 = biomass, 6 = tree-ring studies, 7 = forest inventory

1.10. Comments

This text refers to the 1850-1997 period and is based on 135 selected bibliographical references out of which 26% represent the works printed after 1980 and 13% those printed after 1990.

Austrian forest mensuration may be considered as a part of German school, with similar principles and goals but its development began later, after 1850, when the basic concepts on tree measurement were developed in Germany. In Austria like in other central European countries the major problems of the 19th century forest mensuration referred to stem form, volume tables, form factors and form quotient, (a term introduced by A. Schiffel), yield tables tree and stand growth. The most representative Austrian foresters involved in forest mensuration during the 19th century were K. Bohmerle, R. Feistmantel, O. Simony and A. Schiffel.

New techniques and methods emerged during the 20th century and were adopted in Austria: mathematical statistics, aerophotogrametry, remote sensing, GIS. Forest mensuration literature was dominated by the works of W. Bitterlich and his relascope and angle count sampling, angle count sampling being in general considered as a revolutionary concept. Remarkable works of W. Tischendorf, H. Wodera, J. Pollanschutz, R. Braun, F. Zohrer, H. Sterba and H. Hasenauer enforced the prestige of Austrian forest mensuration. On the other hand it should be noted the reduced number of tree ring studies in comparison with other European countries. In our opinion site and stand productivity researches deserve more attention.

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(AUSTRIAN FOREST INVENTORY 1971-1980. Vol. I: Ten-year results). Österreichische Forst inventur 1971-1980. Band I.: Zehnjahrergebnis. Mitteilungen der Forstlichen Bundesversuchsanstalt Wien (1985) No. 154/I, 1-216.

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2. FORMER CZECHOSLOVAKIA

General information

Land area: 77,280 sq. km Czech Republic (29,838 sq. mi.), 48,080 sq. km (18,564 sq. mi.) Slovak Republic: forest and wooded land: Czech Republic 26,290 sq. km (10,150 sq. mi.) or 33,4 % land area; Slovak Republic 19,900 sq. km (7,685 sq. mi.) or 40.6 % of land area. Czech Rep. and Slovak Rep.: average volume 221m^3/ha, average biomass 147 tons/ha. (FAO-1995-124 Forest resources assessment).

Round wood production (1991-1993):

	Industrial round wood (m^3)	Fuel and charcoal (m^3)	Total round wood (m^3)
• Czech Rep.	9,310,000	996,000	10,306,000
• Slovak Rep.	4,482,000	521,000	5,003,000

Forest vegetation: Temperate mixed forests
(World Resources 1996-97, Table 9.2., p. 218 and 9.3., p. 220.)
* Prins, K. and Korotkov, A. 1994

	Czech Rep.	Slovak Rep.
• Conifers *	84 %	44 %
• Broad-leaved *	16 %	56 %

Main species:

• Czech Rep.: Norway spruce (*Picea abies*) - 60 %, pines (*Pinus* spp.), European beech (*Fagus sylvatica*), oak (*Quercus robur*) European larch (*Larix decidua*).

• Slovak Rep.: European beech (33 %), Norway spruce (29 %), oak, other broad-leaved, fir (*Abies alba*), pine (*Pinus* spp.)

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

Czech Republic:

• Agricultural University of Praha, Faculty of Forestry, Praha (1919);

• University of Agriculture, Faculty of Forestry and Wood Technology, Brno (1919);

Slovak Republic:

• Faculty of Forestry, Zvolen;

• Forest Research Institute, Zvolen. (1989);

Publications (Primary Journals and Serials):
• Lesnicka Práce, Praha;
• Lesnictvi - Forestry, Czech Rep;
• Lesnictvi Časopis (Zvolen, Slovakia);
• Acta Instituti Forestalis Zvolensis;
• Acta Dendrobiologica;
• Ekólogia ČSFR, Brno;
• Communicatione, Inst. Forest. Czch. Praha;
• Acta Universitatis Agriculturae, Series C (Facultas Silviculturae, Czech Rep., Brno.

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KORF, V. 1953. Taxace Lesŭ (Forest mensuration). Praha, Statni Zĕmĕmedelské Nakladatelstvi.
VYSKOT, M. et al. 1981. Československe pralesy (Czechoslovak virgin forests). Praha.

2.1. Textbooks on forest mensuration and tables collections

In 1953, Vaclav Korf published "Taxace Lesu"a remarkable textbook on forest mensuration (327 pp.) containing seven sections: (1) stereometric techniques for determination of the volumes of trees and their parts, (2) physical methods for determination of volumes, (3) determination of the volume of single trees, (4) determination of the standing volume of entire stands, (6) determination of increments, and (7) the growth of trees and stands from the stands point of forest mensuration. A new edition of Korf's book was published later in 1972.

Another standard forest mensuration textbook was completed by Leporsky in 1960.

In 1971, Vyskot published his "Bases of growth and production of forests."

Later, in 1987, the 2nd edition of Halaj's et al. growth tables for the main species in Czechoslovakia (361 pp.) was published in Bratislava.

Cited authors:

Halaj et al. 1987, Korf 1953, 1972; Leporsky 1960, Vyskot 1971.

2.2. Tree measurement

In 1928, Polansky considered the girth as a basis of dendrometrical calculus, and in 1929 he constructed an auxometer for measurement of the growth - as far as we know this was one of the earliest instruments of this kind.

Korsun (1931) determined the error of Huber's formula, developed the instructions for volume determination of round wood (1934 a) and of standing trees (1934 b). In 1940 Korsun established the percentage of bark and branches of Norway spruce stands, and in 1949 proposed a new and simple formula for volume of standing trees:

$$v = 0{,}4363\ h \cdot d_{0.1}$$

where h = total tree height, and $d_{0.1}$= tree diameter at one-tenth height.

In 1955 Halaj published volume tables for standing trees that contain also form height values (hf), where Korsun (1955) presented stem volume as a function of height and dbh:

$$v = a\,(D+1)^b \cdot H^c \text{ or}$$

$$\log V = \log a + b \log (D+1) + c \log H$$

where V = volume, D = dbh, H = total height.

This formula is mentioned in almost all standard mensuration books, (U.S.A. included: Husch 1963, p. 119).

In 1973 Korf discussed the determination of height growth for spruce growth tables.

Halaj et al. presented in 1980 the height growth of spruce (*Picea abies*) trees according to new growth tables (1980).

Nociarova (1996) developed a mathematical method for expressing the loss due to decreasing the volume increment of species.

In 1997, Glomb put in evidence the pollution damage and growth relationships within a stand of spruce by measuring geo-phyto currents and electric impedance (relative vitality). He concluded that in the spruce trees geo-phyto currents increased with greater stem diameter, whereas the volumes of electric impedance decreased that meaning that in the case of spruce pollution damage is better characterized by geo-phyto currents than by electrical impedance; in the case of beech, it was possible to measure the effects of one species on the other taking into account the effects of the distances between the trees.

Cited authors:

Glomb 1997, Halaj 1955, Halaj et al. 1980, Husch 1963 (U.S.A), Korf 1973, Korsun 1931, 1934a, 1934b, 1940, 1949, 1955, Nociarova 1996, Polansky 1928, 1929.

2.3. Assortment tables for trees and stands

Tables for stem profile (taper) and for assortments were constructed by Korsuň in 1961.

Pařez (1969) used the percentage assortments for study of standing volume of trees and in 1973 published assortment tables for spruce, Scots pine, beech and oak stands.

New tables for beech were constructed in 1978 by Hubač.

In 1987 (a) Pařez developed assortment tables for spruce and Scots pine of different quality. Tables are given for sound trees and trees with decay or other defects; in the same year (1987 b) Pařez published percentage assortment tables for larch, birch and hornbeam stems of various qualities, and timber assortment tables for beech and oak stands with trees of different quality (1987 c).

In 1988 Cermák et al. constructed stand assortment tables for larch (*Larix* spp.) in Czechoslovakia.

In 1994 Mecko et al. developed new stand assortment tables for larch, hornbeam and birch.

Cited authors:

Čermak et al. 1988, Hubač 1978, Korsuň 1961, Mecko 1994, Peřez 1969a, 1973, 1987a, 1987b, 1987c.

2.4. Site and forest productivity

In 1959 Halaj investigated height growth of forest trees in Slovakia and developed a project of site classes based on height which was considered as the major criterion for the evaluation of site quality. Later, in 1978, Halaj proposed regional yield tables based on two independent variables: age and stand height. He distinguished more than on level of productivity for the same stand productivity class an chose as criterion for site quality the dominant height or mean height or the increment of all yield at a given age. All these characteristics are considered to be good indicators of site quality for a given species.

Locvenc (1980) analyzed the influence of site conditions on the canopy of forest stands and concluded that in poor site sometimes it is not possible to obtain stands with closed canopy.

Cited authors:

Halaj 1959, 1978; Locvenc 1980.

2.5. Stand structure

One of the earlier works on stand structure is that of Houba (1953) who constructed a curve of diameter distribution in *Pinus sylvestris* stands.

Mathematical statistics researches on diameter structure of Slovakian stands were developed in 1957 by Halaj who constructed tables of distribution of trees by diameter categories using Charlier's A and B functions. Borota (1960) used also mathematical statistics method to establish the influence of thinning on stand structure.

Halaj (1963) developed height series by species and diameter classes and volume series which are in concordance with these height series.

Korpel and Vinš (1965) studied the structure of mixed stands and an illustration of this type of structure for two stories and two species is given in Fig. 2.5.–1.

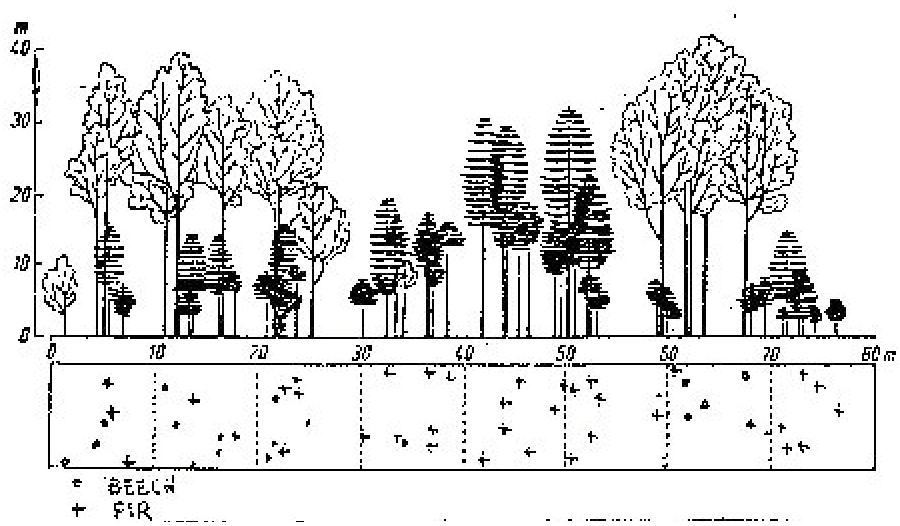

Fig. 2.5.–1. Two–storied stand with beech and fir.
SOURCE: Korpel and Vinš 1965 "Postovanie jedle", redrawn after Giurgiu 1979, Dendrometrie si auxologie forestieră, p. 598, fig. 12.10.

Zakopal and Mareš (1968) investigated mixed stands establishing the significance of spruce admixture for volume and value production of oak stands situated on the richer types of beech–oak forest.

Priesol (1971) determined a regression quotation between the number of trees per hectare (N) and the average distance l_i between trees

$$\log N = b_0 + b_1 \log l_i$$ with R values of 0.998.

The structure of stands according to height confirmed the suitability of Charlier A distribution for the characterization of distribution of trees by height classes (Halaj 1978). Peřina (1973 b) underlined the importance of spruce in the mixed stands of Scots pine and oak.

In 1971, Vyskot et al. presented in a textbook the Czechoslovak virgin forests and characteristics of their structure.

Šmelko (1982) constructed a mathematical model of uniform volume curves in even–aged stands in Slovakia and in 1987 developed mathematical formulation of the system of uniform height curves of even–aged stands in Slovakia for 12 species. An examination of 9 equations for expressing the relation between height and diameter was satisfactory and the simple two parameter of the Michajlov's function were found to be most suitable.

In 1984 Ondok experimented the simulation of stand geometry in photosynthetic models based on hemispherical photographs taken with fish-eye lenses for the non-destructive determination of leaf position and orientation in a stand giving the mathematical required for processing the data. He investigated the stands of *Salix cinerea*, and *S. pentandra*.

Estimation of the potential density of stands from thinning experiments and inventory data was performed by Sterba (1987) an interesting paper, synthesizing the structure and production of mixed stands in Slovakia.

Kupka (1992/1993) modelled the diameter structure of mixed stands of Norway spruce and Scots pine in southern Bohemia. These two species are the most common in Bohemia and cover 73,4 % of Czech forests. The author noted that the first attempts of diameter modelling (Flury 1916, Halaj 1957) used age and site index as main characteristics.

"The research was done also on changes of diameter structure of mixed stands in comparison with pure even-aged stand structure. The result showed that Scots pine does not change basically the diameter structure (from pure to mixed stands) while Norway spruce has changed its structure as much as changes its share in mixed stands" (p. 450 IUFRO Centennial 1992). The best driving variable is the fraction of stand diameter on stand height of both species. Diameter structure can be expressed by suitable regression function with parameters that are influenced by this relationship. The author intended to use these results for the construction of a distance independent model of mixed stands of spruce and Scots pine.

Cited authors:

Borota 1960, Halaj 1957, 1963, 1978; Hladik 1991, Houba 1953, Korpel and Vinš 1965, Kupka 1992, Ondok 1984, Peřina 1973b, Priesol 1971, Šmelko 1982, Šmelko et al 1987, Sterba 1987, Vyskot 1981, Zakospal and Mareš 1968.

2.6. Stand growth

Strogl discussed in 1940 the physiological basis of growth of the stands and the concept of stocking.

In 1975 Šmelko established the following statistical relation between stand volume increment (i_v) and stand volume (v).

$$i_v = b_0 + b_1 v \quad \text{and} \quad i_v = b_1 v \quad \text{from where} \quad b_1 = \Sigma i_v / \Sigma_v$$

Šika and Viňs (1980) found that the trend of growth of Douglas fir in the forest stands in Bohemia and Moravia followed those of Bergels's yield tables for north–western Germany (see Forestry Abstracts 33, 3035).

In 1995 Cerny et al. investigated modelling of the stand growth under changing environment. Taken into account the data from they tried to explain the differences stand height development and age-height relationship of the different age-same site stands (inventory curves) and quantified the development of current height increment from the beginning of this century. They concluded that "the results clearly document the increase of increment during the investigated period. Research results have been linked to the existing growth model using the scenario approach" (From authors abstract, Tampere, IUFRO XX World Congress, Inviting Papers, 1995 p. 285).

Kouba (1995) presented growth trends of forest in Czech Republic and Poland at IUFRO XX World Congress (1995). Concerning Czech Republic the author mentioned the available data from national forest inventories carried out in 1950, 1960, 1970, 1980 and 1990 (since 1979 the national inventory has been done annually). Kouba concluded that "For the whole period, this time series indicate the rise in the average volume (in m^3/ha), the most rapid increase being at the 70^{th} and 80^{th}… Although certain areas show the decrease in increment caused by emissions (more than 40000 ha of dead forests were cut), this has not outweighed the general positive trends in the increment changes " (p. 271 authors summary at the IUFRO XX World Congress, 1995).

A growth simulation model for beech was constructed by Simon, Zach and Drapela in 1996 (Czech Republic).

Cited authors:
Cerny 1995, Koupa 1995, Šika and Vinš 1980, Simon et al 1996, Šmelco 1975, Srogl 1940.

2.7. Stand productivity and yield tables

In 1969 Jurko presented a study of woodlands productivity in Czechoslovakia at a UNESCO Symposium (Brussels, October 1969) on "productivity of forest ecosystems".

Halaj, in 1973, developed a program for the construction of yield tables for main species in Czechoslovakia.

The yield and growth of mixed spruce - Scots pine stand was investigated, among others by Poleno in 1975. Paule (1978) discussed the possibilities to determine the productivity of mixed beech and spruce stands. The influence of the stand species composition on productivity was studied in the case of *Piceeto–Fagetum* vegetation type by Prudič (1978).

In 1979 Halaj and Řehák published in Bratislava yield tables for the main species growing in Czechoslovakia and next year Poleno (1980) analysed the potential production of mixed stands. A sample of Halaj- Rehak yield table is given in tables 2.7.–1.

TABLE 2.7.–1. A sample from Halaj / Řehák 1979 spruce yield table
SOURCE: Halaj and Řehák 1979 "Rastové tabulky blavných drevin ČSSR":
Reproduced after Schmidt–Vogt 1986, p. 169, table 57.

Age (years)	Trees (number)	Mean height (m)	Mean diameter (cm)	Stand basal area (m^2)	Stem volume (m^3)	Annual Increment (m^3)	Mean average increment (m^3)
				Bonität 40			
	6930			21.0	56	-	5.6
10	5877	4.5	5.6	17.7	47	-	4.7
	4822			14.4	39	-	3.9
	3081			35.7	219	16.6	11.0
20	2645	12.0	11.9	30.5	188	14.4.	9.4
	2208			25.3	155	12.1	7.8
	1845			43.2	383	15.8	12.8
30	1597	18.3	17.8	37.2	330	14.0	11.0
	1350			31.3	278	12.1	9.3
	1294			48.6	535	14.5	13.4
40	1128	23.3	23.0	42.2	464	12.9	11.6
	962			35.8	394	11.3	9.9
	993			52.9	673	13.3	13.5
50	870	27.4	27.5	46.2	588	11.8	11.8
	747			39.6	503	10.5	10.1

New yield tables for spruce, fir, oak and beech were published in Acta Instituti Forestalis Zvolensis by Halaj et al. in 1987 and 1988.

Cited authors:

Halaj 1973, Halaj and Řehák 1979, Halaj et al. 1987, 1988; Jurko 1969, Paule 1978, Poleno 1975, 1980, Prudič 1978.

2.8. Biomass studies

Root biomass of silver fir (*Abies alba* Mill.) was investigated in a detailed work by Vyskol (1973) who determined in 1979 the biomass of spruce trees and in 1981 the biomass of the tree layer of a spruce forest in the Bohemian Uplands.

An interesting study was completed by Elias (1983) on biomass estimation of *Loranthus europaeus* coenopopulation in an oak-hornbeam forest. *Loranthus europaeus* is an epiphytic hemiparasite of termophilous trees species of south-eastern Europe and Little Asia. The total *Loranthus* biomass (calculated per sample stand area -1 ha- was found to be 53.4 Kg dry matter).

Tokar (1987) determined the above ground biomass of a pure stand of red oak (*Quercus rubra*), and Benčat that of black locust biomass production in southern Slovakia.

Vacek et al. (1996) determined biomass production of virgin beech stands. The total accumulation biomass of living as well as dead trees varied from 222 to 758 m^3/ha. "A relatively high mortality rate was observed during the last 12 years; this was partly a result of the over-mature status of the stands. The rate of mortality accelerated in the period from 1981 to 1987 as a consequence of air pollution" (Vacek et al. 1996).

Cited authors:

Benĉat 1988, Elias 1983, Tokar 1987, Vacek 1996, Vyskot 1973, 1979, 1981.

2.9. Tree-ring studies

Up to 1970 Czechoslovakian tree-ring studies were represented almost exclusively by the works of Vinš. In 1962, Vinš improved the Eklund device built in Sweden for the measurements of tree-ring samples, and evaluated the dendrochronological works in spruce stands affected by smoke in Erzgebirges Mountains. In 1965 he developed a method of smoke injury evaluation of increment decrease. Vinš determined disturbances in tree-rings growth caused by the use of increment borer (Pressler's borer). In 1970, Vinš summarized in a short article the methods and use of tree ring analyses in Czechoslovakia.

In 1969 Vinš and Tesař determined increment loss due to smoke emissions in the region of Trutnov. The same subject was analyzed later (1973) by Vinš and Mrkva.

Unfortunately, we had no information about dendrochronological studies after 1971, except the work of Janonš and Barták (1991) – a dendroclimatological study of Turkey oak (*Quercus cerris* L.). In this case the major limiting factor of increment was precipitation, especially the total precipitation in a 14-

months period, autumn and spring precipitation, while summer precipitation and temperature characteristics were considered less significant. The above mentioned authors developed a statistical model to predict increment from 14 month precipitation, mean January temperature and mean growing-season temperature.

Cited authors:

Janouš and Barták 1991, Vinš 1962a, 1962b, 1965, 1966, 1970; Vinš and Mrkva 1973, Vinš and Tesař 1969.

2.10. Forest inventory and remote sensing

In former Czechoslovakia forest inventories were carried out in 1950, 1960, 1970, 1980, 1990 and since 1979 the national forest inventory was done annually. In the determination of stand volume in 1953 circular sample plots were used.

Aerophotogrammetry was used in Czechoslovakia since the early 1920. In 1923 Tichy introduced courses on forest photogrammetry at the Forest Faculty in Brünn, mapped the Maseric Forest near Brünn in 1927 and the Zebuce forest district in 1934. A research group for aerial photography was organized at the Forest Institute of the Slovakian Academy of Sciences at Bratislava, headed firstly by V. Cermak in the mid 1950s. In Prague researches were developed by Pohorely, and in Zvolen by Visnovsky. Important contribution were also made by the forest management planning office in Zvolen by Halaj. Stereo mapping was used on a large scale in mountainous forest regions (after G. Hildebrandt, 1993).

In 1987 Scheer and Račko determined tree variables from large scale aerial photographs (1: 1900 scale, taken from a meteorological balloon with a Kiev 80 camera having 45 mm lens). They investigated beech trees (*Fagus sylvatica*) and for the values of diameter, height and distance between individual trees obtained accuracies of 11.8, 12.4 and 6.5 % respectively.

The results of the use of integrated ground and remotely sensed data for forest monitoring of the Sudety Mountains were presented by De Roover et al. (1993) at a symposium held in Finland, in 1992 (Ilvessalo Symposium on National Forest Inventories).

The use of remote sensing and GIS in detection of stand characteristics was also analyzed in Slovakia in 1996 by T. Bucha who used Landsat TM imagery based on GIS.

In the same period Fajman (1996) presented brief results on the bark beetle (*Scolytidae*) infestations using aerial photographs (Czech Republic).

Cited authors:

Bucha 1996, De Roover et al. 1993, Faiman 1996, Kajfez 1953, Scheer and Račko 1987.

2.11. Chronology of selected works

1927: Application of forest photogrammetry (Tichy);

1928: Girth as basis of dendrometrical calculus (B. Polanski);

1929: Auxometer – a device for measurement of diameter growth during vegetation season (B. Polanski);

1934: Volume determination of round wood (F. Korsun);

1940: Physiological basis of growth of stands (K. Srogl);

1949: F. Korsun's simple formula for the volume of standing tree ($v=0,4363h\ d_{0,1h}$);

1953: Taxace Lesu: Dendrometrie. A textbook on forest mensuration (Vaclav Korf);

1955: Volume tables for standing trees (J. Halaj);

1955: Stem volume as a function of height and dbh (F. Korsun);

1957: Mathematical statistics researches of diameter structure in Slovakian stands (J. Halaj);

1959: Investigations on height growth of forest trees (species) in Slovakia and a project of productivity site classes based on heights (J. Halaj);

1960: Dendrometrie (A. Leporsky);

1965: A method of smoke injury evaluation for determination of increment decrease;

1970: Methods and use of tree ring analyses in Czechoslovakia (B. Vinš);

1972: Dendrometrie (V. Korf et al.);

1973: A program for construction of yield tables for main species in Czechoslovakia (J. Halaj);

1973: Assortment tables for spruce, Scots pine, beech and oak stands (J. Pařez);

1978: Possibilities of productivity determination of mixed beech spruce stands (L. Paule);

1978: Influence of stand species composition on productivity of *Piceeto–Fagetum* vegetation type (Z. Prudič);

1979: Yield tables for main forest species in Czechoslovakia (J. Halaj and J. Řenák);

1980: Potential production of mixed forest stands (Z. Poleno);

1981: Biomass of the tree layer of a spruce forest in the Bohemian Uplands (M. Vyskot);

1981: Czechoslovak Virgin Forest (M. Vyskot et al.);

1982: Mathematical model of uniform volume curves in even-aged stands in Slovakia. (Š. Šmelko);

1984: Simulation of stand geometry in photosynthetic models based on hemispherical photographs (J. P. Ondok);

1987: Growth tables for main forest species in Czechoslovakia (J. Halaj et al);

1987: Determination of tree variables from large scale aerial photographs (L. Scheer and J. Račko);

1987: Assortment tables for spruce and Scots pine trees different quality (J. Pařez);

1987: Timber assortment tables for beech and oak stands with trees of different quality (J. Pařez);

1987: Mathematical formulation of the system of uniform height curves of even-aged stands of the Slovakia Socialist Republic. – 12 species (Š. Šmelko);

1988: Yield tables for spruce, fir, oak and beech (J. Halaj, R. Petraš, F. Pánek and J. Grék);

1991: Study of the structure and production of mixed stands in Slovakia (M. Hladik);

1992: Modelling the diameter structure in mixed stands in southern Bohemia (Ivo Kupka);

1994: The construction of new stand assortment tables for larch, hornbeam and birch (J. Mecko, R. Petraš and V. Nociar);

1995: Growth trends of forest in Czech. Republic and Poland (J. Kouba);

1996: A growth simulation model for beech (T. Simon, J. Zach and K. Drapela);

1996: The use of Landsat imagery and GIS for the detection of forest characteristics (T. Bucha);

1997: The pollution damage and growth relationship assessed by measuring geo-phyto currents and electric impedance (V. Glomb).

2.12. Selected contributors

Author	Printing years	Field
B. Polansky	1920s	1
F. Korsun	1930s-1960s	1
J. Halaj	1950s-1980s	4, 3, 1, 01, 2
V. Korf	1950s-1970s	01, 1
A. Leporsky	1960s	01
J. Pařez	1960s-1980s	1, 4
B. Vinš	1960s-1970s	6
Š. Šmelko	1970s-1980s	2, 3, 4
M. Vyskot	1970s-1980s	5, 3, 4
H.Sterba	1980	3

01 = textbook, 1 = tree and primary products, 2 = site evaluation, 3 = stand structure, 4 = stand growth and yield, 5 = biomass, 6 = tree ring studies

2.13. Comments

Czech and Slovak forest mensuration used in general the techniques of this discipline practiced in Germany. Remarkable early textbook on dendrometry (forest mensuration) were written by V. Korf (1953, 1972), and A. Leporsky (1960) and among the selected contributors should be mentioned B. Polansky, F. Korsun, B. Vins, J. Halaj and H. Sterba.

Out of the 80 cited papers 33 % were printed after 1980 and 15 % after 1990. The time lag between the Czecho-Slovak development of forest mensuration and that of Austrian and especially German is visible and is due to political situation of Czechoslovakia after the Second World War when the Soviet influence was not so evident as in other former socialist countries.

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3. FRANCE

General information

Land area 543,250 sq. km (209,757 sq. mi), forest and other wooded land 141,540 sq. km (54,651 sq. mi.), total forest 13,110,000 ha (50,620 sq. mi) or 24 % of land area; volume 136 m^3/ha, biomass 93 tons/ha (FAO 1995-124 Forest resources assessment).

Round wood production: industrial round wood 33.167 mil. m^3, fuel and charcoal 10.450 mil. m^3, total round wood 43.617 mil. m^3 (World Resources 1996-1997, table 9.3, p. 200).

Forest vegetation: temperate mixed forests (predominant) and Mediterranean dry forests in the south, along the sea coast.

- Conifers ca. 30 %
- Broad-leaved ca. 70 %
- Main species: oaks (*Quercus robur, Q. petraea, Q. pubescens, Q. ilex*), beech (*Fagus sylvatica*), pines (*Pinus maritima, P. sylvestris*), fir (*Abies alba*), Norway spruce (*Picea abies*), European larch (*Larix decidua*), hornbeam (*Carpinus betulus*), poplars (*Populus* spp.).

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

- École Nationale du Génie Rural, des Eaux et de Forêts (ENGREF), Nancy (1824);
- Centre de Cooperation Internationale en Recherche Agronomique pour le développement, Forestry Department (CIRAD-FORET), Nogent-sur-Marne, (1950);
- INRA, Departement des Recherches Forestières, Centre de Recherche de Nancy, Seichamps, (1964).

Publications:

- Annales des Sciences Forestières (1923);
- Annales ENEF: Annales de l’École Nationale des Eaux et Forêts et de la Station de Recherches et Expériences;
- Bulletin de la Société Forestière de la France Comté et de provinces de l’Est;
- Revue des Eaux et Forêt (Paris, Nancy);
- Revue Forestière Française (Nancy);
- Revue du Bois et de ses Applications, Paris;
- Bois et Forêts de Tropiques (1947), Paris; Société pour le Développement

de l'utilisation des Bois Tropicaux. Quarterly;

• Bulletin technique de l'Office National des Forêt;

Annales de l'AFOCEL.

Database:

France has its own forestry database called VELLEDA, created by École Nationale du Génie Rural, des Eaux et des Forêts, Nancy.

A short chronology of events and situations during the beginnings of French forestry:

• In the middle of the fourteenth century the main forest owners were crown, ecclesiastical bodies, communes and private individuals.

• Earliest forest ordinances for the control of wood harvesting: 1280, 1318, 1346.

• Mélun ordinance became law in 1376 and restricted clearing area up to 10-15 hectares. Trees for felling were marked with a stamping hammer ("martelage") and annual felling determined by area (aire) that had to be adjacent (à tire).

• The beginning of the 17th century: increasing demand of timber as a result of the Thirty Years War determined a deterioration of the state of forests.

• 1668: probably the earliest directions for the sale of King's woods (Louis de Froidour).

• 1669: it was established a new forest code and the number of grand masters (grand-maître) in forest administration was reduced. Usually, the masters had no knowledge of forestry, for example the outstanding French writer Jean de la Fontaine (1621-1695).

• After the beginning of the 18th century books on different aspects of forestry began to be published (see 3.1).

• Since 1760 heavy fellings (especially of oaks) needed to replace naval losses in the Seven Years War (1756-1763).

• Social unrest and war (French Revolution 1789-1794, Napoleon's wars, Treaty of Paris in 1815) affected the development of French forestry: "The revolution had two important forestry results: the dissolution of the forest service, and secondly, the change in land ownership. Although some remained unaffected, many private owners were dispossessed of their estates and ecclesiastical property was confiscated; in both cases forests and woodlands were involved. Communal forests, on the other hand, received very different treatment; feudal dues and payments were abolished, and in some cases their area was increased by the transfer of woodlands from monasteries and church authorities. The overall effect on forestry was to produce a period of stagnation during which German forestry exerted an increasing influence" (James 1996, p. 27).

• A sign of a return to normal conditions was in 1824 when "L'École National de Eaux et Forêts" (National School for Water and Forests) was founded.

SOURCES: James 1996, Fernow 1907.

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3.1. Books containing information on forest mensuration and other books that contributed to the development of this field of forestry

Among the early texts on forestry it should be mentioned "Instructions pour la Vente des Bois du Roy" (Directions for the sale of the king's woods) written by Louis de Froidour and published at Toulouse in 1668. In 1685 De Froidour wrote also "Règlement Concernant les Forêts du Pays de Bigorre" (Regulations relating to the forests in the District of Bigorre). In 1680 De Froidour "introduced to the Pyrenees the method of management termed "*jardinae*" but now known as the "*selection system*" or "*Plenterbetrieb*" in Germany. Under this system, trees are removed singly or in small groups scattered through the area consequently producing an uneven-aged type of forest" (Reed 1954, p. 47: reference by James 1996, p. 25).

After the beginning of the 18th century textbooks were published on different aspects of forestry. One of the most notable was R. A. F. Reamur's "Réflexions sur l'État des Bois Royaume" (Thoughts on the condition of the royal forests) published in 1721. Reamur, known especially for his thermometer, was considered in "Biographie Universelle, Ancienne et Moderne" (Paris: Michaud Frères, 1811-1862) as "one of the cleverest naturalists and physicists that France had produced".

In 1755 the first two volumes of books were published by Henri Louis Duhamel de Monceau (1700-1782) as parts of the "Traité Complet des Bois et des Forêts" (A comprehensive treatise on wood and forests) which comprised eight volumes. The first two volumes referred to: "Traité des Arbres et Arbustes qui se cultivent en France en Plain Terre" (Treatise on trees and shrubs cultivated in France on the plains): Paris, H. L. Guerin and L. F. Delatour – with a German version printed in 1763 at Nürenberg. The next two volumes appeared in 1758: "La Physique des Arbres" (Structure of trees) having the same publisher who printed also in 1760 the volume "Des Semis et Plantations ou Methodes pour Multiplier et Élever les Arbres, les planter en Massifs and en Avenues" (Sowing and planting or methods for multiplying and raising trees, planting in stands and along avenues). In 1764 Duhamel (the same publisher) completed "De l'Exploitation des bois, ou, Moyens de Tirer un Parti Avantageux de Taillis, Demi-Futaies et Hautes-Futaies, et d'En Faire une Juste Estimation" (The utilisation of woodlands or ways to turn to advantage coppice, young high forest, and high forests and make an accurate valuation). The last volume: "Du Transport, de la Conservation de la force des Bois ou l'On Trouvera des Moyens d'Attendir les Bois, de Leur Donner des Pièces Simples" (On transporting, conserving wood strength) was published in 1763 (published by L. F. Delatour, Paris).

Duhamel de Monceau (1700-1782) was a forest land owner and a naturalist, he wrote also books on agriculture and in 1732 was appointed "Inspecteur Général de la Marine (!) and is generally considered the originator of the scientific approach to silviculture and woodland management (according to James 1996, p. 26/27).

"Duhamel de Monceau (1764) est le premier auteur qui ait fait dans un ouvrage forestier, une place important à la Dendrométrie. Après lui les specialistes du 190 siècle ne traitèrent que la question que fragmentairement, et il faut attendre Huffel (1919) pour trouver un text qui constitue veritablement une étude fouillée et complète: les 325 premières pages de tome II de son oeuvre magistrale: "Économie forestière" sont vraiment un traité de Dendrométrie moderne" (Pardé 1961, p. 5). (Duhamel de Monceau (1764) is the first author who offered in a forest textbook an important position to forest mensuration. After him the specialists of the 19th century examined the problem (of forest mensuration) only fragmentarily, and it had to wait Huffel (1919) to find a text which represents a real study detailed and complete: the first 325 pages of the second volume of his masterly "Forest economics" are truly a modern treatise of forest mensuration).

A sample of books and textbooks on forest mensuration and other areas as forest management, statistics, forestry and biology which influenced its development are shown in the table 3.1.-1.

TABLE 3.1.-1. Selected books containing information on forest mensuration and other books which contributed to the development of this field

Year	Author(s)	Title	Publisher, place
		1. Books containing information on forest mensuration	
1764	Henri Louis Duhamel de Monceau	De l'Exploitation des Bois, ou, Moyens de Tirer un Parti Avantageaux des Taillis, Demi-Futaies, et Hautes-Futaies, et d'En Faire une Juste Estimation [The utilisation of woodlands, or ways to turn to advantage coppice, young high-forest, and high forest and make an accurate valuation]	H. L. Guerin and L. F. Delatour, Paris
1770	Guiot	Manuel Forestier et Portatif [Forester's manual and pocket book]	Paris
1791, 1815	Blanquart de Septfontaines	Encyclopédie méthodique. Forêts et bois; arbres et arbustes. Part 2. Methodes et tables pour la cubature de bois, par de Septfontaines and de Prony, 1815. [Forest encyclopedia. Part 2. Methods and tables for volume determination]	Paris
1859	A. Bouquet de la Grye	Guide du Forestier [The forester's guide]. 14th edn. 1947 entitled Technique Forestière [Practical forestry]	Paris
1889	Devarenné	Cubage, estimation … [Volume determination, evaluation …]	Chaumont
1890	A. Frochot	Guide théorique et practique de cubage et d'estimation des bois [Theoretical and practical guide on volume determination and estimation]	Paris, 3rd edn.
1904-1907	Gustav Huffel	Economie forestière.[Forest economics]	2nd edn. L. Laveur 1910-1927 Paris

TABLE 3.1.-1. (cont)

Year	Author(s)	Title	Publisher, place
1905	Berger, Levrault et al.	Cubage des bois sur pied and abattus manuel pratique [Standing and cut tree volume determination. Handbook]	Paris
1919	Gustav Huffel	Economie forestière Tome II [Forest economics vol. II]	2nd edn. La maison rustique Paris
1924	Gustav Huffel	Economie forestière, II Dendrométrie. [Forest economics, II, Forest mensuration].	Paris
1930	A. Schaeffer, A. D'Alverny, A. Gazin	Sapinières. La jardinage par contenance. [Fir forests. Selection system]	Les Presses Universitaires de France, Paris
1956	P. Chaudé, E. Decesse	Barème de cubage des bois en grumes d'ouvre, bois d'industrie, bois de mine. [Standard norms for saw logs, industrial wood and mining timber]	Le Bois, Paris
1958	P. Chaudé	Tarif de cubage à décroissance variables pour les arbres sur pied [Tariffs for standing trees with variable taper]	Paris
1960	A. Adrian	Barème forestier [Forestry standard norms]	Berger-Levrault, Paris
1961	J. Pardé	Dendrométrie	L'Ecole Nationale des Eaux et de Forêts, Nancy
1971	P. Duvigneaud (ed.)	Productivity of Forest Ecosystems. Proceedings of a symposium, Brussels Oct. 1969 (Core monograph)	Paris, UNESCO
1981	Pierre Duplat Georges Perrotte	Inventaire et estimation de l'accroissement de peuplements forestiers	Office National des Forêts
1983	INRA	Mesures des biomasses et des accroissement forestiers. Orleans 3-7 Octobre 1983. [Biomass and forest growth measurements]	Ed. INRA Publ.
1988	J. Pardé J. Bouchon	Déndrométrie. [Forest mensuration].	ENGREF, Nancy, 2nd edn.
		2. Books on forest management containing information on forest mensuration. Books on statistics and nomography	
1792	P. C. M. Varennes de Fenille	Memoires sur l'Amenagement des Forêts Nationales, sur l'Administration Forestière, sur les Qualités Individual des Bois Indigènes … [Reports on the management of the national forests, on forest administration, on the individual characteristics of the timber of native trees].	Paris, 2nd edn. 1808 A. I. Marchant.

TABLE 3.1.-1. (cont)

Year	Author(s)	Title	Publisher, place
1790	J. B. Bridel	Manuel Practique du Forestier: Ouvrage dans lequel on traite de l' Estimation, Exploitation, Conservation, Repeuplement, des Semise, Plantations des Forêts [The forester's practical handbook; a work dealing with forest valuation, utilisation, conservation, restocking, sowing and plantations]	
1858	Louis Tassy	Étude sur l'Amenagement des Forêts. [Studies in forest management]	J. Rothschild, Paris, 5th edn. 1887
1859	Henri Nanquette	Exploitation, Débit et Estimation de Bois. [Utilisation, conversion and valuation of woods]	Nancy, Raybois
1860	Henri Nanquette	Cours d'Aménagement des Forêts [Manual of Forest Management]	Bouchard-Huzard, Paris.
1865-1898	Adolphe Gurnaud	Cahier d'Aménagement sur la Forêt des Esperons [Manual of management for the application of the area method as used in Des Esperons Forest]	English edition 1953, Edinburgh
1874	Puton	L'aménagement des forêts [Forest management]	Paris, 2nd edn.
1879	Fallotte	Aménagement des forêts – Estimation. [Forest management – estimation]	Carcassonne
1885	Grandjean	La methode du contrôle de Gurnaud [Gurnaud's method of control]	Paris
1887	Adolphe Gurnaud	L'art forestier et le contrôle [Forestry art and the control]	Besançon
1888	Reuss	Cours d'aménagement professé a l'Ecole forestiere (1885-1886) 2 cahiers [Management course at the Forestry School, 2 vol.]	Nancy
1888	Puton	Traité d'économie forestiére [Treatise on forest economics]	Paris
1890	Adolphe Gurnaud	La méthode du contrôle á l'Exposition de 1889 [The control method at the 1889 exhibition]	Paris
1891	Puton	Traité d'économie forestiére. Amenagement [Treatise on forest economics. Management]	Paris
1894	Bizot de Jontez	Estimations et exploitabilités forestières [Estimation and rotation in forestry]	Gray, Paris
1898	F. De Liocourt	De l'amenagement des sapiniéres [Management of fir forests]	Besançon

TABLE 3.1.-1. (cont)

Year	Author(s)	Title	Publisher, place
1906	Broilard	Mathématique et nature [Mathematics and nature]	Besançon
1934	G. Darmois	Statistique et ses applications [Statistics and its applications]	Paris
1935	V. Voltera U. D'Ancona	Les associations biologiques au point de vue mathematique [Biological associations from mathematical point of view]	Paris
1936	P. Chaudé	Traité practique et théorique des estimations [Practical and theoretical treatise on estimation]	Paris
1937	Y. A. Kostitzin	Biologie mathematique [Mathematical biology]	Paris
1940	E. Borel R. Deltheil	Probabilités, Erreurs [Probability, Errors]	Paris
1946	M. Frechet H. Roulet	Nomographie [Alignment charts]	Collection Armand Colin, Paris
1946	H. Perrin	Etudes statistiques sur les taillis sous-futaie [Statistical studies on coppice and middle high forest]	Annales E.N.E.F. Nancy
1947	R. A. Fisher	Les methodes statistiques adaptées à la recherche scientifique [Statistical methods adapted to scientific research]	Presses Universitaires de France
1950	M. Fréchét	Généralités sur les probabilities. Eléments aleatoires [General consideration on probabilities. Aleatory elements]	Gauthier-Villars Paris
1950	A. Vesereau	La statistique [Statistics]	Press Univ. de France
1953	L. Brenac L. Schaeffer	La méthode statistique et ses applications en matière forestière [Statistical method and its applications in forestry]	Rev. For. Fr. agoût numéro spécial
1964, 1970	Office National de Forêts	Manuel d'aménagement [Management textbook]	ONF Paris
1997	J. Dubourdieu	Manuel d'aménagement forestier. Gestion durable et integrée des écosystèmes forestiers [Management textbook …]	ONF Paris
3. Books on sylviculture, biology, forestry and other disciplines which contributed to the development of forest mensuration			
1755	H. L. Duhamel de Monceau	Traité des Arbres et Arbustes l'On Cultive en France en Plaine Terre [Treatise on trees and shrubs cultivated in France]	Michel, Paris German version 1763 Nürnberg

TABLE 3.1.-1. (cont)

Year	Author(s)	Title	Publisher, place
1837	Bernard Lorentz A. L. F. Parade	Cours Élémentaire de culture des Bois [Elementary course on the cultivation of woods]	5th ed. 1867, B. Lorentz and Parade and Nauquette; 6th ed. 1882, Paris
1893	G. Huffel	Les arbres et les peuplement forestiers [Trees and forest stands]	Paris
1894	Broilard	Le traitement des bois en France [Treatment of forest in France]	Paris
1907	Demorlaine	Aide mémoire du forestier-sylviculture [Ready-reckoner of forester – sylviculture]	Besançon
1924	P. Caziot	Expertises rurales et forestières [Rural and forestry survey]	Paris
1957	J. Pourtet	La culture du peuplier [Poplar's cultivation]. (Contains volume tables)	Baillière et fils – Paris 2nd edn. 1961.
1961 (7th edn.)	Societé Forestière de Franche Comté et des Provinces de l'Est	Vade-mecum du forestier [Forester's handbook]	La Maison Rustique, Paris
1965	R. Tomassone	L'analyse des components principales [Analysis of main components]	Station de Biométrie (SB) Nancy
1967	R. Tomassone	Analyse factorielle à trois facteurs contrôles [Factorial analysis of three factors]	S.B. Nancy
1967	R. Tomassone	Analyse des composantes principales et régression orthogonale [Analysis of the principal components and regression orthogonal]	S.B. Nancy
1973	M. Guinochet	Phytosociologie [Phytosociology].	Masson, Paris
1976	F. Cailliez J. P. Pages	Introduction à l'analyse des données [Introduction into data analysis]	S.M.A.S.H. Paris
1980	E. Z.	Étude des exigences stationnelles, des performances de croisance et de la qualité du bois de Chêne rouge d'Amérique et de l'Érable sycomore en Alsace [Study on site exigencies and growth performances and wood quality of the American red oak and maple in Alsace]	ENITEF Strasbourg
1981	E. Teissier du Cros (coordinator)	Le Hêtre. Monographie [Beech. Monograph]	INRA Paris

TABLE 3.1.-1. (cont)

Year	Author(s)	Title	Publisher, place
1983	Societé Forestière de Franche Comté et des Provinces de l'Est	Vade-mecum du forestier [Forester's Ready-reckoner]	Paris La Maison Rustique
1984	Cicéron Rotaru	Les interactions entre les methodes d'exploitation et la sylviculture [Interactions between the logging methods and sylviculture]	Centre Tech. Du Bois (CTBA) Paris. Reprinted in 1990
1989	E. Dreyer et al. (eds.)	Forest Tree Physiology (A core monograph)	Edtions Scientifiques Elsevier
1993, 1994	Cicéron Rotaru et al.	Manuel d'exploitation forestière. Tome I (1993) and Tome II (1994) [Manual on tree logging]	ARMED-CTBA-IDF Paris

In the field of forest mensuration, except for Duhamel de Monceau's works should be mentioned: Guiot's (1770) forester's manual, in spite of the fact that "… of whom little appears to have been recorded, except that the title page termed him a "garde-marteau" in the "Forêt de Rambouillet". The title page also states that the book is taken to a large extent from the work written by M. Duhamel de Monceau. The first part describes "sixty-seven species of trees and shrubs, growing in the royal forest, the second deals with sowing and planting, forest management, amnety planting in parks, marking standards, valuations, sales, utilisation and forest inventories" (James 1996, p. 27); Septfontaines' (1815) volume tables; Bouquet's (1859) foresters guide may be considered as one of the most successful French books (14^{th} edition in 1947); Frochot's (1890) guide for wood volume determination; the second volume of Huffel's "Économie forestière" (1919, 1924) that covered forest mensuration, production and valuation; Schaefer's et al. (1930) fir forests and selection system with information on the structure of uneven-aged forests; Chaudé and Decess's (1956) standard norms for saw logs; Chandé's (1958) tariffs for determination of standing trees volume; and excellent forest mensuration books written by Pardé (1961) and Pardé and Bouchon (1988). Both books are structured in five chapters: (1) Mathematical and statistical notions necessary for forest mensuration, (2) Measurement of trees, (3) Forest stands, (4) Growth measurement of trees and stands, (5) Aerial photography and forest mensuration.

According to Huffel (1919) "La Dendrométrie" learns us to determine the volume of the forest products.

Pardé (1961, p. 5) detailed the meaning of "dendrométrie": (1) it has as first object the measurement of the dimensions of the trees, study of their form and estimation of their volume; (2) the second stage – which results from the first – refers to the establishment of the methods that make possible the estimation of stand volume; (3) it has to establish the means and computations for growth determination of trees and stands.

Among numerous French forest management textbooks which contain data on forest trees and stands it will be mentioned the following texts written by: Tassy (1858), Nanquette (1860), Gurnaud (1865-1898 "Cahier d'Aménagement …"), Puton 1891, and the "Manuel d'aménagement" completed by Jean Dubourdieu and edited in 1997 by the Office National des Forêts.

In the field of statistics and nomography (alignment charts) should be remembered the works of Frechet and Roulet (1946), Perrin (1946), Fischer (1947), Brenac and Schaeffer (1953), Tomassone (1965, 1967 a, 1967 b), and Cailliez and Pages (1976).

In the field of sylviculture and biology the following works are worth mentioning: the first volume of Duhamel de Monceau (1755), "Traité des Arbres et arbustes que l'on cultive en France" (Treatise on trees and shrubs that can be grown in France) published in 1800 after the previous works of Duhamel de Monceau, named also "Nouveau Duhamel" (The New Duhamel) edited by F. Michel, Lorentz and Parade's (1837) an elementary course on the cultivation of woods ("Cours Elementaire de Culture des Bois"), considered by Kitchingman (1952) as the most important book on French sylviculture written in 19th century, "Vademecum du forestier" (Forester's handbook) the 7th edition (1961) and the 10th in 1983, Guinochet's phytosociology (1973), Zahnd (1980) exigency to site of some species, the INRA (1981) remarkable monograph on beech, and a forest tree physiology (1989) – a core monograph edited by Dryer et al. in English and French.

Remarkable short summaries on French forest literature, in which some important texts on French mensuration are included, were completed by Kitchingman (1952) and James (1996).

As regards English, German and French early forest writers an interesting remark of James is worth mentioning: "The authors (English authors – our note) of such books differ noticeably from the German and French contemporaries since their interests covered a much wider background. In Germany, authors were usually professional foresters, or professors, on the staff of academic institutions. Writers in France tended to be private landowners or simply those who were interested in forests until after the founding in 1824 of L'École Nationale when they were largely members of the school. In contrast, in the British Isles, authors might be connected with the royal forests, be landowners, writers on agriculture and rural matters in general, land agents (managers of land estates), or foresters." (James 1996, p. 34).

Cited authors:

(1) Forest mensuration: Adrian 1960, Berger 1905, Bouquet 1859, Chaudé 1958, Chaudé and Decesse 1956, Devarenne 1889, Duhamel de Monceau 1764, Duplat and Perrotte 1981, Davidneaud (ed.) 1971, Frochot 1980, Guiot 1770, Huffel 1904-1907, 1919, 1924; INRA 1983, Pardé 1961, Pardé and Bouchon 1988, Schaefer et al. 1930, Septfontaines. 1815 (1791).

(2) Forest management, statistics, alignment charts: Bizot de Jontenz 1894, Brenac and Schaeffer 1953, Bridel 1790, Chaudé 1936, Dubordieu 1997, Fallotte 1879, Fischer 1947, Frechet and Roulet 1946, Gurnaud 1865-1898, 1885, 1887, 1890; Liocourt, De 1898, Nanquette 1859, 1860; Office National des Forets 1964, 1970; Perrin 1946, Puton 1874, 1888, 1891; Reuss 1888, Tassy 1858, 1887; Varennes de Fenille 1792.

(3) Other fields: Borel and Deltheil 1940, Broillard 1894, 1906; Cailliez and Pages 1976, Caziot 1924, Darmois 1934, Demorlaine 1907, Dreyer 1989, Duhamel de Monceau 1763, 1800-1819; Fréchet 1950, Froidour 1668, 1665; Guinochet 1973, Huffel 1893, INRA, 1981, James (U.K.) 1996, Kitchingman (U.K.) 1952, Kostitzin 1937, Lorentz and Parade 1837, Pourtet 1957, 1961; Societé Forestière de Franche Comteé et des Provinces de l'Est 1961, 1983; Tomassone 1965, 1967 a, 1967 b; Vesereau 1950, Voltera and D'Ancona 1935, Zahnd 1980.

3.2. Measurement of trees and primary products. Instruments

According to Huffel (1919), as far as it can be remembered, fuel wood was cut in pieces having an uniform length and arranged in stack containing about a cord which had a volume close to tree steres.

Tree volume was estimated only after felling, and as a rule logs were squared. In 1691, the monks from l'abbaye Cîteaux sold all their standing oak trees adequate to navy and the price was established per standing trees. Selling based on volume appeared in 1747 (Huffel 1919).

For volume estimation in France was used (at least before 1600) a formula called "cubage au cinquième":

$$v = 2l\left(\frac{c}{5}\right)^2$$

where c is the girth at the middle of the log and l is its length, but only in the 18th century logs have been considered by itself and Septfontaines (1791) recommended for log volume calculation the measurement of the terminal sections and the multiplication of mean area of these sections by the log length.

The decimal system (metric system) was adopted in France on November, the 14th 1800, but its application was not facile and the old measure of measurement (steres) was tolerated till the 1st of January 1840.

In 1812, Herbin de Halle was the first who published a "Traité de Cubage de

Bois" (Treatise on volume determination of wood) based on the metric system, but some years the metric system was rejected.

Since the beginning of the 19th century the books on log volume determination and tariffs became more frequent and volume estimation refers in general to logs and was based on product of the middle section and length. During this period the first attempts of volume determination of standing trees appeared.

Huffel (1919) underlined that the girth was always measured and never the diameter. In Duhamel's treatise (1764) there is no mention on a proper device to measure diameters, but Varenne de Fenille (1790, 1792) used a curved and graded caliper for diameter measurements: "un compas courbe graduée pour mesurer les diamètres" (Tome II, 1805 edn., p. 229). Calipers became common after 1820-1830 but girth remains as a preferred measurement. Concerning height determination Huffel (1919) mentioned the existence in France, at the beginning of the 20th century, of more than 40 hypsometers (dendromèters in French) based on different principles: geometrical (similar triangles, right isosceles triangles) or trigonometrical. A hypsometer of French origine was described by Duhamel de Monceau in 1764 ("dendromètre à perpendicule") but it was considered to be less practical. The Christen hypsometer, constructed in 1891, in Switzerland (Pardé 1961, p. 95), was used in France on a large scale. Monceau proposed a "canne dendrométrique" (Revue des Eaux et Forêts 1882, p. 250) whereas the Stanlaville hypsometer was completed earlier, in 1842 (Pardé 1961, p. 94).

In the area of log volume estimation there will be mentioned the works of Frochot (1887), Francon (1889), Prezmeaux (1889), Frochot (1890), Cordoin (1899), Berger et al. (1905), "Cubage des grumes d'ouvre" (Volume determination of logs) edited by l'Association Française de Normes (AFNOR) in 1945 (NF B 53-015), and "Cubage des bois d'industrie et des bois de feu" (Volume determination of industrial wood and fuel wood) published also by AFNOR in 1952 (NF B 53-018). A little earlier Roussel (1947) proposed the determination of stem volume by using graphical procedures.

Many editions of forest norms (standards, including logs) have been published by Adrian (to mention only the 1950 and 1976 edn.) standards for wood and logs were published later by the Office National des Forêts (1980), Claudé and Decesse (1983) and Normand (1983).

Bitterlich relascope for basal area of stand and tree height determination has been used in France since 1955 (Barrault 1955, Pardé 1955, 1956 and Viney 1956) – with some critical observations on this method. A new French hypsometer named l'altamètre was described in 1959 by Pardé.

Ravart (1981) presented a description of the Wheeler pentaprism caliper for measuring diameters of standing trees and its use in conjunction with a Suunto clinometer. In the same year he described Bitterlich's "Tele-Relascop" and its use to measure height and diameters of standing trees. Ravart (1982) presented also a description of the Suunto PM-5/1520 P hypsometer (and its versions), its use for measuring heights of standing trees, slopes and plot areas.

Cited authors:

Adrian 1950, 1976; Barrault 1955, Berger et al. 1905, Claudé and Decesse 1983, Cordoin 1899, Duhamel de Monceau 1764, Francon 1889, France (AFNOR) 1945, 1952, Frochot 1887, 1890; Herbin de Halle 1812, Huffel 1919, Normand 1983, Office National des Forêts 1980, Pardé 1955, 1956, 1961; Prezneaux 1889, Ravart 1981 a, 1981 b, 1982; Roussel 1947, Varenne de Fenille 1792, Viney 1956.

3.3. Tree volume tables

Towards the end of the 19th century, in 1899, De Montrichard published a note on the rule for tree volume determination.

In 1894, Henri Algan (1855-1923) "Inspecteur des Eaux et Forêts" in eastern France published (in November) in "Revue des Eaux et Forêts the essence of his paper on (the well-known and used a long time and on large scale) special tariffs, "Algan's tariffs". Detailed tariffs were printed in 1901 in BSFFC and Revue Forestière Française (RFF) under the title "Tarifs unifiés", and in 1902 in the "Bulletin Soc. For. Franche Comté" (BSFFC) under the title "Tarifs de cubage". In 1995, Pardé commemorated Algan's remarkable contribution in Revue Forestière Francaise (47, 1, p. 89-93): "Il y a 100 ans: la naissance de tarifs Algan" (One hundred years since the origin of Algan volume tables).

After numerous measurements of trees grown in resinous stands, Algan observed that in this type of forests a tree increased its volume ten times when its diameter (dbh) increased from: 20 to 50 cm, 25 to 65 cm, 30 to 80 cm and increased five times when its dbh increased from 35 to 70 cm, increased its volume when dbh increased from 60 to 100 cm and it became twice as great when dbh increased from:

20 to 25 cm
30 to 40 cm
45 to 60 cm
65 to 90 cm

These relations being accepted by Algan, he established 20 tariffs noted from 1 to 20 in such a way that from one tariff to the next, the volume of a tree having a dbh of 45 cm increased with one dm^3:

No. of tariff	1	2	3	……18	19	20
V_{45}	0.9	1.0	1.1	……2.6	2.7	2.8

These tariffs for different diameters are presented in table 3.3-1 in which Pardé (1961) introduced, only for orientation, the average approximate height of the tree (the second line represents the total tree volume). On the other hand, we note that between the tariff number N and the volume of the tree having 45 cm dbh, there is the relationship $IOV_{45} = N + 8$ that makes possible to choose the tariff to be applied if the average volume of the tree having 45 cm dbh is known as a result of some volume determinations. In the case of fir and spruce the relation $V_{50} = H/10$ is usually accepted, V_{50} being the volume of a tree with dbh 50 cm and H its height. For beech, to choose the tariff it is indicated the Bouvard's formula using the H of a 45 cm dbh tree: $V = 0.5\ D^2H$ that is equal with $V_{45} = H/10$, or the general rule: the number of tariff is equal with the total height in meters of a beech having 45 cm dbh minus 8. For larch it is applied a similar relation which shows that the average volume of a tree with 55 cm dbh is represented by H/10. The tables are used as follows: "(1) Caliper the entire forest according to diameters and species. (2) Measure a number of type trees, selected at random, after felling them. (3) Find that volume table amongst the 20 tables given which correspond best with the diameters and volumes of the type trees. Apply the volume table, which is found to be proper one, to all diameter classes calipered in the woods" (Schenk 1905, p. 44).

Two things should be noted: (1) Algan's tariffs show by construction the total volume of a tree, but may be used, after an adaptation, for the determination of "bois fort" (top diameter > 7 cm) and (2) they are not based on a mathematical relation and present irregularities, and for this reason were improved later by Schaeffer in 1949 by the introduction of the "Tarifs rapides" and "Tarifs lents" (rapid tariffs and slow tariffs) in which taper is taken into account.

Algan proposed also a formula for a quick determination of tree volume (V):

$$v = 0.33\ D^2h \qquad \text{where } D = \text{dbh and } h = \text{total tree height}$$

Other Algan's expeditive formulas can be found in Pardé's (1961) excellent forest mensuration and in "Vade mecum du forestier" (1961) by "Société Forestiere de Franche Comté.

Algan's volume tables (tariffs) were known in India (Indian Forester of July 1902) and Australia (Algan 1902) and translated into the British system.

In the United States, Schenk (1905) strongly criticized the "so-called universal volume tables". Schenk (1905, p. 34) named Algan "Algon, a Frenchman" and formulated the following objections to Algan's method:

"a. The danger of mistakes is very great. In an absolutely even-aged wood, one tree of 15 inches diameter may easily show 50 % more volume than another tree of the same diameter, the latter being more tapering and shorter.

TABLE 3.3.-1. Algan's tariffs; SOURCE: Algan 1901 amended by Pardé 1961, p. 337 Dendrométrie

(Each cell: height in m. / volume in mc.)

DIAMÈTRE à 1 m. 30 du sol (m.)	N° 1	N° 2	N° 3	N° 4	N° 5	N° 6	N° 7	N° 8	N° 9	N° 10
0,20	4 / 0.1	5 / 0.1	5 / 0.1	6 / 0.15	7 / 0.15	8 / 0.15	9 / 0.2	9 / 0.2	10 / 0.2	11 / 0.2
0,25	6 / 0.2	7 / 0.2	8 / 0.2	9 / 0.3	10 / 0.3	11 / 0.3	12 / 0,4	12 / 0,4	13 / 0.4	14 / 0,4
0,30	8 / 0.3	9 / 0.4	10 / 0.4	11 / 0,5	12 / 0,5	13 / 0.5	14 / 0,6	14 / 0,6	15 / 0,6	16 / 0,7
0,35	9 / 0,5	10 / 0,6	11 / 0,6	12 / 0,7	13 / 0,7	14 / 0,8	16 / 0,9	16 / 0.9	17 / 0,9	18 / 1,0
0,40	10 / 0,7	11 / 0,8	12 / 0,8	13 / 0,9	14 / 1,0	15 / 1,1	17 / 1,2	18 / 1,2	19 / 1,3	20 / 1,4
0,45	10 / 0,9	12 / 1,0	13 / 1,1	14 / 1,2	15 / 1,3	16 / 1,4	18 / 1,5	20 / 1,6	21 / 1,7	22 / 1,8
0,50	11 / 1,2	13 / 1,3	14 / 1,4	15 / 1,6	16 / 1,7	17 / 1,8	19 / 1,9	21 / 2,1	22 / 2,2	23 / 2,3
0,55	11 / 1,5	13 / 1,6	14 / 1,8	15 / 2,0	17 / 2,1	18 / 2,3	20 / 2,4	21 / 2,6	22 / 2,8	24 / 2,9
0,60	12 / 1,8	14 / 2,0	15 / 2,2	16 / 2,4	18 / 2,6	19 / 2,8	20 / 3,0	22 / 3,2	23 / 3.4	24 / 3,6
0,65	12 / 2.1	14 / 2.4	15 / 2,6	16 / 2.9	18 / 3,1	19 / 3.4	21 / 3.6	22 / 3.8	23 / 4,1	25 / 4,3
0,70	12 / 2,5	14 / 2,8	15 / 3.1	16 / 3,4	18 / 3,7	19 / 4.0	21 / 4.2	22 / 4.5	23 / 4,8	25 / 5,1
0,75	13 / 2.9	15 / 3.2	16 / 3,6	17 / 3,9	19 / 4,3	20 / 4,6	21 / 4,9	23 / 5.2	24 / 5,6	25 / 5,9
0,80	13 / 3.3	15 / 3,7	16 / 4.1	17 / 4,5	19 / 4,9	20 / 5,3	21 / 5.6	23 / 6,0	24 / 6,4	25 / 6,7
0,85	13 / 3.8	15 / 4,2	16 / 4.7	17 / 5.1	19 / 5,6	20 / 6,0	22 / 6.4	25 / 7·0	24 / 7.2	26 / 7,6
0,90	13 / 4,3	15 / 4,8	16 / 5,3	17 / 5,8	19 / 6,3	20 / 6,8	22 / 7.2	23 / 7,7	25 / 8,1	26 / 8,6
0,95	14 / 4,8	16 / 5,4	17 / 5,9	18 / 6,5	20 / 7.0	21 / 7.6	22 / 8,1	24 / 8,6	25 / 9,1	26 / 9,7
1,00	14 / 5.4	16 / 6.0	17 / 6,6	18 / 7,2	20 / 7,8	21 / 8,4	22 / 9.0	24 / 9,6	25 / 10.2	26 / 10,8

DIAMÈTRE à 1 m. 30 du sol (m.)	N° 11	N° 12	N° 13	N° 14	N° 15	N° 16	N° 17	N° 18	N° 19	N° 20
0,20	12 / 0.2	13 / 0.25	13 / 0.25	14 / 0.25	15 / 0,3	16 / 0,3	16 / 0,3	17 / 0,3	18 / 0,3	19 / 0,4
0,25	15 / 0,4	16 / 0,5	16 / 0.5	17 / 0,5	18 / 0,6	19 / 0,6	20 / 0,6	21 / 0,6	22 / 0,6	23 / 0,7
0,30	17 / 0,7	18 / 0,8	19 / 0,8	20 / 0,8	21 / 0,9	22 / 0,9	23 / 1,0	24 / 1 0	25 / 1,0	26 / 1,1
0,35	19 / 1.0	20 / 1,1	21 / 1.2	22 / 1,2	23 / 1,3	24 / 1,3	25 / 1,4	26 / 1,5	27 / 1,5	28 / 1,6
0,40	21 / 1,4	22 / 1,5	23 / 1,6	24 / 1,7	25 / 1,8	26 / 1,8	27 / 1,9	28 / 2,0	29 / 2,1	30 / 2,2
0,45	23 / 1,9	24 / 2,0	25 / 2,1	26 / 2,2	27 / 2,3	28 / 2,4	29 / 2,5	30 / 2,6	31 / 2,7	32 / 2,8
0,50	24 / 2,5	26 / 2,6	27 / 2,7	28 / 2,8	29 / 3,0	30 / 3,1	31 / 3,2	32 / 3,3	33 / 3,5	34 / 3,6
0,55	25 / 3,1	26 / 3.3	27 / 3,4	28 / 3,6	30 / 3,8	31 / 3,9	32 / 4,0	33 / 4,2	34 / 4,4	35 / 4,5
0,60	26 / 3,8	27 / 4,0	28 / 4.2	29 / 4.4	30 / 4,6	32 / 4,8	33 / 5,0	34 / 5,2	35 / 5,4	36 / 5.6
0,65	26 / 4,5	27 / 4,8	28 / 5,0	29 / 5,3	31 / 5,5	32 / 5,8	34 / 6,0	35 / 6,2	36 / 6,5	37 / 6,7
0,70	26 / 5,3	28 / 5,6	29 / 5,9	30 / 6,2	31 / 6,5	33 / 6,8	34 / 7,1	36 / 7,3	37 / 7,6	38 / 7,9
0,75	27 / 6,2	28 / 6,5	29 / 6,9	30 / 7,2	32 / 7,6	33 / 7,9	35 / 8,2	36 / 8,5	37 / 8,8	38 / 9,2
0,80	27 / 7,1	29 / 7,5	30 / 7,9	31 / 8,3	32 / 8,7	34 / 9,1	35 / 9,4	37 / 9,8	38 / 10,1	39 / 10,5
0,85	27 / 8,1	29 / 8,5	30 / 9.0	31 / 9,4	32 / 9,9	34 / 10,3	35 / 10,7	37 / 11,1	38 / 11,5	39 / 12,0
0,90	27 / 9,1	29 / 9,6	30 / 10.1	31 / 10,6	33 / 11,1	34 / 11,6	36 / 12,1	37 / 12,5	38 / 13,0	39 / 13,5
0,95	28 / 10.2	29 / 10,8	30 / 11,3	32 / 11,9	33 / 12,4	34 / 13,0	36 / 13,5	37 / 14,0	39 / 14,6	40 / 15,1
1,00	28 / 11,4	29 / 12,0	30 / 12,6	32 / 13,2	33 / 13,8	34 / 14,4	36 / 15,0	37 / 15 6	39 / 16,2	40 / 16,8

b. In an uneven-aged wood the tables are necessarily wrong because the form height is a function of age as well of height and diameter.

c. The method does not give any idea of the proportion of logs, fuel, bark, etc.

Algon calls these tables "universal", assuming that they hold good for all species of the universe" (Schenk 1905, p. 34).

Huffel (1919) noted that the early tariffs (one-entry volume tables) were constructed by the graphical method. Such a type of early one-entry (circumference) local tables (tariffs) is shown in figure 3.3.-1., where volumes are located on a logarithmical scale.

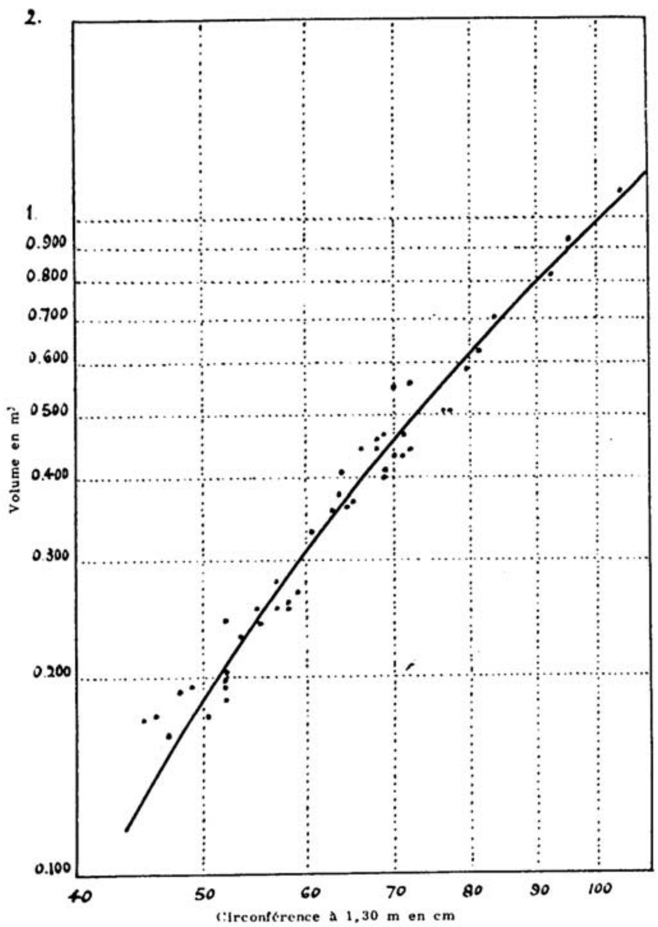


Fig. 3.3.-1. Tariff for an experi mental plot for fir, constructed by graphical method. SOURCE: Pardé 1961, p. 140, fig. 67, Dendrométrie

After 1930 single-entry volume tables and later two-entry volume tables were invariably based on regression analyses which, as it is known, produce a closer fit over the entire domain.

Since the 1930s the method of correlation has been applied for tariffs construction: Schaeffer (1932), Souloumiac (1947), Ayral (1954), Abadié (1956). In spite of the development of statistical methods, graphical techniques have not been rejected for a time; this is the case of Roussell who presented in 1947 a graphical procedure for the determination of tree stems, and the Association Française de Normalisation (AFNOR) established standard norms for volume determination of standing trees (NF 53 017).

In France and Switzerland one-entry volume have been used based on conventional units called *silvae*, applied only in the situation in which the tariffs were constructed for stands having similar structures and site conditions, and if such a table is applied to other uneven-aged forest types, the differences may overtake ± 20 % and in order to avoid this inconvenient the tariffs have been constructed in conventional units.

The following conventional units for uneven-aged stands after Schaffer (1949) are given as an example:

Dbh cm	Volume in silvae	Dbh cm	volume in silvae
15	0.136	55	2.989
20	0.270	60	3.603
25	0.452	65	4.259
30	0.686	70	4.953
35	1.016	75	5.081
40	1.429	80	6.440
45	1.898	85	7.225
50	2.419	90	8.033

In order to improve Algan's tariffs, Schaeffer (1949) constructed, rapid tariffs ("tarifs rapides") and slow tariff ("tarifs lents") depending on stem taper.

Rapid tariffs are based on the relation:

$$V = \frac{M}{1400}(D-5)(D-10)$$

where V = volume in m^3, D = diameter at 1.50 m in centimeters, M = volume of the tree having 45 cm diameter (dbh) expressed in cubic meters. In case of girth measurement (c) the above-mentioned formula becomes:

$$V = \frac{M}{1400\pi^2}(C-S\pi)(C-10\pi)$$

and the establishment of tariff number is made as previously explained.
and slow tariffs (better site conditions) the equation is the following:

$$V = \frac{M}{1800} \cdot D\left(D-5\right)$$

Slow tariffs are used especially in uniform stands and environmental conditions, and for choosing the tariff number it is necessary to take into account the stand age or average diameter (or girth) of the stand. In the same case the tariffs changed in time.

The comparison of the rapid tariffs and slowtariffs, represented by their parabolic functions is shown in figure 3.3.-2.

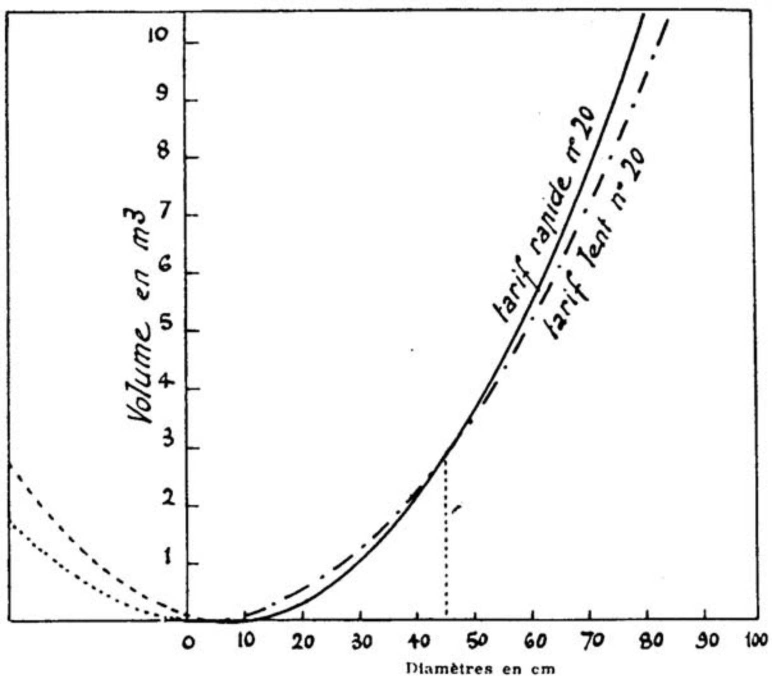


Fig. 3.3.-2. Comparison of parabolic functions of tariff rapid and tariffs slow (lent).
SOURCE: Pardé 1961, p. 144, fig. 68, Dendrométrie

Tariffs rapid and tariffs slow have been published in "Vade-mecum du Forestier" since the 1951 edition. In Poland, Emrovič (1957) constructed an alignment chart for Algan-Schaeffer tariffs (rapid and slow).

As far as we know, the first set ("Gammes") of French double-entry volume tables was published by Schaeffer in 1948 and 1950, followed in 1951 by tables issued by "l'Administration des Eaux et Forêts" – ANFOR NT B 53017 called "Tarifs de l'Administration". A sample of these tariffs is given in table 3.3.-2.

TABLE 3.3.-2. Excerpt from ANFOR NT B 53017 volume table de l'administration A 1
SOURCE: Tarif de l'administration A 1, 1951, reprinted after Pardé 1961, p. 157/158

	Diamètre à 1^m,30 du sol					
Diamètre..	0^m,30	0^m,35	0^m,40	0^m,45	0^m,50	Diamètre
Hauteur	6	7	8	9	10	Hauteur
mètres	m^3	m^3	m^3	m^3	m^3	mètres
3	0.209	0.285	0.373	0.473	0.584	3
4	0.270	0.370	0.485	0.617	0.764	4
5	0.326	0.449	0.591	0.753	0.395	5
6	0.377	0.523	0.691	0.884	1.099	6
7	0.425	0.591	0.786	1.007	1.256	7
8	0.468	0.656	0.874	1.124	1.406	8
9	0.508	0.715	0.957	1.235	1.548	9
10	0.543	0.769	1.035	1.340	1.684	10
11	0.575	0.820	1.107	1.438	1.812	11
12	0.603	0.865	1.174	1.531	1.934	12
13	0.628	0.907	1.236	1.617	2.049	13
14	0.649	0.944	1.294	1.698	2.158	14
15	0.667	0.977	1.346	1.774	2.260	15
16	0.682	1.006	1.396	1.843	2.356	16
17	0.694	1.032	1.436	1.908	2.446	17
18	0.703	1.054	1.475	1.967	2.530	18
19	0.709	1.072	1.509	2.021	2.607	19
20	0.713	1.087	1.539	2.070	2.679	20
21	0.714	1.098	1.565	2.114	2.746	21
22	-------	1.106	1.586	2.153	2.806	22
23	-------	1.111	1.604	2.188	2.861	23
24	-------	1.113	1.618	2.218	2.911	24
25	-------	-------	1.629	2.243	2.956	25
26	-------	-------	1.635	2.264	2.995	26
27	-------	-------	1.639	2.281	3.030	27
28	-------	-------	1.639	2.294	3.060	28
29	-------	-------	-------	2.303	3.084	29
30	-------	-------	-------	2.308	3.115	30
31	-------	-------	-------	2.310	3.120	31
32	-------	-------	-------	-------	3.132	32
Diamètre	0^m,30	0^m,35	0^m,40	0^m,45	0^m,50	Diamètre
	6	7	8	9	10	

Note: il s'agit non pas de la hauteur totale, mais de la hauteur à la découpe choisie (height is from the ground to chosen point at the stem)

Schaeffer (1950) established ten pairs (dix barêms de cubage) of two-entry volume tables, ten for diameter and ten for girth (not as Chaudé's tariffs using metric taper) based on the coefficient of decreasing ("coefficient de décroissance") r:

$$r = \frac{girth\ at\ the\ middle\ of\ stem}{measured\ girth}\ which\ is\ in\ fact = \frac{diameter\ at\ the\ middle\ of\ stem}{measured\ diameter}$$

r is a variable value: r = f [length (height), girth, species, site and management]. Schaeffer summarized the combinated action of these factors using a general formula:

$$\mathrm{r} = \frac{a - bh - k\,c}{100} \quad \mathrm{or} = \frac{a - bh - kd}{100}$$

where h = length of stem or log

a, b, k, k' = convenient number established according to species and forest type (see Schaeffer 1950 or Pardé 1961, p. 160).

c = girth of the height of man

(d = diameter) b determine rapidity of the r decreasing depending of height or length of stem.

k = equal to zero in all cases except for two.

Schaeffer's volume tables are included also in the textbook by Adrian (1950, 1960 p. 205-234 and 1976 text).

"Tarifs de l'Administration" were transformed in modern alignment charts by Gay (reference by Pardé 1961) which gave on the spot a graphic determination (estimation) of the curves of trees having intermediate values of taper located between the type values determined by "Direction Génerale de Eaux et Forêts" (Direction General of Water and Forests).

The graphical methods of Huffel's period were improved by Ayral and Abadie (1956) who used statistical methods in the case of one-entry tables (tariffs). These modern tariffs are based on sampling and other statistical methods as equations. Abadie used the equation $v = a + bx^2$ where x = diameter at 1.50 m and *a* and *b* regression coefficients. Batias (1958) constructed a tariff based on general equation $v = a_0 + a_1x + a_2x^2 + a_3x^3$ (v = volume, x = diameter or girth and $a_0 \ldots a_3$ coefficients). Another tariff was constructed by Brenac (1958).

In the 1950s, in France, "tarifs Chaudé" were used frequently constructed by Chaude (available editions: 1958 and 1982) for a variable decreasing taper of standing trees (Tarif de cubage à décroisance variable pour les arbres sur pied"-352 pp.); 24 tariffs with variable tapering. No. 6 has the following characteristics:

girth at human height, cm	decreasing of girth per meter, cm
20-35	2
40-55	3
60-75	4 etc.

but the choosing of the tariff's number is not easy. According to Pardé (1961, p. 159) the tariffs no. 1 to 6 are convenient for conifers at higher altitude or dispersed, no. 7 to 14 are adequate for broad-leaved species in coppice, normal coniferous stands and poplar stands while no. 15 to 20 remain suitable for closed high forest (resinous or broad-leaved).

Special volume tables were constructed for poplar by Pourtet (1957, 1961 2nd edn.) and Bonduelle (1974), *Pinus maritima* by Lapasse (1958, improved in 1973) and Maugé (1961).

New standards for volume determination were published in 1960 (Eaux et Forêts series 4, no. 12). Pardé (1961) noted that the equation for tariffs $v = a + bx^2$ used in France was also preferred by Ditmar (1958) in Germany.

New standards for volume determination were published in 1960 (Eaux et Forêts serie 4, Nr. 12).

The method of taper equations for construction of volume tables was used for the first time in France in 1971 by Mendibourne for multi-entry tables (d, h, age). Tariffs were constructed by Bouchon (1974) who completed in 1982 two-entry volume tables for beech, by Bérard et al. (1983) for young Douglas-fir, by Duplat and Tran-Ha (1974), INRA (1974) and Luce (1976) for fir. Among other authors who constructed tariffs it should be mentioned Bartet and Guilloud-Bataille (1975), Duplat and Bolliet (1979 – for spruce in the southern part of the Massif Central), Goupil (1981 – Scots pine), Otoul and Rondeux 1988 (the first tariff constructed using a mini computer). In 1991, Courbet constructed volume tables for *Cedrus atlantica* (Manetti) which is a dominant species in about 11,000 ha of which 80 % of them located in Provence – Alpes – Côtes d'Azur and Languedoc-Roussilon regions (most of them are younger plantations).

Bouchon, Delord and Rousseau (1986) compared two methods of volume calculation: a detailed method used in French forestry research (diameter measured every meter) and the second, much used in the French national forest inventory (for a tree it was mentioned the diameter at 1.30 m and 2.60 m and at each main point where the shape changes and it is calculated the main "second" log – above 2.60 m – using Newton's formula). Both of these methods gave very similar results and the authors concluded that data of the National forest inventory database could be used to construct good one- or two-entry volume tables.

In 1994 Guinaudeau and Duplat proposed unique volume tables for Norway spruce.

In spite of the French experience in the construction of volume tables, the problem how to choose between constructing a new table or using an existing one, remains actual (Vallance 1995). Vallance discussed especially the difference between tree measurements made and estimation of standing or felled timber volume and finding that variation can be large with remarkable differences within stand and between regions. In Vallance's work there are listed the volume tables prepared by the Technical Research Department of the French National Forest Office (ONF) by species, type or cut (commercial felling, first thinning etc.) and volume (especially merchantable volume, but in the same cases crown and stem + branch volumes are included). Available tables refer almost to all species grown in France: *Carpinus* sp. *Quercus* spp., *Pseudotsuga menziesii*, *Picea abies, Fraxinus* sp., *Fagus sylvatica, Larix* sp., *Pinus mugo, P. pinaster, P. nigra, P. sylvestris, Abies alba*, except for *Cryptomeria* sp. and *Tamarix* sp. growing in Réunion.

The use of mean taper, tables and tariffs for the estimation of standing trees volume and problem of chosing a good method was discussed again in 1996 by Vautherin.

Cited authors:

Abadie and Ayral 1956, Adrian 1950, 1960, 1976; AFNOR 1945, 1951 a, 1951 b; Algan 1901a, 1901b, 1902; Ayral 1954, Bartet and Goilloud-Bataille 1975, Batias 1958, Bérard et al. 1983, Bonduelle 1974, Bouchon 1982, Bouchon et al. 1986, Brenac 1958, Bailliez and Pages 1976, Chaudé 1958, 1982, Chaudé and Decesse 1983, Courbet 1991, De Montrichard 1899, Dittmar 1958 – Germany, Duplat and Bolliet 1979, Duplat and Tran-Ha 1974, Emrovič 1957 – Poland, France 1960, Goupie 1981, Guinaudeau and Duplat 1994, Huffel 1919, INRA 1974, Lanly 1971, Lapasse 1958, 1973; Luce 1976, Maugé 1961, Mendiboure 1971, Normand 1983, Office National des Forêts 1980, Otoul and Rondeau 1988, Pardé 1961, 1995; Pourlet 1957, Roussel 1947, Schaeffer 1932, 1948, 1949, 1950; Schenk 1905, Soloumiac 1947, Vallance 1995, Vautherin 1996.

3.4. Tree growth

Earlier available works on determination of the diameter growth of trees were developed by Fonteny (1914) and Vaulot (1914).

In 1951, Lescafette proposed and analyzed the generating surface (sg), a property of the trees and of the stands that represents the cambium area of all trees. Annual increment of tree volume (dv) is given by the relation:

$$dv=sg \cdot dr \quad \text{and} \quad sg=dr/dv$$

where *dr* is the radial increment of annual ring (or rings). For example, if volume increment of a tree is 30 dm^3 and its ray increment (*dr*) is 3 mm, the generating surface sg = 0.030/0.003 = 30 m^2.

Lescafette constructed *sg* tables for 6-20 N_o Algan tariffs for determination of volume increment if radial increment at man height is determined.

A rapid method for increment determination was proposed by Schaeffer (1956).

Chatelain (1958) recommended a simple method for the estimation of radial increment and of time of passage to the next diameter category. He proposed to count *n* annual rings at a distance of 5 cm from bark. The ration 5/n represents the average annual radial increment for the trees of the immediately inferior diameter category.

Aussenac (1975) published in 1975 a study on the effect of temperature on growth of some coniferous species.

In 1981, Lemoine applied the factorial analysis for the determination of height growth of *Pinus maritima* trees.

The concepts and characteristics of various growth models were outlined by Bouchon (1995) considering principles, concepts and development of different models illustrated with reference to their use to describe and predict stem increment. Empirical and functional models were described and an example for the use of a growth model was given.

Goff and Ottorini (1996) investigated the connection between leaf development and stem growth of ash (*Fraxinus excelsior*) as affected tree competitive status. They developed a basic growth equation and the fact that “the competition between trees was responsible not only for the differences observed in tree dimensions and growth, but also for the differences in foliage efficiency expressed as bole volume increment per unit of foliage biomass”.

In the same year, Ottorini et al. (1996) established the relationships between crown dimensions and stem development in *Fraxinus excelsior*. They used modelling and computer simulation that allowed the reconstruction of the past development of tree crowns. The quantity of foliage in tree crown was estimated by a “foliar volume” computed as a product of the crown surface projection area and height growth.

Cited authors:

Aussenac 1975, Fonteny 1914, Bouchon 1995, Chatelain 1958, Goff and Ottorini 1996, Lemoine 1891, Lescafette 1951, Ottorini et al. 1996, Schaeffer 1956, Vaulot 1914.

3.5. Forest site evaluation. Site index

Under the influence of the Finnish typological school Duchaufour et al. presented in 1958 an example of site cartography in Ban d'Etival forest in Vosges (a high fir-beech selection forest) and the connection between soil, ground vegetation and forest productivity. This was an earlier application of Cajander forest type system in France. Duchoufour et al. distinguished three types:

Type I: fir and beech with abundant *Festuca sylvatica* brun soil with acid mull, 37-45 m average height of the thick trees, 441 m^3 total volume per hectare, 2.5 % amplitude within the type and 8.2 m^3/ha/year average mean annual increment.

Type II: fir without beech with abundant hygrophilic mosses, acid soil with moder or mohr, 32-38 m height of the thick types, 376 m^3 volume per hectare, 1.5 % amplitude within the type, 6.5 m^3/ha/year average annual increment.

Type III: fir without beech, acid soil, abundant xerophilic mosses, 28-33 m height of thick trees, 293 m^3 volume per hectare, amplitude within type 3.4 % and average annual increment 4.5 m^3/ha/year.

The productivity of these types using two indicators is compared graphically in fig 3.5-1 in which it is shown that there is no overlapping in the case of indicator m^3/ha/year (average annual increment, but a slight overlapping appeared in the case of height of the thickest trees. In conclusion, the delimitation of the above-described types may be accepted.

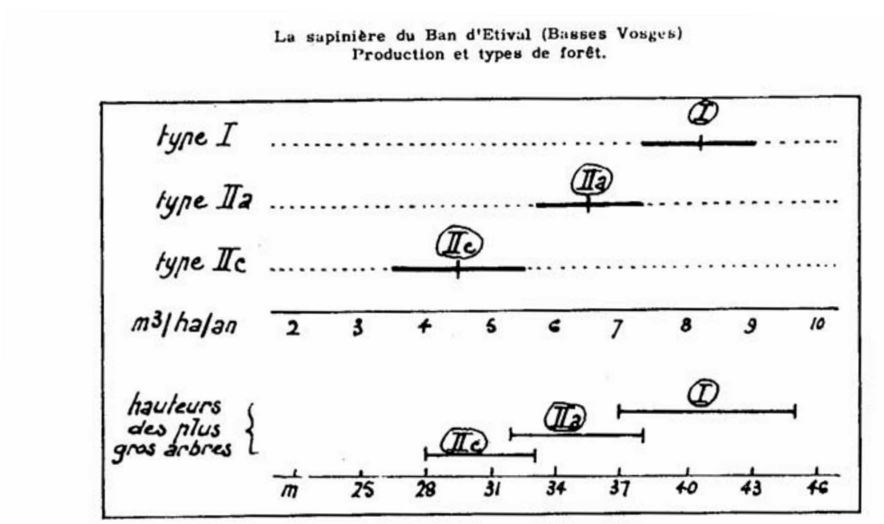


Fig. 3-5.-1. Comparison of fir forest types
SOURCE: Duchaufour et al. 1958, reprinted after Pardé 1961, p. 255, fig. 119, Dendrométrie

Duchaufour et al. (1958) concluded that the estimation of forest yield is more precise with simple knowledge of site characteristics than based only on a climatic index.

In 1960 Duchaufour et al. discussed the problem of site, humus types and ecological groups.

Decourt (1967) investigated Douglas-fir in north-eastern Massif Central and proposed as an index of site productivity the top height defined as average height which corresponds to average diameter of basal area of 100 biggest trees per hectare.

In 1969 Gounod published a remarkable book on the methods for quantitative studies of vegetation that contributed to the investigation and delimitation of forest types.

Different statistical methods have been compared for the interpretation of connections between forest yield and environmental factors in the case of Scots pine in Sologne and considered as possible for direct evaluation of forest site based on its characteristics (Decourt 1969).

Decourt and Le Tacon (1971) tried to forecast the production of spruce based on simple soil characteristics (on calcareous plateaux in eastern France).

Aussenac (1975) studied the effect of temperature on height growth (the major indicator of stand productivity) of some coniferous species.

Chessel (1975) completed the study of horizontal structure in the steppe and silvo-steppe environment.

Many site types were described by Brethers and INRA (1976), Becker (1978 – sites of beech and oak), Becker, Le Tacon and Timbal (1980 – calcareous plateaux of Lorraine), Girauld (1981 – forest sites in Woërre-Lorraine), Brethers (1981 – a forest site catalogue for Haute Normandie).

Phytoecological studies were completed by Jouratic et Plan (1976) in Grande-Chartreuse forest, and by Becker (1979) in beech forest located on calcareous plateaux of north-eastern France.

Toth (1983) established four yield classes for Austrian black pine and Atlas cedar in South East France using four class age determination of dominant height. His yield classes are based on stem analysis of dominant trees and, as far as we know, represents one of the earliest works of this type in France (fig. 3.5.-2)

The influence of logging and soil compacting on site productivity was investigated in detail by Rotaru and presented in remarkable works (1984a, 1984b, 1990), figure 3.5.-3.

Site studies were continued in Lorraine by Le Goff and Madesclaine (1987).

A remarkable work on vegetal layer, its structure and integrated ecological methods was completed by Rameau in 1988.

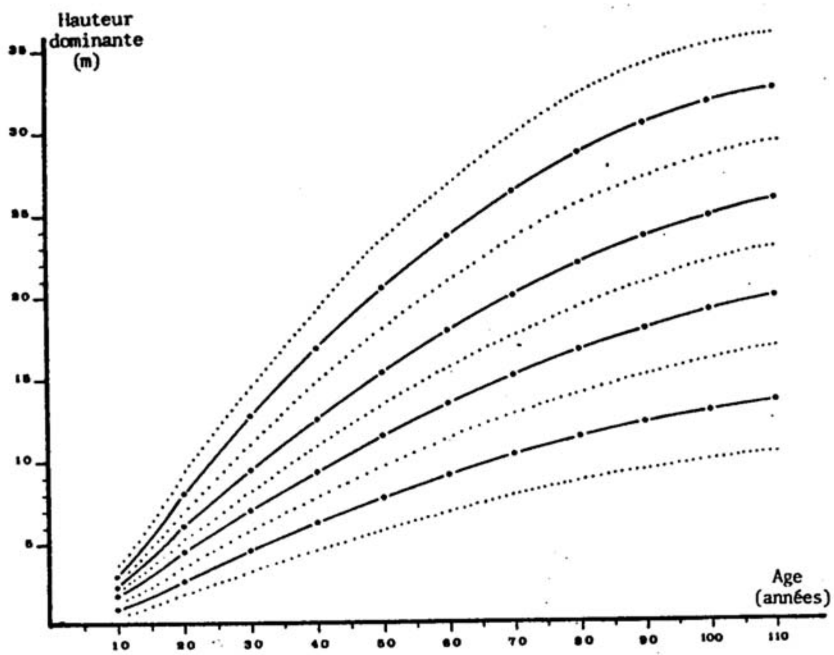
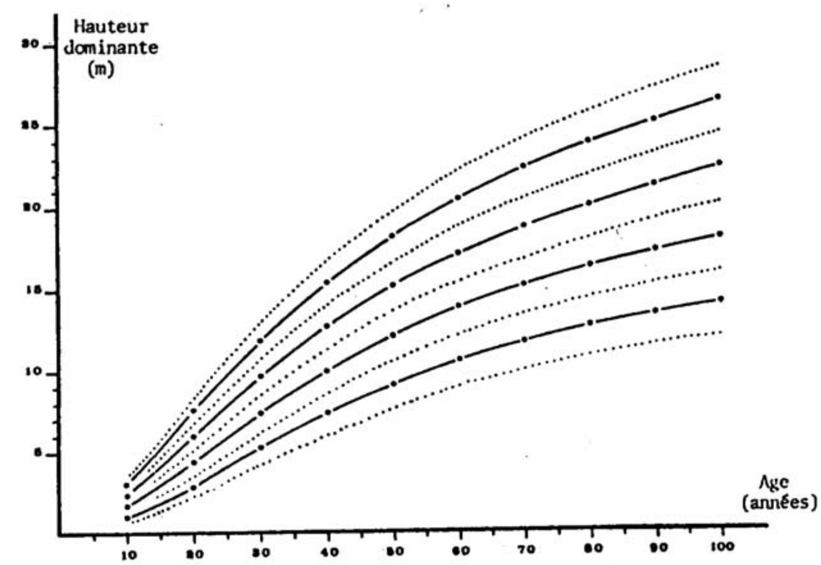


Fig. 1 : Cèdre de l'Atlas



. 2 : Pin noir d'Autriche

Fig. 3.5.-2. Height-age curves as indicators of four yield classes for Atlas cedar and Austrian pine. SOURCE: Toth 1983, reproduced after Pardé, p. 280, Dendrométrie

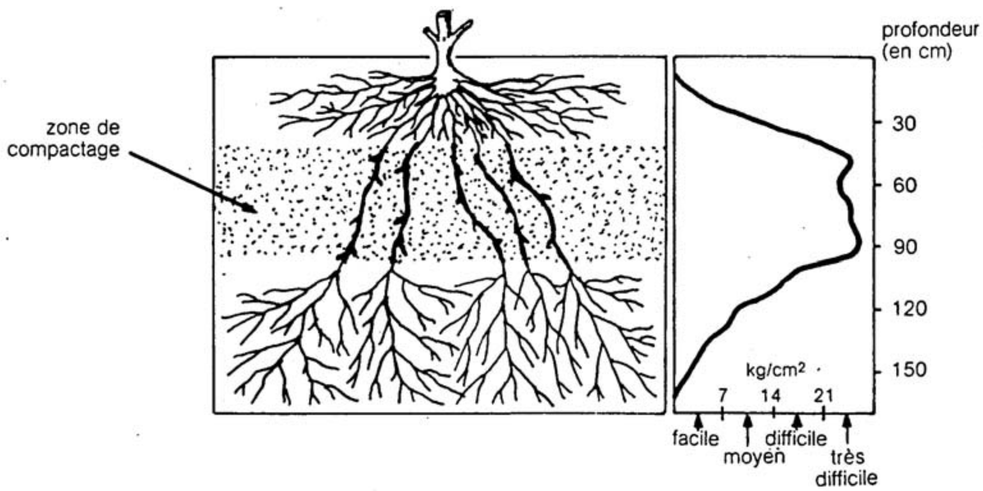


Fig. 3.5.-3. Compact zone formed in a clay layer of soil after logging works (transport by caterpillar) determine the disappearance of fine roots
SOURCE: Cicéron Rotaru 1984 b, p. 6.

In 1992 a study was undertaken by Trencia with the purpose of evaluateing the best age for assessing top (or dominant) height of sessile oak (*Quercus petraea*). He investigated permanent sample plots in different parts of northern France and concluded that the most accurate forecasting of yield was the use of a site index constructed with top height at the age of 100 years, and before the age of 50 all predictions will be inaccurate. The constructed curve gave similar results to those for yield tables used in UK, Switzerland and Austria. A remark for the reader: site index with 100 years as reference age is not used in the case of short-leaved fast growing species where the reference age is 50, 25 or 5 years, the last one for short rotations of eucalypts.

Cited authors:

Becker 1978, 1979; Becker, Le Tacon and Timbal 1980, Brethers 1981, Brethers and INRA 1976, Chessel 1975, Décourt 1967, 1969; Decourt and Le Tacon 1971, Duchaufour et al. 1958, 1960, Girault 1981, Gounod 1969, Jouratic et Plan 1976, Le Goff and Madesclaire 1987, Rameau 1988, Rotaru 1984a, 1984b, 1990, Toth 1983, Trencia 1992.

3.6. Stand structure

In 1898, De Liocourt developed the first mathematical studies on the structure of uneven-aged stands concerning the distribution of trees by diameter categories in his well-known paper “De l’aménagement des sapiniéres” (Management of fir forest). Liocourt hypothesised that the ratio of the number of trees in successive diameter classes was constant within a given forest, which is typical in this forests, but varied for different forests. In this type of uneven-aged forests the size distribution of stems tended to form a reverse J curve (a negative exponential distribution). If n_i is the number of trees in a diameter category and the diameter classes are of the same size (width) then

$$\frac{n_1}{n_2} = \frac{n_2}{n_3} = \frac{n_3}{n_4} \ldots$$ and this ratio is known as De Liocourt's quotient q.

The number of trees per hectare (N_i) in the i-th diameter class with class midpoint d_i is given by the relation

$$N_i = e^{b_o + b_1 \cdot d_i}$$

Alternatively this equation is written as

$$N_i = k \cdot e^{-a \cdot d_i}$$

which is known as negative exponential function with $k = \exp(b_o)$ and $a = -b_1$. For $d = d_i$ and $d = d_i + 1$ we obtain:

$$N_i = k \cdot e^{-a \cdot d_i}$$

$$N_{i+1} = k \cdot e^{-a \cdot (d_{i+1})}$$

and $q = \frac{N_i}{N_{i+1}} = e^a$

Later, in 1930, Schaeffer, d'Alverny and Gazin investigating selection fir forests established four types of stem repartition by diameter categories and constructed for them type curves of equilibrium ("types de courbe d'equilibrium en futaie jardinée"). An example of these curves for types I and IV (normal and semi-logarithmic coordinates) is given for illustration in figure 3.6.-1.

François (1938) also studied normal theoretical composition of selection forests in Savoie determining curves of equilibrium and made a connection between normal structure ("l'équipe normal") and ingrowth ("temps de passage").

Guinochet (1955) analyzed the logic and dynamics of vegetal associations.

Tomassone (1963) proposed a graphical method for the calculation of the mean and amplitude of a normal distribution test of normality. A procedure for rapid determination of the Hart-Becking factor of distances was completed by Bouchon (1966). Chessel (1978) described a non-parametric spatial dispersion of individuals of a species valid also for forest species.

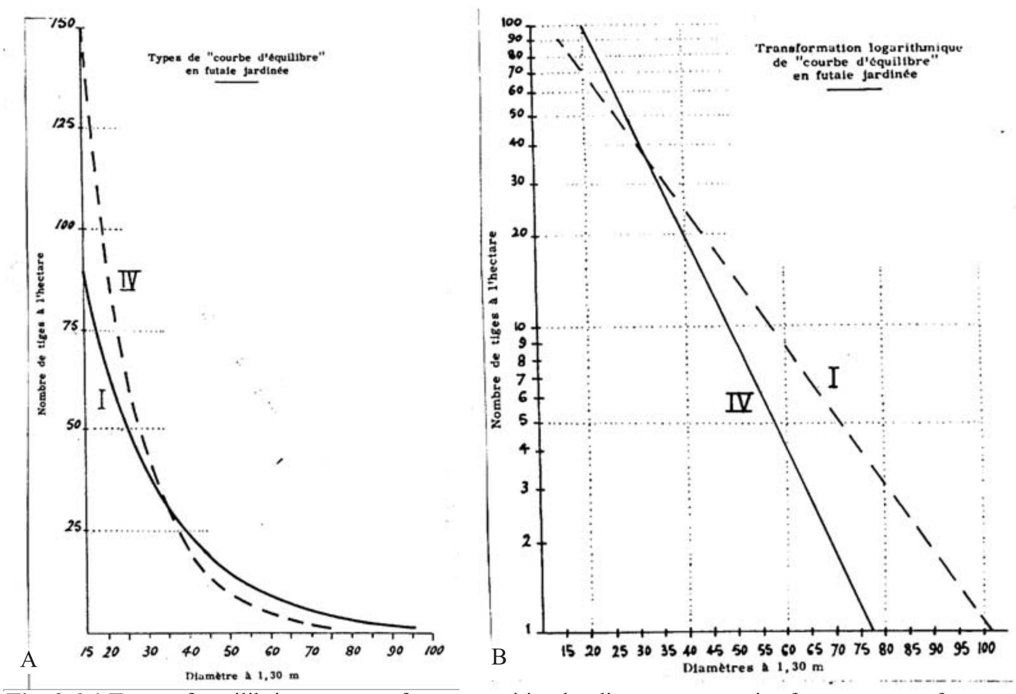


Fig. 3.6-1 Types of equilibrium curves of tree repartition by diameter categories for two types of selection forests: A - normal coordinates, B- semi-logarithmic
SOURCE: Original: Schaeffer, d'Alvenny and Gazin 1930. These are reproduced after Pardé 1961, p. 116-117, fig. 55 and 56, Dendrométrie

Ottorini (1978) investigated the relationship between stand density and growth of trees. A special work dedicated to the structure of forest stands was completed in 1979 by Bouchon. Le Golff and Ottorini (1979) presented density standards for beech stands located in north-eastern and northwestern France.

In 1984, Riou-Nivert established a density factor as a guide for the first thinnings in resinous stands.

In 1990 Chevrou introduced the truncated Liocourt's law to be used in all aged stands. This law is described by the negative exponential function with

$$K = N \cdot (q-1) \quad q^{d_0 - 1}$$

where there is the following relation between *k* and *a*: *k* = Nwa where *w* = class width and d_0 = midpoint of the lowest diameter class ($q = e^a$). The truncated law is an empirical diameter distribution and fits better the real data than the De Liocourt law for irregular as well for regular stands.

Cited authors:

Bouchon 1966, 1979; Chessel 1978, Chevrou 1990, François 1938, Guinochet 1955, Le Goff and Ottorini 1979, Lioucourt 1898, Ottorini 1978, Riou-Nivert 1984, Schaeffer et al. 1930, Tomassone 1963.

3.7. Stand volume, growth and yield

3.7.1. Stand volume and productivity

One of the earlier information on the determination of stand volume (forest inventory) is given in the "Manual Forestier et Portatif" (Forester's manual and pocket book) by Guiot (1770) probably extracted from Duhamel's de Monceau (1764) textbook.

In 1942, Chaudé constructed a tariff for standing coppice in real cubic meters and steres for the evaluation of standing volume (wood for fuel and mine).

Arbonnier (1958 a) proposed an alignment chart for Douglas-fir volume (Fig. 3.7.1.-1.).

The determination of standing volume using the Bitterlich relascope was described by Arbonnier (1958 b), Hanras (1956), Blutel (1960).

Statistical methods were used in 1956 by Ayral and Abadie for the determination of volume in experimental plots. Later, in 1973, Décourt presented a protocol on the installation and measurement of semi-permanent plots.

Chatelain (1951) determined ingrowth and production (yield) in the uneven-aged forests. Pardé (1955) studied the production of some larch stands.

The connection between wood production, yield and climate indexes as Paterson index were analyzed by Pardé (1959, 1964). Paterson (1956) named his bioclimatic index CVP (climate, vegetation and productivity):

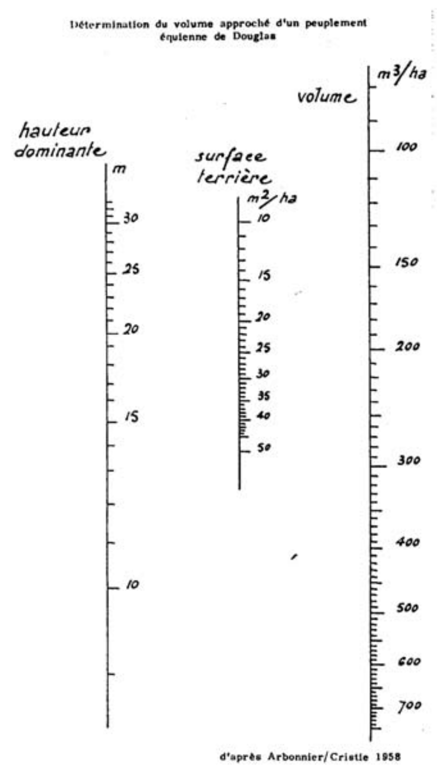


Fig. 3.7.1.-1. Alignment chart for volume determination of a stand of Douglas-fir.
SOURCE: Arbonnier 1958 b (Revue Forestiere Française, December 1958. Reproduced also by Pardé 1961, p. 238, fig. 113, Dendrométrie

$$CVP = \frac{PTGE}{12100Ta}$$

where P = precipitation;
T = average temperature of the hottest month;
E = radiation index established depending on latitude;
G = duration of period of vegetation;

Ta = difference between the average temperature of the hottest month and that of the coldest one.

According to Patterson the potential forest productivity *y* (in m^3/ha/year) can be expressed depending on CVP:

$$y = b_1 \log CVP - b_0$$

For France, Pardé (1964) developed the following relation between forest productivity and CVP index:

$$y = 0.0267\ CVP - 1.43$$

The Paterson index gives reasonable results only for large areas.

Productivity of Alep pine stands was determined by Pardé in 1957. In 1961 (p. 109) Pardé presented a set of data onthe proportion of total fuel wood of mature trees for the main species:

Tree species	high forest	coppice
oak	15-25 %	30-40 %
beech	25-40 %	40-60 %
birch	5-40 %	
poplar, Scots pine	20-30 %	
fir, spruce, larch	10-20 %	

As fuel wood is a historical category that depends on the technical possibilities to transform wood, the percentage of fuel wood has a decreasing trend during the last decades, so the above-mentioned data have only a historical value which should be compared with the actual situation resulted from forest inventories.

Influence of the observer in qualitative grading of standing trees was discussed early, in 1971, but we have no more information about this area.

In 1973 Toth presented the first data on the yield and potential productivity of Atlas cedar growing in southern France. In the same region Toth and Turrel (1983) determined the productivity of *Pinus nigra* var. *austriaca*.

Ottorini (1981) discussed the utilization of data from forest inventory in Margeride for Scots pine studies: (1) height growth and (2) total yield in volume.

Le Goff (1984) determined productivity index of oak coppice in Region Centrale.

In the same year, Goff and Lévi (1984) published data on ash productivity in northern Picardie: relations between productivity and environment.

Rondeux et al. (1985) developed an equation to estimate the volume per hectare for Norway spruce from a regression equation taking into account the basal area per hectare, dominant height and their linear interdependence.

Cited authors:

Arbonnier 1958 a, 1958 b; Ayral and Abadie 1956, Blutel 1960, Chatelain 1951, Chaudé 1942, Décourt 1973, Guiot 1770, Hanras 1956, Le Goff 1954, Le Goff and Lévy 1984, Ottorini 1981, Pardé 1955, 1957, 1959, 1964; Paterson 1956 (Sweden), Rondeaux et al. 1985, Toth 1973, Toth and Turrel 1983.

3.7.2. Stand growth

One of the earliest alignment charts on growth determination was constructed by Bartet in 1889 and printed in Nancy.

For a long time in France it was applied the "classical" method of growth determination based on successive measurement of the same plot(s). This is the method of "temps de passage" using the following relation between passage time (ingrowth) t_p and annual increment of diameter i_d:

$$t_p \text{ x } i_d = 5 \quad \text{or} \quad i_d = 5/t_p$$

Replacing i_d in this formula with volume (V) we have:

$$i_v = \frac{V_{d+5} - V_{d-5}}{2t_p}$$

This formula was proposed by Bougenot (1951), Chatelain (1958) and is similar to the one introduced by Lachausse in 1937 and published in "Vademecum du Forestier" since the 1937 edition (Pardé 1961, p. 286). The Pressler formula (see Germany) was also applied on a large scale. The procedure proposed by Lescafette (1951) on the use of cambium area (see 3.4) is valid in the case of stand, but we have no information of its application in practice.

Pardé (1961) proposed the use of the "interpolation method" elaborated by Meyer (1942) in the U.S.A. and named by Loetsch (1953, 1954) in Germany as "method of tariff differences" or in French "methode de différence des tariffs".

In a study on the characteristics of Alep pine forests Pardé (1957) constructed a straight line which represents the average annual growth of the stand ("bois fort") from the origin up to 75 years, depending on total average height at this age. A statistical study on growth of high resinous forests was developed by Batias in 1960.

Bouchon and Stipanic (1967) practiced comparison of growth using different number of tree rings. Simplified formulas were used by Brenac (1978) during a national forest inventory.

In 1981, Duplat and Perrotte published a remarkable textbook: “Inventaire et estimation de l’accroissement des peuplements forestières” (Inventory and estimation of stand growth) in which part III refers to the estimation of stand growth in the following chapters: (4) Yield and growth of forest stands, (5) Growth estimation by comparison of forest inventories, (6) Estimation of growth using samples on the ground in two ways: (a) estimation of current increment by plots as sampling units and (b) estimation of current growth (increment) using tree samples as sampling units.

One of the major problems of forest mensuration was and remains the determination of forest growth trend. A medium-term forecast of available yield from Norway spruce forests in the north-east of France was completed by Ottorini in 1984. In 1994 Becker et al. published a short paper on long-term trends of growth of different broad-leaved and resinous species in north-eastern France after the middle of the 19^{th} century. Badeau et al. (1995) investigated long-term growth trends of beech in north-eastern France using 1025 trees growing in high forest (high density stands) and coppice-with standards (low density stands). Trees belonged to all age classes were scattered in 102 sites. They used two standardization techniques and “Both showed a significant increasing radial growth trend since the last century (19^{th}), independent of biological effects related to age. However, this trend was steeper and began earlier in high forests than in coppice-with-standards stands. This result, that the current increasing growth trend is partly due to silvicultural effects or interactions between silviculture and environmental changes” (After Forestry Abstracts 5886/1995).

At the IUFRO XX World Congress (1995, Tampere, Finland) Dupouey et al. (1995) presented a synthesis on growth trends of French forests. They studied radial growth of individual trees of many species in several regions (*Abies alba* in the Vosges and Jura mountains; *Picea abies* in the Vosges mountains; *Fagus sylvatica* in the Loraine plain and Vosges mountains; oaks (*Quercus robur* and *Q. petraea*) in the eastern part of France; *Pinus uncinata* in the Pyrenees mountains and *Pinus nigra* spp. *laricio* var. *corsicana* in western France); 500-1500 trees were sampled in each case on regional level. The authors mentioned: “In order to take into account the confounding effect between age and date, a peculiar standardization method was adopted: standardization was done at the regional level, instead of tree by tree. This was done either by construction of a mean regional age curve, either by the analysis of variance of the whole bulk of data. In all cases, a significant increasing growth trend appears during the last 150 years” (p. 270). This trend growth was assigned to silviculture changes, nitrogen pollution effects, CO_2 fertilization and climatic changes, In some cases they observed that this increasing trend is only apparent after the elimination of competition effect.

Cited authors:

Badeau et al. 1995, Bartet 1889, Batias 1960, Becker et al. 1994, Bouchon and Stipanic 1967, Brenac 1978, Duplat and Perrotte 1981, Dupouey et al. 1995, Lescafette 1951, Loetsch 1953 and 1954 (Germany), Meyer H. A. 1942 (U.S.A.), Ottorini 1984; Pardé 1957, 1961.

3.7.3. Growth and yield tables

For many reasons growth and yield tables were constructed in France later than in other advanced European countries. In 1938 Sargos recorded in Landes *Pinus maritima* forest types having different productivities (index: m3/ha/year). Later Mathey (reference by Perrin 1946) distinguished six classes of productivity in a coppice. In 1950 Gannevat presented in his short paper "Courbes et tables de croissance" (Curves and growth tables) a volume table (in connection with age) in steres for 9 classes of productivity – in fact this is a simplified yield table.

In 1961, Pardé (p. 267/268) noted in section 455 (which refers to French foresters and yield tables: "… si les tables des production sont si répondues à l'étranger et tenues pour si utiles, pourqoiu n'ont-elle pas de longue date obtenue droit de cité en France? Les causes de cet état de fait sont nombreuses. La première est que les tables de production on vu le jour on Allemagne à un moment où les relations entre ce pays et le nôtre était dramatiquement tendue: on admettait alors volontiers chez nous que ce qui venait d'outre –Rhin était fort sujet à caution et à critique. La critique justement était facile: il est certain qu'ou début du siècle, basées sur des données insufisantes, les première table étaient trop souvent d'une fragilité disarmante …. Du reste, la grand diversité de la forêt française, peu fournie en peuplements homogènes et equiennes, alors que le taillis sous-futaie, y tenait encore, une place considerable était un grave obstacle à la diffusion dans un large public des tables de production. Les choses ont bien changé depuis. Les peuplements de futaie plus ou moins équiennes ont augmenté leur emprise dans notre pays. Les énormes reboisements réguliers réalisés grace ou Fonds Forestier National sont un champ d'application tout trouvé." […if yield tables are so spread outside France and considered so valuable why did they not obtain the citizenship of France a long time ago? Causes of this fact are numerous. The first is that yield tables were born in Germany at a moment when the relations between that country and ours were dramatically tense: it was accepted then by us, that what came beyond the Rhin is a serious object of caution … and of critic. The critic was in fact really easy: certainly at the beginning of the century (20^{th}), based on insufficient data, the early tables were too frequently disarmed fragil …. On the other hand, the high diversity of French forests with less homogeneous and even-aged stands, in spite of young high forest, coppice with standards still cover a considerable area being a serious impediment to the introduction of yield tables to a large public. But things changed after that. The high forest stands more or less even-aged cover larger areas in our country. Reforestation works performed regularly owing to the National Forestry Fund represent a large area of (yield tables) application.”]

Limits of utility of yield tables were underlined also by Décourt in 1964 who described the first French yield tables in 1966 and 1968 and he himself was author of yield tables for Norway spruce in 1971 (average height, six classes, ages 25-90), Norway spruce in northern France 1972a, Norway spruce and Douglas-fir in western “Massif Central”. Décourt (1972b) also described a method for rapid construction of preliminary yield tables, method based on computerized algorithms, especially for regional yield tables. A collection of ten yield tables for species grown in France was published in 1973 by ENGREF and reprinted in 1984 in an improved edition.

Ottorini and Toth (1975) constructed yield tables for Austrian pine (*Pinus nigra* Arn. ssp. *nigricans*) grown in south-eastern France. In the same year Ottorini (1975) published functions for yield tables to be computerized.

Duplat and Bolliet (1979) studied the yield of spruce in the southern part of Massif Central.

Growth and yield of *Pinus maritima* was studied by Lemoine (1983).

The yield of Sitka spruce in France (65,200 ha in 1986, in Brittany, Normandy and southern Massif Central) was analyzed by Serrière-Chadoeuf (1986) who considered that “there are not enough data available to construct a yield table for Sitka spruce in France, but by superimposing the available data on yield tables for Britain it is clear that increment is similar to that of British tables”. Courbet (1986, 1987) developed yield tables for Sitka spruce in Brittany (Bretagne) with seven site classes.

Cited authors:

Courbet 1986, 1987; Décourt 1964, 1966, 1968, 1971, 1972a, 1972b, 1973; Duplat and Bolliet 1979; E.N.G.R.E.F. 1973, 1984; Gannevat 1950, Lemoine 1983, Ottorini 1975, Ottorini and Toth 1975, Pardé 1961, Perrin 1946, Sargos 1938, Serrière-Chadoeuf 1986.

3.7.4. Growth and yield modeling

In 1974, Mendiboure and Barneoud (1974) presented a model of spruce growth at Stockholm symposium on growth models for tree and stand simulation. This should be considered the first French trial in the field. In the next year, Maugé (1975) constructed a growth and yield model for *Pinus maritima*.

Bartet and Boilliet (1976) presented models based on the methods used for the construction of yield tables under conditions of variable silviculture. Their models refer to growth and development functions to be solved by computers.

A review on growth models and competition, achievements and perspectives was completed by Mendiboure, Brunet and Najar in 1981.

Mitchel Oswald and Ottorini modelled the growth of Douglas-fir in France.

In 1996, Duplat and Tran-Ha constructed models for the growth of dominant height for beech, fir and Scots pine growing in Aigoual area.

A bibliography on growth models for stands was prepared by Dhôte (1987).

Houllier et al. (1995) linked growth modelling to timber quality assessment for Norway spruce.

Courband (1995) discussed the perspectives of the growth modelling in uneven-aged stands.

Dhôte (1996) developed a model of even-aged beech stands productivity with process-based interpretation. In this way he proposed a system of three differential equations for dominant height, basal area and total volume growth. In the model there are involved parameters at the forest and stand levels, and site index is the asymptote of the height-age curve. The model structure is in such way that permits for any given height some differences in total volume yield which exist between stands of different productivities and in this case Eichhorn's rule is contradicted, but in the model no parameter other than site index is necessary for the characterization of stand productivity. Dhôte discussed the possibility to use the model in a larger frame of ecological conditions, taking into account a process-based interpretation (carbon balance models, linear relationship between basal area and height-growth rates - that are investigated using separate model of sapwood geometry and dynamics.

Cited authors:

Bartet and Boilliet 1976, Courband 1995, Dhôte 1967, 1966; Duplat and Tran-Ha 1996, Houllier et al. 1995, Maugé 1975, Mendiboure and Berneoud 1974, Mendiboure et al. 1961, Mitchel et al. 1963.

3.8. Weight and biomass studies

Table 3.8.-1. presents a sample of biomass studies performed in France between 1979 and 1997.

Some methodological problems are presented in the following text.

In 1969, Reidacker presented methods of biomass estimation of a tree. Sussenac (1969) determined the production of litter in different forest stands in eastern France.

TABLE 3.8.-1. A sample of French biomass studies

Year	Author(s)	Species	Remarks
1978	J. P. Mounet	*Quercus pubescens*	Evaluation of production and biomass in some ecosystems
1978	J. Ranger	*Pinus laricio*	Plantation in Corsica
1979	S. Métayer	*Carpinus betulus* *Quercus* spp. *Betula* sp.	Above ground biomass in coppice stands near Orleans
1980, 1981	M. Rapp A. Cabanettes	*Pinus pinea*	Biomass, mineral mass and productivity. An ecosystem near the Mediterranean coast. Total annual production was 186 t/ha of which 40 % was needless, cone production was 3.7 t/ha and stem wood production was 38 t/ha
1981	B. Lemoine, J. Gelpe, J. Ranger, C. Nys	*Pinus maritima*	Biomass and bioelements in a 16 years old stand
1981	D. Ranger, C. Nys, J. Ranger	*Picea abies*	Above ground biomass of a plantation
1981	J. Ranger, C. Nys, D. Ranger	Conifers and broad-leaved	Ecosystems in the Ardennes
1983	J. Toth	*Cedrus atlantica* *Pinus nigra* spp. *nigricans*	In the south-east of France. For each of these species (stem 22 cm top girth) biomass was 550 kg/m^3 at 12 % moisture or 650-900 kg/m^3 (green wood, fresh) 50-60 % humidity
1984	B. Lemoine, J. Gelpe, J. Ranger, C. Nys	*Pinus pinaster*	16-yr old stands
1985	J. Bouchon, C. Nys, J. Ranger	*Quercus* spp. *Betula verrucosa* *Sorbus aucuparia*	Biomass and mineral content of mixed coppice stands in the Ardennes
1986	L. Pagès	*Robinia pseudacacia*	Biomass production in the Loire Valley
1997	J. Y. Pontailler, R. Ceulemans, J. Guittet, F. Mau	*Populus* spp.	Orsay, near Paris, different clones

Bouchon (1973) studied branches biomass and Reidacker (1973) established allometric relationship in a young coppice of *Eucaluptus camaludensis* and indicated how to obtain samples of above ground biomass, and in other paper (1979) be presented indirect methods for the estimation of tree and stand biomass. The same problems of aboveground biomass and biomass production of coppice stands was investigated by Auclair and Metayer (1990).

Ranger et al. (1991) developed a comparative study of two ecosystems in Ardennes (coppice above ground biomass). Papers on biomass as energy were written by Pardé (1980a, 1960b).

Granier (1991) studied the relationship between the sap-wood section area and foliar biomass in the case of Douglas-fir.

Francine Cupi (1982) completed a review on biomass papers published between 1950 and 1981.

In the proceedings of a symposium held in 1963 in Orleans there were included some papers on the measurement of growth and estimation of forest biomass (a book of 365 pp. published by INRA in 1963).

Nys et al. (1963) developed comparative biomass studies in two ecosystems in Ardennes.

Auclair and Bige (1964) presented a method for the estimation of biomass on regional level based on the data.of the national forest inventory.

In 1997, Pontailler used nondestructive methods for the determination of *Populus* sp. tree biomass based on linear and nonlinear functions.

Cited authors:

Auclair and Digs, 1984, Auclair and Métayer t980, Ausenac 1969, Bouchon 1973, Bouchon and Reidacker (1973), Bouchon et al. 1985, Cabanettes and Rapp 1981, Cupi 1982, Granier 1981, INRA 1983, Lemoine et al. 1984, Métayer 1979, Mounet 1978, Nys et al. 1983, Pagès 1986, Pardé 1980 a, 1980 b; Pontaillier et al. 1997, Ranger D. et al. 1981, Ranger J. 1978, Reidacker 1968, 1978; Toth 1983.

3.9. Tree-ring studies

3.9.1. Early works

Acording to the American scientist Fritts (1976) - based in information provided by Heizer (1956) and Studhalter (1955) information - the honour to discover the first crossdating belongs to Frenchmen Duhamel and Bouffon in 1737. In any case tree-ring crossdating (or at least comparison) is mentioned by Duhamel de Monceau in his textbook "La Physique des arbres" (1758).

E. Mer was writing about early wood (“bois de printemps”) and late wood (“bois d’automne”) in 1892, and in 1895 the demonstrated the influence of climate on fir growth.

Daniel (1914) discussed the existing relationship between the age of dycotyledonous trees and the successive number of their wood layers (tree-rings).

The first modern French tree-ring chronology was constructed for oak species in northern France by Giertz (unpublished) and refers to the period 1610-1280 (Eckstein 1972, p. 5), and other chronologies were mentioned in Fontainebleau forest and Brittany (Pilcher 1996).

3.9.2. Dendroclimatology

The first dendroclimatological studies began in France in the 1960s. Florence published a dendrochronological study related to the climate of Carpier and Cerdagne areas. Serre et al. (1966) carried out the first researches on the relation between tree-rings of *Pinus halepensis* and annual variations of climate using statistical techniques (simple correlation and coefficient of variation).

The relation between tree-rings and climate, between dendroclimatology and dendrochronology (*in sensu stricto*), respectively, were underlined in 1970 by de Martin.

A detailed work on dendroclimatology was completed by Serre (1973) on *Pinus halepensis* Mill. (pin d'Alep) in his doctoral thesis at the University D'Aix-Marseille. Huber (1976) examined the problems of climate influence on Scots pine structure of growth rings. In 1976, Serre analyzed (a) the connection between growth and climate in *Pinus halepensis* and (b) climate activity and length growth of buds and eagles of the same species.

In 1978, Serre estimated the dendroclimatological value of the European larch (*Larix decidua* Mill. in the French Maritime Alps (Vallée des Merveilles, north of Nice) and concluded that "using climatic data from various sources (history, cronicle, variation of the glacial front lines, known climatic episodes) shows that climate reconstruction over several centuries, at the limits of the Mediterranean zone, can be obtained with larch of the French Maritime Alps" (p. 25, Serre's abstract). In fig. 3.9.2-1, presented after Vivian-1975 (reproduced by Serre 1978), ring-with running means for twenty years are compared with the supposed variations of the "Argentière" glacier front line, and in fig. 3.9.2.-2 ring width running means for twenty years of living trees and the whole set of trees (living + stumps).

In a doctoral thesis (University of Aix-Marseille) Tessier (1984) presented a detailed study on dendroclimatology and ecology of *Pinus sylvestris* L. and *Quercus pubescens* Wild. in south-eastern France.

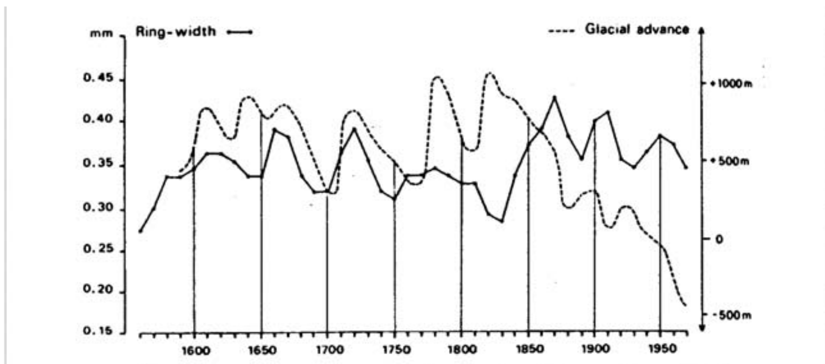


Fig. 3.9.2.-1. Ring-width running means for twenty years (unbroken line) compared to the supposed decennial variations of the "Argentière" glacier front line (broken line) (from Vivian 1975), reproduced by Serre (1978) in Tree-Ring Bulletin, 1978, 38, p. 32.

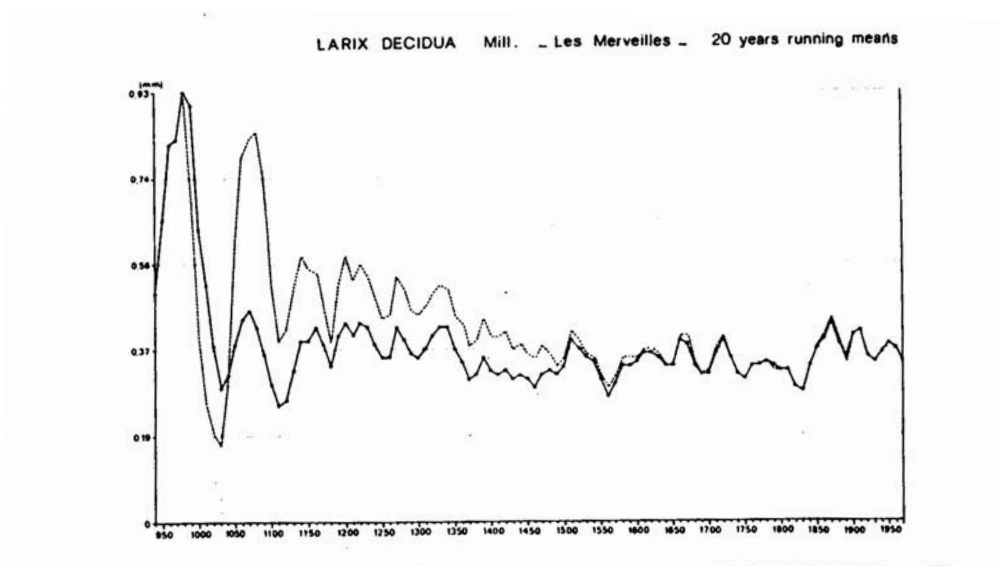


Fig. 3.9.2.-2. Ring-width running means for twenty years of living trees (broken line) and of the whole set of trees (living trees+stumps) (unbroken line)
SOURCE: Serre 1978, Tree-Ring Bulletin,1978, 38, p. 32.

In the 1990s, a set of new interesting papers have been published in the field of tree-ring and climate relationships.

Rolland (1993, published in 1995) studied tree-ring and climate relationships in the internal Alps using correlation functions and discovered that "fir (*Abies alba* Mill.) shows an accurate response to climate, especially by prior August rainfall which enhances ring size, or by high temperatures, which shows the opposite effect. The most critical period extends from prior July to prior

September and a favourable water balance seems to be decisive" (Rolland's abstract, p. 1). As growth is strongly linked to climate, Rolland attempted to determine growth indices (I) (relative value of width tree-ring compared to a standards value = 100 or deviation from a trend line) with linear multiple regression. His best result (R^2 = 0.894) was obtained with the following equation which is mentioned here to illustrate the complexity of the problem:

$$I = 6.1947(T_7) + 0.0059(R_9) + 0.1422(P_6) + 0.672(R_{10}) -$$
$$4.3694(U_9) + 2.9004(U_5) + 0.0532(P_{12}) + 0.0453(R_1) + 3.2289$$

where: T_7 = current July temperature;
R_9 = prior September precipitation (reserves);
P_6 = current June precipitation;
R_{10} = prior October precipitation (reserves);
U_9 = prior September temperature (rapid end of summer);
U_5 = prior May temperature (warm May);
P_{12} = current December precipitation (rapid end of current summer);
R_1 = prior January precipitation (snow melt).

Rolland confirmed that extreme data provide more information than average values.

Using the same method of correlation functions, Rolland and Schueller (1996) investigated dendroclimatology of mountain pine (*Pinus uncinata*) in the Briançon and Queyras areas (in the interior French Alps), in relation to site conditions.

In 1997, Zhang analyzed variations and correlations of various ring width and ring density features in European oak and their implication in dendroclimatology. Oak species were *Quercus robur* and *Q. petraea.* As new contribution it should be mentioned ring density features (referring to early and late wood, average ring density, minimum and maximum density) that showed correlation with a comprehensive climatic variable and ring width features and concluded that "total ring width, as a climatic parameter, was not as good as late wood width, and maximum (late wood) density appeared not to contain as much climatic information as average late wood density and average early wood density respectively (quoted from Forestry Abstracts 5851 1997).

3.9.3. Dendroecology

An early example of dendroecological work is given by Borel and Serre (1969) who attempted to make a connection between phytosociology and tree-ring analysis in three forests.

Panaïotis et al. (1995) used dendrochronological methods for dating natural gaps in the holm oak forest (*Quercus ilex* L.) in Fango MAB Reserve (Corsica) by reading rings of maquis components – vegetation developed from stem breakage due to the fall of trees of gap creation; the best species for this dating was *Phillyrea latifolia*.

Lévi et al. (1996) investigated element analysis of tree rings in pedunculate oak (*Quercus robur*) in Amance forest (north-eastern France) as an indicator of historical trends in the soil chemistry related to atmospheric deposition and established that (340 investigated trees) there was an increase in nitrogen and aluminium, a reduction in phosphorus, potassium and magnesium and no change for calcium, in growth rings corresponding to the last 30 years of hardwood (1938-1967). In Lévi's opinion these results were in concordance with floristic and edaphic survey: increase in nitrogen and a trend towards soil acidification (mainly due to atmospheric deposition). Lévi et al. considered that "Tree-ring analysis of oak hardwood appeared to be an effective approach in order to reveal historical changes in forest soil chemistry". In our opinion chemical analysis of tree-rings should be interpreted with more prudence because there is a radial movement from external to inner rings and vice versa, via radial rays, known in the last years and noticed especially in the American literature.

Dendroecological study of Corsican pine in western France performed by Lebourgeois and Becker (1996) revealed changing growth potential over the last few decades. They studied the changing mean increment rates for each tree (1808 trees!), and the relationship between stem radial growth and present crown conditions. Their researches confirmed (1) the existence of a strong annual variation in relation to annual conditions, (2) several crises during which growth declined because of a sustained climatic stress (1952, 1962 and since 1981). In conclusion, their results confirm the long-term growth trends observed for different species in several French regions as a result of global climatic change – consequence of increase in atmospheric CO_2, deposits of nitrogen components of antropogenetic origin, and improvement of silvicultural techniques.

3.9.4. Methods used in tree-ring studies

In 1963, Polge proposed density analysis of radiographic photos of wood as a new method for the determination of texture. In 1965 Polge used curves of wood density variation for the study of environmental factors, of climatic factors in particular. In 1966, in his doctoral thesis (1966 and the other work in 1970), Polge established variation of the wood density using densitometric scanning of tree rings. To obtain continuous record of wood density several non-mechanical methods have been previously used: beta ray observation (U.S.A.: Phillips 1960), photometry (U.S.A.: Green and Worral), techniques used with microscopic sections (Elliot and Brook 1967). Polge densitometric scanning of X-ray negatives has the advantage that the increment cores can be used with a little preparations. Apart from the densitometric records based on X-ray (Fig. 3.9.4.-1.) Polge introduced synthetic xylochronologic profiles (Fig. 3.9.4.-2.) "which are diagrams that record, for each year the mean ring-width in abscissa and the mean maximum and minimum wood densities, and on which these extreme values of density are going together by segments of straight lines. Thus details in the shape of densitometric records are not utilized. Yet these profiles make the work of wood dating very easy because they summarize the annual variations of two criteria instead of one in the usual ring-width chronology" (Polge, Tree-Ring Bull. 30, p. 8, 1970. On the other hand, Polge and Thiercelin (1970) studied the damage caused by the extraction of increment cores which can be less important if some protective measures are taken.

Factor analysis of correspondences (Escofier-Cordier 1965, Benzecri 1973, Briane et al. 1974 – applied to trees) was applied by Serre (1977) to variations as a function of time of ring widths of the Aleppo pine (*Pinus halepensis* Mill.) in the French Mediterranean region. Since numerous factors determined ring width "the factor analysis of correspondences enables the demonstration that an important factor is the rain which falls during the vegetation period preceding the summer drought…" (p. 21 TR-Bull. 37, 1977, Serre). According to Serre factor analyses of correspondences can be used for any analysis of ring width, either alone or as a preliminary study to more extensive research concerning the causes of these variations (ibid. p. 30).

Statistical significance and reproducibility of tree-ring response functions were discussed by Gray et al. (1981-U.K.) and their paper contains a dendrochronology from Fontainbleau that is a particularly long and modern site chronology which extends from 1540 to 1979 (climatic data exist for Paris from 1770 onwards, so the early part of the record may be unreliable. On the other hand, Gray et al. (1981) in connection with this statistical procedure mentioned that a test of significance is devised based on the binominal distribution and may be used (combined with other tests) to compare two different response functions to examine the reproducibility of climate – chronology response and in essence "has been proposed as an indicator of the overall significance of a response function" (Gray et al. 1981).

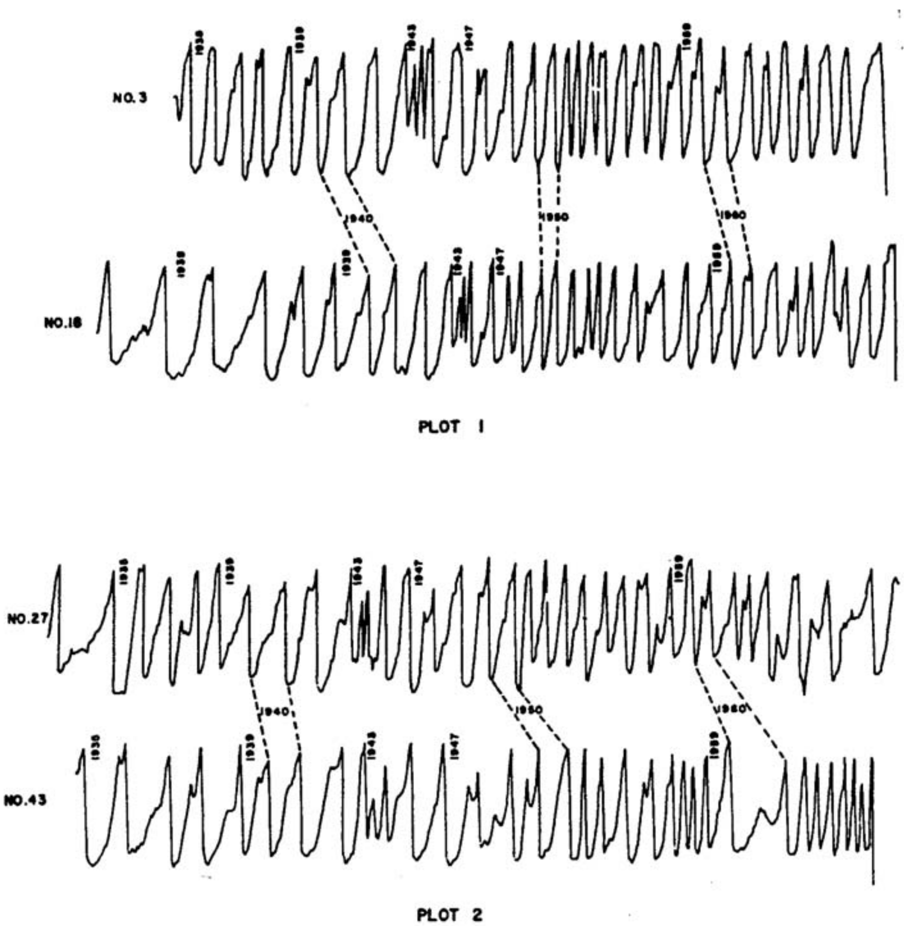


Fig. 3.9.4.-1. Examples of densitometric records.
SOURCE: Polge 1970, Tree-Ring Bulletin, vol. 30, p. 4, fig. 1.

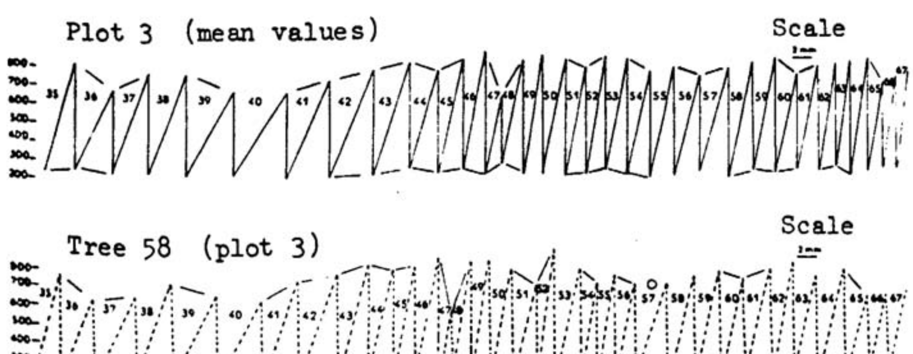


Fig. 3.9.4.-2. Synthetic Xylochronologic Profiles
SOURCE: Polge 1970, Tree-Ring Bulletin, vol. 30, p. 9, fig. 3.

In 1986, Guiot applied ARMA (autoregressive mean average processes) technique for modelling tree-ring responses to climate and for reconstructing variations of paleoclimates.

The principle of response functions was described in 1976 by Fritts and discussed in Hughes et al. in 1982. In connection with this subject Guiot (1991) presented what he named “the bootstrap procedure which provides a way to test the significance of the regression coefficients and stability of the estimates in response functions generated by regression on principal components”. A subroutine RESBO which calculates a bootstrapped response function has been added to Fritts’ program PRECON.

In 1996 Badeau et al. presented a short paper on “Long-term growth trends of trees: ten years of dendrochronological studies in France”.

Cited authors (3.9):

Badeau et al. 1996, Benzecri 1973, Briane et al. 1974, Borel and Serre 1969, Daniel 1914, De Martin 1970, Duhamel de Monceau 1758, Eckstein 1972 (Germany), Elliot and Brook 1967, Escofier-Cordier 1965, Florence 1962, Fritts 1976 (U.S.A.), Gray et al. 1981 (U.K.), Green and Worral 1964 (U.S.A.), Guiot 1986, 1991, Guiot et al. 1982, Huber F. 1976, Lebourgeois and Becker 1996, Lévy et al. 1996, Mer 1892, 1895; Panaïotis 1995, Phillips 1960, Pilcher 1996), Polge 1963, 1965, 1966, 1970; Polge and Thiercelin 1970, Rolland 1993, Rolland and Schueller 1996, Serre 1973, 1976 a, 1976 b, 1977, 1978; Serre et al. 1966, Tessier 1984, Vivian 1975, Zhang 1995.

3.10. Forest inventory and remote sensing

Like in other central European countries the volume of forest was determined on stand level (relatively not large areas using visual methods plots, strips, a variable number of selected trees or a total enumeration of trees).

In Central Europe “The expanding system of transport and the industrialization caused a shift of forest production from fuel to timber. Consequently, the area-related tree information “total volume per hectare”, which could be obtained visually, became unsatisfactory….The visual estimate was therefore more and more abandoned and replaced by methods of measuring the growing stock…The 20th century brought a number of technical inventories which revolutionized the methods of forest inventory….An example of the technical progress is the method of control developed by A. Gurnaud in France and H. Biolley in Switzerland which by the way of a continuous forest inventory determines the increment for each compartment by comparison of two periodical inventories plus the removal during the period (H. Biolley 1897). The invention of the meam-stem stand tariffs by K. Krenn (1948 - Germany) and the ingenious invention of W. Bitterlich (1947-Austria) to obtain the stand basal area per unit area directly by sampling are further milestones of the technical progress of forest inventory in Central Europe…. A decisive influence on the methods of forest inventory had the rapid development of the mathematical statistics….it is interesting in this context to compare the development of forest inventory methods in Central Europe with the development in the U.S.A….the methods of stand inventories and the compilation of figures for the whole management units from the data for relatively small units of assessment were developed in Central Europe at a time when statistics in the modern sense did not yet exist. The progress from the small to the larger unit is still today (1964, our note) typical of the forest inventory methods in Central Europe. Regional and national forest inventories with a proper statistical design have only recently been introduced (our underline) for instance in Great Britain, Austria and Central Germany. In the U.S.A. forest inventories were not undertaken before the 20th century and so started at a time when mathematical statistics had already been introduced into forestry science. The large sizes of forest properties and the lack of detailed forest maps have contributed to bring about a development of forest inventory techniques which was a complete reversal of the process in Central Europe. The sampling was primarily concerned with a large unit and information on small sub-units of assessment were obtained by derivation as far as this was considered worthwhile from the statistical point of view. As a result of the low intensity of sampling the information on sub-units, that is units of assessment of second order, are of little use, because they are too imprecise….The present trend (1964 our note) of inventory methods in the U.S.A. is therefore to further elaborate the methods from the top down to the bottom…The second major technical advance is the use of aerial photography for purposes of forest inventory" (Loetsch and Haller 1964, pp. 7-10) to which we have to add, since the 1960s the radar and since the 1970s satellite imagery.

The original concept of the control method was developed in 1878 by Adolphe Gurnaud (1825-1898) a French forester but the method was more widely practiced in Switzerland than in France and was first applied in selection forests (Biolley H. 1897, 1920). A description of the history of this method was summarized in 1991 by J. Pardé. "Principles were: (1) plots or stands were treated and assessed individually with no reference to general forest condition; (2) short (5-10 yr) intervals between treatments; (3) stand volume was assessed by periodic inventory; (4) the periodic inventory provided a guide to final harvest volume; and selection of superior trees was made with reference to the population of that individual plot or stand only" (For. Abs. 6224/1993). Pardé (1991) considered that the today development of Gurnaud's ideas correspond with controlled sampling in Germany and continuous forest inventory in the United States of America and Canada.

The early forest surveys were described in a paper published in 1924 by P. Caziot. The first modern inventory cycle in France was from 1960 to 1980, the second from 1980 to 1990. During these inventories it was assessed also line planting (hedges and road side planting). In the case of units with an area of more than 4 ha there were used aerial photographs for the separation of forest stand types, point sampling and interpretation. "During the new inventory cycle ecological and floristic data are collected in addition to the stand variables" (Pelz 1933, p. 15).

During the 1950s and the 1960s a series of papers have been published on methodological aspects of forest inventories, some of them mentioned in this text.

Abadie and Ayral (1956) presented the methods of determination of stand standing volume (definitions and mathematical statistic studies (135 pp)). In the same year Pardé analyzed statistical methods for forest inventories.

Morice (1957) completed a special book on statistical methods for economical studies including inventories. Pardé (1957s, 1957b, 1960) presented the results of the application of statistical methods in the inventory of high, forests and coppice forests and in his "Dendrométrie" published in 1961 he included a special compartment to the classical methods of forest inventories. That problem of forest inventories in hilly ground areas was discussed by Consigny (1961). An inventory of a middle aged oak was analyzed by Pardé (1963) on the basis of statistical methods while Lanly (1963) determined sampling procentage in function of the density of the inventoried stands. The relation between forest inventories and management was examined by Bouchon (1966) who presented also in 1968 the results of systematical sampling along the contour lines of the ground. An easy and clear book on sampling techniques (but with emphasis on demographic surveys) was published by Desabie in 1966. Assessment of the commercial wood volumes during forest inventories in tropical areas was carried out by Lanly and Lepitre (1970). The first results of the forest inventories based on statistical sampling completed in the Alps Mountains in 1970 were presented by Bartet (1971).

Matheron published in 1970 a book on the theory of regionalized variables land that was applied for the first time in forestry at the end of the 1960s. (Miller et al. 1972, Alexe and Milescu 1983).

For estimating the accuracy of a forest inventory Guidicelli, Lanly Ouakan and Pietri applied in 1972 the theory of the aleatory processes in the case of systematic sampling. Cherron completed in 1973 a forest inventory of line planting (hedges and road side planting).

The experience gained by Centre Technique Forestier Tropical - Nogent sur Marne - in automatic processing of inventory data was summarized by Guinadeau (1973) at a IUFRO meeting held in Nancy in June 1973 by the Subject Group S4.02 (Forest inventory).

Bauchon (1974) described again the utilization of regionalized variables in forest inventories.

In 1975, J.P. Lanly completed a forest inventory manual with special references on heterogeneous tropical forests; this manual was published by FAO in Rome.

A theoretical study on sampling plots with a constant number of trees was developed by Perrotte in 1976.

At a IUFRO meeting held in Bucharest in 1978 Brenac presented French national forest inventory and Bertrant explained the processing and publication of data.

In the 1980s new works enforced French contribution to the development of forest inventory in this country.

In 1981, Duplat and Perrotte published a 432 pp. book on “Inventaire et estimation de l’accroissement des peuplements forestièrs” (Inventory and the growth estimation of forest stands). This book is a practical guide divided in five parts: 1) Inventory of standing trees; 2) Inventory by sampling; 3) Estimation of stand growth; 4) The method of O.N.F. (National Forest Office) of forest inventory by sampling; 5) Practical guide for the application of O.N.F. method. Duplat and Perrotte detailed same aspects of the theory of regionalized variables developed in France by Matheron, cited before. In forestry the regionalized variables are the number of trees per hectare, volume per hectare, soil depth, regeneration density et al., and value of these variables depend on the environment that is investigated.

A special number of “Revue Forestière Française” was dedicated to French National Forest Inventory (Bazire 1984).

In connection with successive inventories in the forest Houllier (1985) discussed theoretical advantages and practical limits of sampling with partial replacement (SPR). “SPR can be applied to successive inventories of the same population. It is based on a mixed sampling design composed of permanent and temporary plots and on the classical linear statistical model…The SPR estimators can be generalized when there is a dynamic model of the population. SPR does not take into account the spatial structure of forests, but this can be compensated for by using the theory of Regionalized Variables…Two examples, are presented and they show that SPR could give considerable increases in accuracy for both regional and management inventories” (For. Abs. 1099/1986).

A booklet edited by the Ministry of Agriculture in 1985 presented a synthesis of the purpose and methods of National Forest Inventory. In his thesis (Université de Lyon) Houllier (1986) analyzed sampling and modelling of stand dynamics applied in the case of National Forest Inventory.

In 1987, Pardé and Bouchon published the second edition of "Dendrometrie" - a remarkable forest mensuration textbook - which contains a 64 pp. compartment referring to forest inventory and - whole chapter (5) to aerial photography in forestry including recent developments at the level of 1986/87. The first edition (1961) contains also a chapter with the aerial photography but at the level of knowledge available in the 1960 summarized in Spurr's (1960-U.S.A.), the second edition of "Photogrammetry" (first edition: 1948-U.S.A.).

The ECE worked out guidelines for Forest Damage Surveys. In 1988 most European countries, including France, followed these guidelines in assessing forest decline. For this type of inventories in France it was adopted a 16 x 16 km grid, with 24 trees per plot (Koehl 1996).

In 1992, Houllier and Pierrat presented application of Statistical spatio-temporal models to successive forest inventories, a work in connection with the theory of regionalized variables and sampling with partial replacement theory (SPR).

A relatively recent information on the French National Forest Inventory was published in 1995 at Nagent-sur-Vernisson, France, by "Inventaire Forestier National".

As many other European countries France adopted the principle of developing multi-resource forest inventories - MRI (Valdenaire 1997, Lagarde 1997).

The first practical photograph was announced to the French Academy of Arts and Sciences on the 7th of January 1839 by Arago. Daguerre and Niepce had succeeded to record permanent images (cited after Hildebrandt 1993). The first aerial photographs were attempted by Laussedat in France in 1858. Laussedat prepared in 1851 maps from terrestrial perspective and mapped French mountains by terrestrial photographic methods in 1861 (Spurr 1960, Ragey 1952).

Aerial photography was used in French forestry since the 1950s: Boutin (1953) - short information of the use of aerial photographs; Revue Forestière Française (1953) - a number devoted to aerial photography and its forestry applications; Huguet (1957) - the use of aerial photographs in forestry.

In 1960 there were published the instructions for photo interpretation of aerial photographs during the sampling (National Forest Inventory).

The information summarized by Pardé in his forest mensuration textbooks (Dendrométrie, 1961, and 1981 with Bouchon) on the use of aerial photographs have been already mentioned before. The use of aerial photographs in forest inventory was also described in 1962 by Brenac.

Hemispherical photography (from the ground) was used for the determination of standing tree volume (Ducrey and Bertoli 1974) and for the measurement of permeability of the canopy to the rays of the sun (Ducrey 1975). Spatial heterogenity of Scots pine canopy was assessed by Walter and Himmler in 1966 by hemispherical photographs.

Satellite imagery was used in France since the early 1970s. Since 1972 remote sensing was used for mapping forest fires in the Mediteranean area from Landsat data (Husson 1982). In 1985, Canavese and Dagorne assessed forest fire zones by airborne color infrared remote sensing (Tanneron massif, SE France) and showed that: “forest fires spread independently from the topography and were not halted by roads, and air photographs were accurate enough for insurance purposes and for investigating causes and exacerbation of forest fires”. (For. Abs. 3091/1988).

Based on SPOT simulation of the Landes forests Guyon et al. (1982) concluded that “it is possible to map different vegetation types associated with relative vigor of the trees” (For. Abs. 4015/1985).

Landsat and SPOT imagery of forests of Ardennes and Orleans make possible to establish vertical and horizontal structure of plant formation, forestry practices and the main species.

The application of nadir looking airborne radar proved to be possible in forestry to measure height and density of maritime pine stands in SW France (Bernard et al. 1987). By satellite image processing and application of stepwise discriminant analysis was possible to distinguish 12 forest types in the Haugenau forest of Alsace (Schneider and Hirsch 1987).

Leprieur et al. (1988) analyzed the influence of topography on forest reflectance using Landsat Thematic Mapper and digital terrain data in mountainous forest in eastern France. Remote sensing (data from Landsat TM and SPOT) makes possible the classification of forest vegetation, shrubby wasteland, grassland and bare soil on quarry sites (Pasquier and Girard 1988).

Comparison of different treatment methods for the principal analysis of Landsat - 5 TM data was applied to the inventory of Mediterranean forests of the south of France by Manière et al. (1991).

Forest biomass was related to synthetic aperture data (SAR) for *Pinus pinaster* in the Landes (Toan et al. 1992).

Satellite imagery was used for the assessment of forest damage since the 1980s. Three examples will be mentioned: the decline of oak (*Quercus robur*) in the French forest using SPOT simulation (Riom et al. 1982), Pyrénées atlantiques

(Rion 1985), and forest damage in Normandy (Boissard and Andrien 1985).

Remote sensing was used in 1990 for the estimation of optical properties of vegetation canopies (Guyot G.).

The analysis by linear spectral breakdown of pixels developed in 1994 by Cadima and Deshayes was “a first attempt to apply a new method for the analysis and processing of multispectral images, called Spectral Mixture Analysis, in which the spectral information of the minimum element (i. e. the pixel) is broken down into its more significant basic components (of shade, soil and vegetation type). In this work a linear model is tested on a multispectral TM image of hilly forested region of southern France (Monts de Lacaune. Since there are only a few publications on this method, this paper essentially establishes the technique. Based on the results archived, further development is proposed, and the first results obtained indicate how this work should proceed” (For. Abs. 1912/1966).

The modelling of forest ecosystem requires information on canopy chemistry. To determine this chemistry Zagolski et al. (1966) tried high spectral resolution remote sensing. According to the application of laboratory derived predicative equations to airborne data the best correlations (r^2) were obtained for nitrogen (AVIRIS 55% - Airborne visible/infrared Imaging Spectrometer, ISM 66% - Infrared Spectra Meter) and cellulose (AVIRIS 63%).

Using plan metric AIRSAR (satellite synthetic aperture radar) Proisy et al. (2000) obtained interpretation of polarimetric signatures of mangrove forests; the P-band provides the most pronounced polarimetric signatures.

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3.11. Chronology of selected papers and events

Before 1600: Application of the formula “cubage au cinquième” for logs, volume = *2(C/5) l*, *c* = girth in the middle of the log and *l* = its length (Gustav Huffel).

1691: First selling of standing trees, price per tree (G. Huffel).

1721: Textbook: "Reflexions sur l'Etat des Bois Royaume" [Thoughts on the condition of the royal forests] (R. A. F. Reamur).

1747: Selling of trees based on volume appeared in France in 1747 (G. Huffel).

1755: Textbook: "Traité Complet des Bois et des Forêts". [A comprehensive treatise on wood and forest. Vol. I and II] (Henri Louis Duhamel de Monceau).

1758: "La Physique des Arbres" [Structure of trees] (H. L. Duhamel de Monceau).

(1737) ? 1758: According to Fritts (1976) the honour to discover the first crossdating belongs to Duhamel de Monceau and Buffon in 1737. Crossdating of tree-ring samples is mentioned in "La Physique des Arbres (1758) by Duhamel de Monceau.

1764: Textbook: "De l'Exploitation des Bois …" [The utilization of woodlands …] with consistent references on forest mensuration being the first French book which contains important information in this field (H. L. Duhamel de Monceau).

1770: "Manuel Forestier et Portatif [Foresters manual and pocket book] (Guiot).

1791: A formula for log volume determination based on the measurement of terminal sections and multiplying the mean of these sections by log length. This formula is equivalent to Smalian's formula (Blanquart de Septfontaines).

1790, 1792: The use of first graded curved caliper. In France girth is measured instead of diameter (Varenne de Fenille).

1800: Adoption of metric system in France; compulsory since the 1st of January 1840.

1812: The first treatise on volume determination of wood based on the metric system (Herbin de Halle).

1815: Encyclopédie méthodique. Part 2: Methodes et tables pour la cubature des bois [Forest encyclopedia. Part 2: Methods and tables for volume determination] (Blanquart de Septfontaines).

1839: The first practical photograph was announced to French Academy of Arts and Sciences.

1851: Maps from terrestrial photographs.

1858: The first aerial photographs were attempted by Lausedat (L. Ragey 1952).

1859: "Guide du Forestier" [The forester's guide] considered as one of the most successful French books: 14th edition in 1947! (A. Bouquet de la Grye).

1861: French mountains mapped.

1878: The original concept of the control method (A. Gurnaud).

1889: One of the earliest alignment charts on stand growth determination (Bartet).

1892, 1895: Influence of climatic factors on early and late wood in tree-ring (E. Mer).

1894, 1901, 1902: Algan's "universal" tariffs: one entry volume tables (H. Algan).

1898: The first successful study (based on mathematics) on structure of uneven-aged stands concerning distribution of trees by diameter categories (F. de Liocourt).

1914: Early works on determination of the tree diameter growth (B. de Fanteny; G. Vaulot).

1919, 1924: "Économie forestière" Tome II (Forest economics vol. 2). Edn. 1924: "Économie forestiere, II Dendromètrie. [Forest economics vol.2, Forest mensuration (Gustav Huffel)].

1924: Method used in early forest surveys (P. Caziot).

1930: "Sapinières. Le jardinage par contenance" [Fir forests. Selection system]. Information of the structure of uneven-aged forests (A. Schaeffer, A. D'Alverny and A. Gazin).

1932: Application of the statistical method of correlation in construction of tariffs (L. Schaeffer).

1945, 1952: Volume determination of logs NF B 53-015, industrial wood and fuel wood NF B 53-018 (AFNOR: Association Française des Normes).

1948, 1950: The first two entry volume tables for the stem of standing trees (L. Schaeffer).

1949: A major improvement of Algan's tariffs: "Tarifs rapides et tarifs lents". [Rapid tariffs and slow tariffs] constructed depending on taper and based on equations (L. Schaeffer).

Since 1950: Aerial photography was used in forestry.

1950: Curves and tables of growth (in stere) and a simplified yield table for coppice – 9 classes of productivity that may be considered as the earliest yield table constructed in France (F. Gannevat).

1950s-1980s: Use of tarifs Chaudé (24). [Chaudé tariffs or one-entry volume tables for standing trees with variable decreasing taper] (P. Chaudé).

1951: Tree and stand cambium area as a characteristic for growth determination (J. Lescafette).

1953: Revue Forestière Française - A number devoted to aerial photography and its forestry applications.

1954, 1956: The use of statistical methods (regression equations) for the improvement of volume tables constructed by graphical methods (P. Ayral –1954, J. Abadie and P. Ayral - 1956).

1955:Application in France of Bitterlich relascope (P. Barault, J. Pardé).

1956: Methods for volume determination of standing trees on experimental plots in forestry (J. Abadie and P. Ayral).

1956-1963: Forest inventory and statistical methods (J. Pardé - 1956, 1957a, 1957b; E. Maurice 1957, J. Pardé 1960, 1961, V. Consigny 1961, J. Pardé 1963).

1956: "Barème de cubage des bois en grumes d'oeuvre, bois d'industrie, bois de mine" [Standard norms for saw logs, industrial wood and mining timber] (P. Chaudé and E. Decesse).

1956: Researches on connection between forest productivity (m^3/ha/yr) and CVP Paterson climatic index (J. Pardé).

1958: Examples of application in France of Cajander's forest site type system (Duchaufour-Jacamon-Debazac-Pardé).

1958: Tariffs for standing trees with variable taper (P. Chaudé).

1957-1961: Early volume tables constructed by species and named in France as "special volume tables" (J. Pourtet-1957, L. de Lapasse-1958, J. P. Maugé 1961).

1960: Publication of instructions for photo-interpretation.

1960s-1970s: Beginning of the first dendrochronological studies in France and the first tree ring chronology by Giertt (unpublished) and mentioned by Eckstein-1972 (J. Florence-1962; F. Serre, H. Lück and A. Pons-1966, P. de Martin 1970, F. Serre 1973).

1960-1980: The first modern inventory cycle of National forest inventory.

1961: Déndrométrie [Forest mensuration] (J. Pardé).

1966, 1970: Densitometric scanning of the tree-ring cores using X-ray and densitometric scanning of X-ray negatives, introduction of synthetic xylochronologic profiles (Hubert Polge).

1967, 1969: Forest yield and environmental factors and index of site productivity (N. Decourt).

1968: Forest inventory based on systematical sampling along the contour lines of the ground (J. Bouchon).

1968: Methods of tree biomass estimation (A. Reidacker).

Since 1970: The use of satellite imagery.

1971: First use of taper equation method for construction of two entry volume tables (P. Mendiboure).

1971, 1973: Decourt's yield tables for spruce (north-eastern France and Douglas-fir (eastern Massif Central) (N. Decourt).

1973: A collection of ten yield tables for species grown in France (ENGREF).

1974: The use of the regionalized variables in forest inventories (J. Bouchon).

1974, 1975: Early growth model for Norway spruce growth [P. Mendibourne and C. Barneoud (1974)], and growth and yield model of *Pinus maritima* (J. P. Maugé).

1974, 1975: Utilization of hemispherical photographs (on the ground) for determination of tree volume and permeability of canopy to the rays of the sun (M. Ducrey 1975, M. Ducrey and M. Bartoli 1974).

1974, 1977: Application of factor analysis of correspondences in dendrochronology (J. P. Briane, J. J. Lazare, G. Roux, C. Sastre-1974; Francoise Serre 1977).

1975: Functions for yield tables for computerized use (J. H. Ottorini).

1978: Investigations on the relationship between stand density and growth of trees (J. M. Ottorini).

1978: Estimation of the dendrochronological value of European larch (*Larix decidua* Mill.) in the French Maritime Alps: Vallée des Merveilles, north of Nice (F. Serre).

1980s-1990s: The construction of two entry volume tables by species continued (J. Bouchon-1982 beech, T. Bérard and P. Caillebotte, M. Najar, J. Lauvier-1983 Douglas fir; F. Courbet – 1991 *Cedrus atlantica*; F. Guinaudeau and P. Duplat 1994-Norway spruce).

1981: Application of factorial analysis for determination of *Pinus maritima* height growth (B. Lemoine).

1981: A textbook on the inventory and estimation of stand growth (P. Duplat and G. Perrotte).

1982: Remote sensing in France for mapping forest fires (A. Husson).

1982: A review of biomass papers published between 1951-1981 (Francine Cupi).

1982: The assessment of oak decline using SPOT simulation (J. Riom, P. Mouhot and C. Torres.

1982: The use of ARMA model in French dendrochronology (J. Guiot, F.Serre-Bachet, L. Tessier).

1983: The use of age-dominant height (determined by stem analysis) as basis for yield classes (J. Toth).

1984: A detailed study on dendroclimatology and ecology of *Pinus sylvestri*s L. and *Quercus pubescens* Willd. in southeastern France (L. Tessier).

1985: Biomass and mineral content of mixed coppice stands in Ardennes: *Quercus* spp., *Betula verrucosa, Sorbus aucuparia* (J. Bouchon, C. Nys and J. Ranger).

1985: Successive inventories in the forest: theoretical advantages and practical limits of sampling with partial replacement (F. Houllier).

1985: Oak dieback in France: the contributions of remote sensing (J. Riom).

1987: Déndrometrie [Forest mensuration] (J. Pardé and J. Bouchon).

1990: Optical properties of vegetation canopies (Guyot, G.).

1990s: Volume tables prepared by the Technical Research Department of the French National Forest Office (ONF) by species, type of cut (commercial felling, first thinning, etc.) and volume (especially merchantable volume, merchantable volume crown and stem branches included). Tables refer almost to all species grown in France and are also listed in M. Vallance's (1995) work.

1991: Bootstrap statistical procedure which provides a way to test the significance of the regression coefficients and stability of the estimates in the response functions generated by regression on principal components (J. Guiot).

1992: Application of statistical spatio-temporal models to successive forest inventories (F. Houllier and J. C. Pierrat).

1992: Forest biomass was related to synthetic aperture radar - SAR data (T. Le Toan, A. Beaudoin, J. Riom, D. Guyon).

1993 (1995 publ.): Application of multiple correlation functions in dendroclimatology (C. Rolland).

1995: A summary on concepts and characteristics of various growth models (J. Bouchon).

1995: Growth trends of French forests (Jean Luc Duponey, Michael Becker, Jean-François Picard, Guy-Didier Bert, Vincent Badeau and Francois Lebourgeois).

1995: Growth modelling linked to timber quality assessment for Norway spruce (F. Houllier, J. M. Leban, F. Colin).

1996: A model of even-aged beech stands productivity with process-based interpretation (J. F. Dhôte).

1996: Element analysis of tree-rings in *Quercus robur* as an indicator of historical trends in the soil chemistry related to atmospheric deposition (G. Lévy, C. Bréchet, M. Becker).

1996: Forest canopy chemistry with high spectral resolution remote sensing (F. Zagolski et al.).

2000: Interpretation of polarimetric signatures of mangrove forests (C. Poisy, E. Mougin, F. Fromard, M. A. Karam).

3.12. Selected contributors

In chronological order:

Contributor	Printing years	Field
Louis de Froidour	1665, 1668	Regulations relating to forest
Henri Louis Duhamel de Monceau	1758, 1764	Forest mensuration, general
Blanquart de Septfontaines	1815	1
Adolphe Gurnaud	1825-1898	Forest management, 3, 7
A. Bouquet de la Grye	1859	Guide general, the most successful forest book
Henri Nanquette	1860	General, forest management
Alexis Frochot	1887, 1890	1
E. Mer	1890s	6
H. Algan	1894, 1900s	1
F. de Liocourt	1898	3
Gustav Huffel	1919, 1924	General forest mensuration
P. Chaudé	1930s-1980s	1
L. Schaeffer	1930s-1950s	1, 4, 3
P. Ayral	1950s-1980s	1, 4, 7
J. Pardé	1950s-1990s	General forest mensuration 4, 1, 5,7
L. Brenac	1950s-1970s	1, 7
N. Décourt	1960s-1970s	4, 2
J. P. Maugé	1960s-1970	1, 4
Hubert Polge	1960s-1970s	6
A. Reidacker	1960s-1970	6
F. Serre	1960s-1970s	6
J. Bartet	1970s	4
J. Bouchon	1960s, 1980s	5, 3, 1, 4, General forest mensuration, 7
G. Perrote	1970s	7

Contributor	Printing years	Field
J. P. Lanly	1970s-1980s	1, 4, 7
P. Mendiboure	1970s-1980s	1, 4
J. M. Ottorini	1970s-1990s	1, 4, 3
J. Ranger	1970s-1980s	5
P. Duplat	1980s	7
F. Courbet	1980s-1990s	1, 4
J. Guiot	1980s-1990	6
B. Lemoine	1980s	1, 5
J. Riom	1980s	7
J. Toth	1980s	2, 4, 5
F. Houllier	1980s-1990s	7

1 = tree and primary products; 2 = forest site evaluation; 3 = stand structure; 4 = stand growth and yield; 5 = weight and biomass; 6 = tree-ring studies; 7 = forest inventory and remote sensing.

3.13. Comments

French forests became the object of restricted harvesting of wood by ordinances as those of 1280, 1318, 1346. After 1376 when the Mélun ordinance became law, the trees for felling were marked with a special hammer and cleared area was restricted to 10-15 hectares. Forest mensuration procedures began to appear after the beginning of the 17th century. On the other hand "because of increasing demand of timber, the forests had deteriorated as a result of the Thirty Years War, corruption and general instability" (James, 1996, p. 23).

In connection with the development of French forest mensuration the following remarks should be considered:

(1) In French forest mensuration measurement of girth (trees and logs) has been preferred to the measurement of diameters.

(2) French foresters avoided the use of form factors and form quotients and, at the beginning preferred construction of volume tables based on empirical and graphical methods.

(3) Algan's tariffs (20 one-entry volume tables) dominated French forest mensuration up to the 1950s when the first "special" volume tables began to be constructed and refer to species, and later (in the 1970s), two entry volume tables based on equations, having as a rule a regional or local validity.

(4) General, two-entry volume tables, valid for all countries, were developed after 1980.

(5) Up to 1946 the construction of yield tables was avoided. The construction of yield tables, advocated especially by Décourt, began its sustainable developing after 1950.

(6) Age-height relationship was used like in other European countries as a criterion for site evaluation (site index) in the 1980s.

(7) Biomass studies were developed since 1950 and reached a maximum during the 1970-1985 period.

(8) Modelling, computerized modelling respectively, in forest mensuration was used on a larger scale during the last decade of the 20^{th} century.

(9) The major part of tree-ring studies appeared between 1961 and 1980.

(10) Among the classical works of French forest mensuration should be mentioned the one written by Henri Louis Duhamel de Monceau (1764), Guiot 1770, Gustav Huffel (1919), Pardé (1961), Pardé and Bouchon (1988).

(11) The National forest inventory began in 1960.

(12) Aerial photography was used after 1950 and satellite imagery after 1970.

(13) At the end of 1990s France adopted the principle of development of multi resource forest inventories (MRI).

The repartition of cited papers by fields and time periods and by fields within each period suggested the following observations:

(a) The highest frequencies of publications by fields were identified to be the following:

Field	Period with maximum selected titles	Trends: (1981-2000) period compared to the previous period (1961-1980)
Tree	1941-1960	↗
Site	1961-1997	→
Stand structure	1921-1940, 1961-1980	↘
Stand growth and yield	1941-1960	↗
Weight and biomass	1961-1997	→
Tree-ring studies	1961-1980	↘
Forest inventory	1981-2000	↗

(b) The dominant fields by periods show the following

Period	Field with the greatest number of works
Before 1901	Tree and primary products (especially logs)
1901-1920	Tree and primary products (especially logs)
1921-1940	Stand structure
1941-1960	Tree and primary products
1961-1980	Tree-ring studies National Forest Inventory Stand growth and yield
1981-2000	Tree and primary products Growth and yield modelling National Forest Inventory.

The major interest of French timber mensuration in tree and primary products measurement is evident, but during the last decade of the 20th century the interest in growth and yield modelling increased visibly and that in forest inventory based on statistical methods and remote sensing techniques.

Out of 370 bibliographical references selected from 1665-2000 period 33 were printed after 1980 and 12 after 1990.

From a historical point of view it is interesting to mention the works in French about forest mensuration published from 1921 to 1924 as the most important, they have been considered important for the U.S.A. by Chapman: L' aménagement des forêts (2d Edit.) Puton, Paris 1874; Notice sur les dunes de la Coubre, Vasselot de Régné, Paris 1878; Aménagement des forêts - Estimation, Fallotte, Carcassonne 1879; La méthode du contrôle de Gurnaud, Grandjean, Paris 1885; L'art forestier et le contrôle. Gurnaud. Besançon, 1887; L'aménagement des forêts (V. Edit.), Tassy, Paris, 1887; Traitéd'economie forestière, Puton, Paris, 1888; Cours d'aménagement professé à l'Ecole forestière (1885-1886) 2 cahiers, Reus, Nancy, 1888; Diagrammes et calculs d' accroissement, Bartet, Nancy, 1889; Guide théorique et practique de cubage des bois, Frochot, Paris, 1890; La méthode du contrôle á l'Exposition de 1889, Gurnaud, Paris, 1890; Note sur une nuvelle méthode forestière dite du contrôle de Gurnaud, de Blonay, Lausanne, 1890; Traité d'économie forestière. Aménagement, Puton, Paris, 1891; Le traitement des bois en France, Broillard, Paris, 1891; Estimation et exploitabilités forestières, Bizot de Jontez, Gray, 1894; Notes pour la vente et l'achat des forêts, Galmiche, Besançon 1897; Notes forestières - Cubage, estimation, etc, Devarenne, Chaumont, 1889; Economie forestière, Huffel, Paris, 1904-1907; Cubage des bois sur pied et abattus manuel pratique, Berger, Levrault et al. Paris, 1905. Mathématiques et Nature, Broillard, Besançon, 1906; Aide mémoire du forestier - Sylviculture, Demorlaine, Basançon, 1907. There was an "Informational gap" of about 31 - 47 years (!) that explains partially at least the reduced influence of French on the development of American forest mensuration in contrast with the Germans who were represented in the U.S.A. at the end of the 19th century and the beginning of the 20th century by outstanding foresters such as B. Fernow and C. A. Schenk.

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4. GERMANY

General information

Land area 349,340 sq. km (134,885.5 sq. mi), forest and other wooded land 107,350 sq. km (41,449.5), total forest 10,490,000 ha or 24 % of land area; volume 266 m^3/ha, biomass 155 tons/ha. (FAO 1955-124 Forest resources assessment).

Round wood production: industrial round wood 32.45 million m^3, fuel and charcoal 3.795 million m^3, total round wood 32.245 million m^3 (World Resources 1996-1997, table 9.3, p. 200).

Forest vegetation: temperate mixed forest:

- Conifers 70 %;
- Broad-leaved 30 %;
- Main species: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), oaks (*Quercus robur, Q. petraea*), European beech (*Fagus sylvatica*), European larch (*Larix decidua*).

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

Forestry education institutions:

- University of Technology Dresden, Faculty of Forestry, Geology and Hydrology, Department of Forest Sciences, Tharandt (1811);
- University of Göttingen, Faculty of Forestry, Forest Sciences Teaching Area, Göttingen (1868);
- University of Munich, Faculty of Forestry, Chair of Silviculture and Forest Management, Freising (1878);
- University of Freiburg, Faculty of Forestry, Institute of Forest Management and Forest Economics, Freiburg (1920);
- University of Göttingen, Faculty of Forestry, Institute of Forest Management Göttingen (1925);
- University of Freiburg, Faculty of Forestry, Institute of Forest Increment Freiburg (1932);
- University of Freiburg, Faculty of Forestry, Department of Forest Biometrics, Freiburg (1966);
- University of Technology Dresden, Faculty of Forestry, Geology and Hydrology, Institute of Forest Increment and Forest Informatics, Tharandt;
- College of Forestry, Schwarzburg, Thüringia (1994).

Forestry research organizations:

• University of Munich, Chair of forest economics, Freising (1882);

• University of Munich, Chair of Ergonomics and applied Forest Computer Science, Freising (1921);

• University of Göttingen, Institute of Forest Management and Forest Increment, Göttingen (1929);

• Lower Saxony Forest Research Institute, Department of Growth and Yield, Göttingen (1950);

• Forest Research Institute Baden-Württemberg, Freiburg (1958);

• University of Freiburg, Institute of Forest Management and Forest Ecology, Department of Photogrammetry and Remote Sensing, Freiburg (1968);

• University of Freiburg, Department of Remote Sensing and GIS, Freiburg (1969);

• Institute of Ecology, Landscape Depelopment and Forest Planning (LOLF), Recklinghausen (1975);

• Bavarian State Institute of Forestry, Freising (1979);

• Saxony State Forestry Centre, Graupa (1991);

• State Institute for Forest and Forestry, Gotha (1991);

• Federal Research Centre for Forestry and Forest Products. Institute for Forest Ecology and forest Inventory, Eberswalde (1992);

• University of Munich, Teaching area of Forest Biometry and Applied Computer Sciences, Freising (1992).

Publications:

• Journal für Forst- und Jagdwesen 1790-1797 (It is considered by Fernow (1911) as the first European publication on forestry);

• Kritische Blätter, Leipzig, 1823-1870;

• Forst- und Jagdliteratur, 1870-1875;

• Forstliche Blätter, Berlin, 1861-1890;

• Aus dem Walde, Hannover, 1865-1881;

• Zeitschrift für Forst- und Jagdwesen, Berlin, 1869-1943 (published by Julius Springer);

• Planta; Archiv für Wissenschaftliche Botanik. Vol. 1 (1925)+, Berlin, J. Springer-Verlag. Irregular;

• Allgemeine Forst- und Jagdzeitung, Frankfurt a. M. (1825)+;

• Forstwissenschaftliches Centralblat, München-Berlin 1928;

• Tharandter Jahrbuch. Tharandt;

• Mündener Forstliche Hefte. München;

• Allgemeine Forstzeitschrift, München;

• Forst- und Holzwirt, Hannover;

• Holzforschung. Vol. 1 (1947)+. Berlin, Walter de Gruyter. Bimonthly;
• Oecologia. Vol. 1 (1968) +.Berlin, Springer-Verlag. Monthly;
• Archiv für Forstwesen, Berlin (former DDR);
• Forst und Jagd, Berlin (former DDR);
• Forstarchiv, Berlin (former DDR);
• Trees; Structure and Function. Vol. 1 (1986)+. Berlin: Springer International. Quaterly.

German database: ELFIS (1984) = Ernährung Land - und Forstwirtschaftliches. Information system covers forestry, the timber industry and allied agricultural fields. ELFIS has a current annual update about 15,000 records.

History. In his last paper the outstanding British forestry historian, N. D. G. James referring to Germany, France and the United Kingdom, mentioned that: ...”certain features in their respective forest histories are common to all. Early forests were areas of land over which kings or their equivalents exercised the right to hunt: these lands were not necessarily entirely covered with trees but often included cultivated fields, wastes, villages, and scattered woodland. However, in some parts of France and Germany there were large areas of natural forests which at first met the needs of these countries. But in the course of time, as the countries of Europe developed and achieved economic progress, the demand for timber increased, putting great pressure on these remaining forests.” (From “A history of forestry and monographic Forestry Literature in Germany, France and the United Kingdom”, p. 15, James 1996.).

Broad-leaf stands were predominant in Medieval Germany (Rubner, H. 1992). Faster exploitation of mines and salt-wells, and the charcuts in the mountainous areas affected timber supplies. The depletion of the forests was accentuated during the Thirty-Years War (1618-1648). At that time the German empire (founded by Charles IV in 1356) was decomposed in several independent states, principalities and palatinates each with its own legislation and traditions.

During the 17th and 18th centuries the necessity to regulate forestry had become pressing and a number of forest ordinances (Forstordnungen) were issued: Hesse-Kassel Ordinance of 1711, Hesse-Nassau ordinances (1736 and 1761), and as a result of these ordinances areas of land were planted with spruce, pine and oak. Resinous species occupied more and more land and the composition of German forest was changed in favour of conifers (this change should be connected in way with the forest decline phenomena of the 20th century.

As a consequence of the development of silviculture appeared the need for forest management and the necessity to measure and calculate the volume, growth and yield of forest stand.

James (1996) noted that “By 1770, the Germans were gaining a reputation as foresters” and “Germany was in the forefront of a more technical approach to forestry. An increasing number of books on forestry matters being published in Germany provided valuable sources of information as well as a means of disseminating new ideas” (p. 17). For instance, in Herman Schmid´s Fach-Katalogue ...” there are given the titles of German works published from 1870-1875 inclusive, containing 650 references. The classification of these references is interesting from historical point of view because it shows the fields in which foresters of that time were more interested: Forest mensuration, forest tables and measurements 173 titles, game 135 (!), general forest economics 93, forest botany 60, forest legislation and game laws 56, forest history and statistics 50, forest zoology 19, peat and bog treatment 14, Forest Union and yearbooks 13, Forest technology 6. Upwards of a hundred new works had been published annually. (Herman Schmid´s catalogue is mentioned by J. C. Brown, U.K., who in the “Advertisement of preface to the “Forests of England” provided an insight of the literature in late nineteenth century in Germany (reference by Peter Mc Donald 1996).

Information of forest research during the 1881-1884 period are supplied by Grandhoffer (1881-1884) and later publications on timber volume determination during 1930-1939 period given by Tischendorf in 1939.

At the beginning of the 19th century the “Societät der Forst- und Jagdkunde” was probably the first professional forestry society. The first forestry congress was held in Dresden in 1837 with participants from local associations. Finally the “Deutscher Forstverein” (German Forestry Association) was founded in 1899 (Tombauch 1996 reference by Mc Donald 1996).

In 1872 the establishment of the German Union of Forest Research Institutes represented a very important contribution toward the standardisation on mensurational techniques. The Union recommended the establishment of permanent sample plots to be used for the development of yield tables.

The aerial photography was in the service of forest management at least since the 1920s (Krutzsch 1925) and an important bibliography on photogrametry and photography used in forest between 1887 and 1968 was published by Hildebrand (1969).

By the second decade of the 20th century forest science was fully incorporated into university curriculum with education and research.

In 1949 the Hollerit system of punched cards was introduced in state forest administration (Wilckens 1950).

In the early 1960s simulation and modelling by using computers became a new way for the development of forest mensuration and forest management as for other fields of forestry.

In 1992 in "Biometrics and the holistic view" - a short paper presented at IUFRO Centennial - Prodan (1992) remarked that "With the implication and interactions between the forest sciences and the natural and social sciences and between the forestry and the human society and their institutions, the amount of biometrics tasks will also increase. A change in the direction of complex thinking is very necessary".

4.1. Books, textbooks and auxiliary tables containing information on forest mensuration

Except for Noe Meurer´s book published in 1576 which contains information on game law and partly dealing with forestry (according to "Forestry in the Federal Republic of Germany", 4th English edn., Bonn, Ministry of Food, Agriculture and Forestry, 1962, p. 54), the first book referring only to forestry appeared in 1713: "Sylvicultura Oeconomica" [The economics of silviculture" by Hans Carl von Carlowitz (Leipzig: Johan Friedrich Braun)]. This books refers also to forest management and contains a few data on forest measurements.

Oettelt´s (1765) book "Praktischer Beweis, dass die Mathesis bey dem Forstwesen unentbehrliche Dienste tue" (Practical arguments for use of mathematics in forestry) may be considered as the first book regarding to the aspects of timber mensuration, especially basic formulas for log volume determination.

During the second part of the 18th century and the first decade of the 19th century some important categories or characteristics have been defined:

• Formulas for log volume determination (Oettelt - 1765 and Krunitz - 1781) who knew Huber´s (1928) formula 47 years before;

• According to Prodan et al. (1997), Paulsen (1795) developed the first empirical formula for determination of forest productivity. Th. Hartig (1847) reproduced and attributed to Paulsen and G. L. Hartig the first German yield tables (for beech);

• Paulsen developed also the theory of form factors published later by Klauprecht in 1842 and 1846; he recommended also the use of mathematical statistics in forestry;

• A treaty about the growth of forest (J. L. Späth 1798);

• The first volume table (Cotta 1804);

• Later, H. L. Smalian (1837) published "Beitrag zur Holzmesskunst" (Contribution to timber measurement) and that may be considered as the first German study on forest mensuration.

The term “Holzmesskunst” (The art of timber measurement) was used in 1837 by H. L. Smalian, Klauprecht in 1842, Kunze in 1873. The first to use the term “Holzmesskunde” (Forest mensuration) was Franz Baur in 1860 in his first edition of “Die Holzmesskunde”. This term for forest mensuration was used later by Pressler and Kunze (1873), Langenbacher and Nossek (1889), Schwappach (1889), Udo Müller (Mueller) in 1899, Wimmenauer (1907), A. V. Guttemberg-Müller (1927), Hufnager (1931), Krenn (1948). Prodan (1951) noted that “Holzmesskunde” refers to measurement and numerical expression of the characteristics that define the content and form of trees and stands. The term “Holzmesslehre” meaning of “forest mensuration” was used in Austria by R. von Guttenberg (1912) and in Germany by M. Prodan (1951, 1965). H. Kramer and A. Akça used the term “Dendrometrie” (1982).

In 1860, Baur considered that the purpose of forest mensuration is “Baum- und Bestandesschätzung, forstliche Körperlehre” (Tree and stand mensuration, forestry science of stereometry) - volume and age determination and growth determination of tree and the whole stand. Schwappach (1889) and Udo Müller (1899) defined forest mensuration in the same terms as Bauer but underlined that **Ertragskunde** (as part of forest mensuration) is a science of forest productivity connected with natural conditions, forest management and economical aspects. Finally, they considered that the basic elements of forest mensuration are mathematics, applied physics and the use of mathematical statistics methods.

Michail Prodan (1965) and Prodan et al. (1997) presented the following definition: “Forest mensuration is a science of the mensuration of the forest and its products. It represents finally the application of the basic principles of mathematics, geometry and physics.

In table 4.1.-1. is given a list of special works on forest mensuration published during 234 years, between 1765 and 1999. The books published by Weck (1948, 1955), Mitscherlich (1956), Assmann (1970), Prodan (1951, 1961, 1965, 1968), Mitscherlich (1978), Van Laar and Akça (1997) and Prodan et al. (1997) are the most representative exponents of German lore in the field of forest mensuration.

A special textbook is “Modelling Forest Development by Klaus von Gadow and Gangzing Hui published in 1999. The content of this book refers to: (1) types of forest models and data requirements; (2) projecting regional timber resources: empirical yield functions and yield functions based on MAI estimates (mean annual increment); (3) modelling stand development: height, basal area, potential density, state-space models, stand volume and product yields, thinning models; (4) size class models: diameter growth, diameter-height relations, estimating product yields, modelling thinnings; (5) individual tree growth: generating spatial structures, competition indices, spatial growth models, spatial thinning models; (6) model evaluation: qualitative evaluation, quantitative evaluation.

TABLE 4.1.-1. Selected works on forest mensuration

First printing	Other printings	Author(s)	Title
1765		Oettelt	Praktischer Beweis, dass die Mathesis bey dem Forstwesen unentbehrliche Dienste tue (Practical arguments for use of mathematics in forestry)
1781		Krunitz	Ökonomische Encyklopaedie (Encyclopedia of economics)
1795		J. C. Paulsen	Kurze praktische Anleitung zum Forstwesen. Verfasst von einem Forstmanne. Herausgegeben vom Kammerrat G F. Führer (Practical course and recommendations for foresters. Translated by Führer)
1798		J. L. Späth	Abhandlung über den forstlichen Zuwachs und Gehaubestimmung (Dissertation on determination of forest growth)
1813		Gottlob König	Anleitung zur Holztaxation (Instructions on the taxation of timber)
1837		H. L. Smalian	Beitrag zur Holzmesskunst (Contribution to timber measurement)
1840		H. L. Smalian	Anleitung zur Untersuchung des Waldzustandes (Recommendations for investigation of forest condition)
1842	1846 (2nd edn.)	J. L. Klauprecht	Die Holzmesskunst (Timber mensuration)
1846		K. Heyer	Anleitung zur forststatischen Untersuchungen (Recommendations for statistical researches in forestry)
1852		G. Heyer	Über die Ermittlung der Masse des Alters und des Zuwachses der Holzbestände (About determination of volumes, ages and growth in forest stands)
1857		Karl Brehmann	Anleitung zur Aufnahme der Holzmasse (Recommendations for inventory of forest volume)
1860	1875 (edn. 2) 1882 (edn. 3) 1891 (edn. 4)	Franz Baur	Die Holzmesskunde (Forest mensuration)
1868		Karl Brehmann	Anleitung zur Holzmesskunst (Recommendations for timber measurement)

TABLE 4.1.-1. (cont.)

First printing	Other printings	Author(s)	Title
1873		M. F. Kunze	Lehrbuch der Holzmesskunst (Textbook of timber mensuration)
1873		M. Pressler M. Kunze	Die Holzmesskunde in ihrem ganzen Umflage (Timber mensuration and its rules (laws))
1889		F. L. Langenbacher E. A. Nossek	Lehr- und Handbuch der Holzmesskunde (Science and a handbook of forest mensuration)
1889	1903 (ed. 2) 1923 (ed. 3)	Adam Schwappach	Leitfaden der Holzmesskunde (Textbook on forest mensuration)
1899	1900 1901, 1902 1915 (edn. 2) 1923 (edn. 3)	Udo Müller	Lehrbuch der Holzmesskunde (Textbook of forest mensuration)
1907		K. Wimmenauer	Grundriss der Holzmesskunde (Principles of forest mensuration)
1912	1925	R. von Guttenberg	Holzmesslehre. In Loreys Handbuch d. Forstw (Timber mensuration. In Lorey's Handbook of Forestry)
1927		A. V. Guttenberg-Müller	Holzmesskunde im Handbuch der Forstwissenschaft (Forest mensuration in the Handbook of Forestry)
1927		Wilhelm Tischendorf	Lehrbuch der Holzmassenermittlung (Textbook of timber volume determination)
1931		H. Hufnagel	Holzmesskunde, In: "Wald und Holz" (Forest mensuration, in "Forest and Wood")
1941	1948, 1949 (edn. 3)	Karl Vanselow	Einführung in die Forstliche Zuwachs- und Ertragslehre (Introduction into the knowledge of forest increment and yield)
1948		K. Krenn	Vorlesungen über Holzmesskunde (Course on Forest mensuration, Univ. Freiburg)
1948	1956	E. A. Mitscherlich	Die Ertragsgesetze (The laws of forest productivity)
1948	1955 (edn. 2)	J. Weck	Forstliche Zuwachs- und Ertragskunde (Forest growth and yield)
1950	1955 (edn. 2)	Eilhard Wiedemann	Ertragskundliche und waldbauliche Grundlagen der Forstwirtschaft (Fundamentals of growth and forest yield)
1951		M. Prodan	Messung der Waldbestände (Measurement of forest stands)
1951		Wilhelm von Laer Martin Spieker	Massen-Berechnungstafeln (Volume determination)
1957		E. Assmann	Lehr- und Handbücher: Holzmesslehre, in Neudammer Forstliches Lehrbuch (Timber mensuration, handbook)
1961	1968 Polisch translation, 1970 English translation	E. Assmann	Waldertragskunde (The principles of forest yield study)

TABLE 4.1.-1. (cont.)

First printing	Other printings	Author(s)	Title
1961	1968 Translated into English	M. Prodan	Forstliche Biometrie (Forest biometrics)
1965		M. Prodan	Holzmesslehre (Forest mensuration)
1966		W. Erteld E. Hengst	Waldertragslehre (Forest productivity)
1970-1975	1978 (edn. 2)	Mitscherlich G.	Wald, Wachstum und Umwelt. Vol. I, II, III. (Forest growth-development and the environment)
1980		F. Zöhrer	Forstinventur (Forest inventory)
1982	1987 (2nd edn.)	Horst Kramer Alparslan Akça	Leitfaden für Dendrometrie und Bestandesinventur (Textbook of timber mensuration and stands inventory)
1984		H. Kramer	Grundlagen zur Forstlichen Ertragskunde (Basics of forest yield science)
1988		H. Kramer	Waldwachstumlehre (Forest growth Science)
1990		G. Wenk Y. Antanaitis S. Smelko	Waldertragslehre (Textbook on forest yield)
1997		Anthonie Van Laar A. Akça	Forest mensuration
1997		Michail Prodan Roland Peters Fernando Cox Pedro Real	Mensura Forestal (Forest mensuration)
1999		Klaus von Gadow Gangying Hui	Modelling Forest Development

Table 4.1.-2. presents a list of selected works on forest management or forest inventory containing chapters or disparate information on forest mensuration.

Species monographs of German trees containing information on tree or stand mensurational characteristics are shown in table 4.1-3. Among species monographs with more detailed data referring to forest mensuration we have included the works of Wiedemann (1948) for Scots pine, Schoeber (1949) for larch and 1962 for Sitka spruce, Weck (1962) for spruce and H. Schmidt-Vogt (1986, 1991) with his excellent monograph of Norway spruce containing 207 pp. on the growth studies and yield tables for this species at European level.

A remarkable encyclopaedia of forestry (1257 pp.), contribution of many scientists, was published in 1959 ("Grundlagen der Forstwirtschaft") by Shaper-Hannover.

With this occasion it deserves to be mentioned the longest larch avenue in

Europe and its silvicultural importance. This avenue was Brüsenwalde as a road site plantation in 1798 (Sudeten larch - *Larix decidua* of Harbker prevenance and was planted at a spacing of 4 m within and 8 m between the rows and extended for 2.3 km. Of the 1171 trees initially planted (David 1988) 437 still remain. The largest larch, planted in 1780 was 50 m tall in 1987 and had 150 cm dbh.

TABLE 4.1.-2. Works on forest management or forest inventory containing chapters or disparate informa tion on forest mensuration

First printing	Other printings	Author(s)	Title
1795		G. L. Hartig	Anweisung zur Taxation der Forste (Instructions for forest management)
1804		Heinrich von Cotta	Sistematische Anleitung zur Taxation der Waldungen (Systematic instruction on taxation of old forest)
1841	1883 (edn. 3)	Carl J. Heyer	Die Waldertrags-Regelung (The profitable management of forests)
1885		R. Hess	Encyclopedie und Methodologie der Forstwissenschaft (Encyclopedia and the methodology of forest management)
1886		C. von Fischbach	Lehrbuch der Forstwissenschaft (Textbook of forestry)
1888		B. Borggreve	Die Forstabschätzung (Forest evaluation)
1889		F. Graner	Die Forstbetriebseinrichtung (Forest management)
1891		R. Weber	Lehrbuch der Forsteinrichtung mit besonderer Berücksichtigung der Zuwachsgesetze der Waldbäume (Textbook of forest management with special considerations on growth laws of the trees)
1893		F. Judeich	Die Forsteinrichtung (Forest management)
1898		H. Stötzer	Die Forsteinrichtung (Forest management)
1904		W. Weise	Ertragsregelung (Determination of allowable cut)
1938		H. Krutzsch F. Loetsch	Holzvorratsinventur und Leistungsprüfung in der naturgemäßen Waldwirtschaft (Inventory of standing trees and examination of natural productivity in forestry)
1959		Different authors	Grundlagen der Forstwirtschaft (Fundamentals in forestry: a forest encyclopedia)
1959 (edn. 2)		W. Mantel	Forsteinrichtung (Forest management)
1964		F. Loetsch K. E. Haller	Forest inventory vol. I

TABLE 4.1.-2. (cont.)

First printing	Other printings	Author(s)	Title
1973		F. Loetsch F. Zohrer K. E. Haller	Forest inventory vol. II
1979		A. van Laar	Biometrische Methoden in der Forstwissenschaft (Biometrical methods in forest management0
1992		K. von Gadow	Wachstums- und Ertragsmodelle für die Forsteinrichtung (Growth and yield models for forest management)
1996		G. Hildebrand	Fernerkundung und Luftbildmessung (Aerophotogrametry and remote sensing)

TABLE 4.1.-3. A sample of German tree species monographs containing information on tree or stand mensurational characteristics

Printing year(s)	Author(s)	Title (species)
1875	M. Willkomm	Forstliche Flora von Deutschland und Österreich (Forest flora of Germany and Austria)
1888	Robt. Hartig R. Weber	Holz der Rothbuche (Wood of beech)
1888	K. Schuberg	Aus deutschen Forsten. I. Die Weisstanne (About German trees. I. Fir. *Abies alba*)
1894	K. Schuberg	Aus deutschen Forsten. II. Die Rothbuche (About German trees. II. Beech. *Fagus sylvatica*)
1904	A. Cieslar	Waldbauliche Studien über die Lärche (Forestry studies on European larch: *Larix decidua*)
1904	F. Grudner	Untersuchungen im Buchenhochwalde (Researches in beech forests)
1908	A. Schwappach	Die Kiefer (*Pinus sylvestris*)
1919	K. Wimmenauer	Wachstum und Ertrag der Esche (Growth and yield of *Fraxinus excelsior*)
1937	E. Wiedemann	Die Fichte (Norway spruce: *Picea abies*)
1948	Eilhard Wiedemann	Die Kiefer 1948. Waldbauliche und ertragskundliche Untersuchungen (The pine, 1948. Silvicultural and yield research)
1949	Reinhard Schober	Die Lärche (The larch)
1962	R. Schober	Die Sitka-Fichte (Sitka spruce)
1962	J. Weck	Über das Wachstum der Fichte (About the growth of spruce)
1986	Helmut Schmidt-Vogt	Die Fichte. Ein Handbuch in zwei Bändern. Band II/1 Wachstum-Züchtung-Boden-Umwelt-Holz (Norway spruce)
1991	H. Schmidt-Vogt	Die Fichte II/3 (Norway spruce)

A number of auxiliary tables for forest mensuration and forest management (with information on tree and stand mensuration) has been published in Germany during the 19th and 20th centuries but only a few are mentioned here:

Cotta 1817, 1821 (auxiliary tables for forest management and forest appraisal), Schneider 1853 (growth tables and percentages), Pressler 1857 (new tables for forestry), T. Hartig 1874 (cubic and yield volume tables), Pressler 1881, 1882 and 1902 (tables for forestry), Kunze 1884 (tables for inventory of forest volume), Behm 1886 (volume tables for standing trees), Rausch 1886 (tables for determination of log and stem volume), Lorey 1888, 3rd edn. 1913 (forestry handbook), Lizius 1892 (tables for cubic content of round and sawed wood), Eberhardt 1894 (determination of round wood volume according to its length, Hundt 1894 (new system of volume tables), Anonymous 1898 (auxiliary tables for trees and stand volume determination for main species), Philipp of Baden 1896 (auxiliary tables for forest management), Behm 1901 (tables for cubic content of round wood), Stoetzer 1907 (auxiliary tables for forest management), Zimmerle 1930 (volume tables and growth tables for oak stands and empirical data for exotic species in Württemberg), Heck 1931 (handbook of open thinning); Laer 1936 (volume differences of standing trees, tables for forest inventory), Weck 1948 (auxiliary tables for stands, Bavarian Forest Service 1949 (mensurational tables for forest management), Wiedemann 1950 (tables for volumes and value of normal yield), Laer and Spiecker 1951 (tables for determination of standing trees and tables for stand growth), Ministerium für Ernährung, Landwirtschaft, Umwelt Baden-Württemberg 1966 (tables for forest management), Kramer and Bjerg 1976 (recommendations for forest measurements).

Cited authors:

Anonymous 1898, Assmann 1957, 1961, 1968, 1970; Baur 1860, Bayer. Staatsministerium 1949, Behm 1886, 1901, Brehmann 1857, 1868, Borggreve 1888, Cieslar 1904, Cotta 1804, 1817, 1821; David 1988, Different authors 1959 (1959 Encyclopedia of forestry), Eberhardt 1894, Erteld and Hengst 1966, Hunt 1894, Fischbach 1886, Gadow 1992, Gadow and Hui 1999, Graner 1889, Grudner 1904, Guttenberg-Müller 1927, Guttenberg R. v. 1912, 1925; Hartig G. L. 1795, Hartig Robt. and Weber 1888, Hartig T. 1874, Heck 1931, Hess 1885, Heyer C. J. 1841, Heyer K. 1846, Heyer G. 1852, Hildebrand 1996, Hufnagl 1931, James N. D. G. 1996 (U.K.), Judeich 1893, Klauprecht 1842, 1846; Konig 1813, Kramer 1984, 1988; Kramer and Akça 1982, Kramer and Bjerg 1976, Krenn 1948, Krünitz 1781, Krutzsch and Loetsch 1938, Kunze 1873, 1884; Laar 1979, Laar and Akça 1997, Laer 1936, Laer and Spiecker 1951, Langenbacher and Nossek 1889, Lizius 1892, Loetsch and Haller 1964, Loetsch et al. 1973, Lorey 1888, Mantel 1959, Mitscherlich E. A. 1948, 1956; Mitscherlich G. 1970, Müller U. 1899, Oettelt 1765, Paulsen 1795, Philipp 1893, Pressler 1857, 1881-1882, 1902; Pressler and Kunze 1873, Prodan 1951, 1961, 1965, 1968, 1997; Rausch 1886, Schmidt-Vogt 1986, 1991, Schneider 1853, Schober R. 1949, 1962; Schuberg 1888, 1894; Schwappach 1889, 1908; Smalian 1837, 1840;

Späth 1798, Stötzer 1898, 1907; Tischendorf 1927, Van Laar and Akça 1997, Vanselow 1941, Weber 1891, Weck 1948, 1955, 1962; Weise 1904, Wenk and Smelko 1990, Wiedemann 1937, 1948, 1950 a, 1950 b; Willkomm 1875, Wimmenauer 1907, 1919; Zimmerle 1930, Zohrer 1980.

4. 2. Local and regional forest studies containing information on timber mensuration, especially in mixed stands

A sample of local and regional studies containing different data on stand or tree mensurational characteristics is presented in table 4.2.-1.

In this text it will be specified the additional information on the papers included in the mentioned table.

TABLE 4.2.-1. Local or regional German studies on different forest types (especially mixed stands) which containing information on stand structure, growth and yield

Printing year(s)	Author(s)	Species	Location
1884	T. Lorey	European spruce	(yield investigations)
1889	A. Schwappach	Scots pine	Northern low land plains
1889	E. Speidel	European spruce	Württemberg
1896	A. Schwappach	Scots pine	Northern plains
1896, 1902	T. Lorey	Mixed: spruce and beech	
1904	A. Engler	Old mixed forest	Schattawa "virgin" forest, Bohemia
1908	A. Schwappach	Scots pine	Eberswalde
1911	A. Schwappach	Beech	Eberswalde
1923	E. Wiedemann	European spruce	Sachsen
1928	V. Dieterich	Mixed stands: spruce and beech	
1929	K. Klamroth	European larch	Harz
1929	G. Rasul	Mixed stands: Scots pine and European spruce	Baden
1931	K. Mauve	Mixed stands: spruce, beech, fir	"Galizischen Karpathen-Urwald"
1933	H. Zimmerle	European spruce	Württemberg
1937	K. Vanselow	Spruce and fir mixed stands	Köcherhof-Baden
1937	H. Zimmerle	Spruce + fir + beech	Württemberg (Plenterwald)
1940	A. Koehler	Scots pine and European spruce mixed stands	Lettland
1941	F. Firat	European beech	Sachsen
1941	H. Zimmerle	European larch	Württemberg
1942	A. Wobst	Mixed stands of spruce, fir and beech	Riesengebirge Böhmen (now in the Czech Rep.)
1942	H. Zimmerle	*Fraxinus excelsior*	Württemberg
1947	H. Zimmerle	Spruce	Württemberg
1948	J. Weck	Mixed and pure stands of European spruce and oak (*Q. robur*)	

TABLE 4.2.-1. (cont.)

Printing year(s)	Author(s)	Species	Location
1949	M. Prodan	Mixed stand	Selection forest
1952	G. Mitscherlich	Fir + spruce + beech	Baden (Plenterwald)
1953	G. Mitscherlich	Oak + beech + fir	Baden
1953	R. Schober	Japanese larch	
1954	R. Magin	Spruce + fir + beech	Montainous forests
1955	M. Günther	Spruce + beech	Neckar-Württemberg
1955	K. Kwasnitschka	Spruce + Scots pine + fir	Eastern part of Schwarzwald
1955	K. Mang	Spruce + Scots pine + fir	Lindau
1955/56	G. Mitscherlich	Spruce + Scots pine + fir	Baden
1957	A. Crocoll	Poplar	Northern Rhein
1957	G. Mitscherlich	Spruce	Baden
1957	H. U. Moosmayer	Spruce + beech	Schwaben
1957	E. Wohlfarth	Spruce + Scots pine + fir	
1958	E. Zimmermann	High altitude stands	Schwarzwald-Württemberg
1959	W. Drescher	Spruce + fir + beech	Southern Schwarzwald
1959 a, b	R. Magin	Mixed stands	Bayern Alpen
1959	R. Magin	Fir + spruce + beech	Bavaria
1960	E. Wohlfarth	Spruce + Scots pine + fir	Southern Schwarzwald Württemberg
1960	R. Zundel	Spruce + Scots pine + fir	Northern Württemberg
1960	P. Abetz	Spruce + Japanese larch	
1960	F. Albrecht	Spruce + Scots pine + fir	Baden-Württemberg
1960	H. Petri	Spruce	Northern Rhein
1960	E. Zimmermann	Mixed high altitude forests	Schwarzwald-Württemberg
1961	K. Klotz	Spruce + beech	Bayern over 900 m altitude
1961	G. Mitscherlich	Spruce + fir + beech (selection forest)	Schwarzwald, Württemberg
1962	E. Künstle	Spruce + fir + Scotch pine	Southern Schwarzwald
1962	J. Blanckmeister	Beech + spruce + fir	
1962	V. Rodenwaldt	Spruce + Scots pine + fir	Villinger state forest
1963	H. Hamm	Spruce + Japanese larch	
1965	W. Drescher	Beech + spruce Beech + spruce + fir	Southern Hochschwarzwald
1966	F. Fiedler	Spruce + birch	
1966	H. Jaeger	Scots pine + spruce	Thüringen
1966	F. Kable	Spruce + fir Spruce + Japanese larch	Baden-Württemberg
1966	H. Petri	Beech + spruce	Northern Rheinland
1966	H. Wätzig	Spruce	Erzgebirge (northern slope)
1967	O. Seitschek	Fir	Baden
1968	F. Hockenjoss	Spruce + fir + beech	Western Schwarzwald
1969	D. Bergel	Douglas-fir	Northwestern Germany
1972	H. Kasa	Scots pine + spruce	Northern plains

TABLE 4.2.-1. (cont.)

Printing year(s)	Author(s)	Species	Location
1972	H. Petri	Spruce + beech	
1972	W. Schulze	Scots pine + spruce	Bayern
1973	V. Hink	Spruce + fir	Baden-Württemberg
1977	W. Bechter	Spruce	Baden-Württemberg
1984	G. Kenk J. Hradetzky	Douglas-fir	Baden-Württemberg
1984	H. Mayer	Larch + spruce	
1992	G. K. Kenk	Mixed stands	Southwestern Germany
1992	Teja Preuhsler (ed.)	Mixed stands	
1993	Teja Preuhsler	Mixed stands	Southern Bayern (Bavaria)
1995	H. Röhle	Spruce	Southern Bavaria

Lorey (1884): - spruce yield, Schwappach (1889, 1896) growth and yield of Scots pine in northern plains; Lorey (1896, 1902) - yield of spruce + beech mixed forests; Engler (1904) - one of the earliest publications dealing with natural forest research which described the virgin forest of Schattawa in Bohemia and contains a report on the establishment of a forest reserve in the Spessart.

Schwappach (1908, 1911): the management works in Scots pine and beech forest of the experimental Eberswalde Station; Wiedemann (1923/1925) - the decline of spruce growth in Saxony; Dieterich (1928) - growth of young plants (from natural regeneration) in mixed stands of spruce and beech; Klamroth (1929) - growth of larche in Hart; Rasul (1929) - yield of spruce + Scots pine mixed stands; Mauve (1931) - growth and structure of Old Galitzian mixed forests; Zimmerle (1937) - selection forests in Württemberg (spruce + fir + beech), form factor of trees and relationship between them (see also 2.4); for quotient of trees (Zimmerle) $k_z = d_5/d$, $d_5 =$ diameter at 5 m height, d = dbh and form factor $f_{1.3} = b_o + b_1k_z + b_2/k_2$.

Koehler 1940 - yield and structure of mixed Scotch pine + spruce stands in Lettland. Firat (1941) - growth and yield of beech in Saxony; Zimmerle (1941) form factors of European larch (stereometrical approach); (1942) - form quotient of European ash, growth, structure and yield; (1947) -spruce series of form quotients, diameter distribution, and fitting of their curves.

Weck (1948) - growth and influence of draught on growth in mixed spruce + oak stands.

Prodan (1949) - theoretical determination of the state of equilibrium in the selection mixed forests; Mitscherlich G. (1952) - developing Prodan's idea proposed a site classification based on the number of trees per hectare (having ≥

50 cm dbh) and their growth; Mitscherlich 1953 - yield of spruce, beech and fir mixed stands in Baden; Schober (1953) - yield of Japanese larch; Magin (1954) - yield of mountainous mixed stands; Mitscherlich (1955/1956) - growth of Scots pine in Baden; (1957) - growth of spruce in Baden; Crocoll (1957) - yield of poplar stands; Moosmayer (1957) - Eichhorn "law" confirmed in Schwaben in the case of spruce and beech.

Zimmermann (1958) - growth and development of stands located at high altitudes; Drescher (1959) - yield history of mixed stands of spruce, beech and fir situated at high altitude; Magin (1959 a) - crown size and growth in Bavarian old multistories mixed forest (Urwald); (1959 b) - structure and productivity of multistoryed forests in Bavarian Alps.

Abetz (1960) - growth of Japanese larch and spruce in similar sites; Zimmermann (1960) - growth of main forest species at hight altitudes (Württemberger Schwarzwald); Kunstle (1962) - height growth of spruce, fir and Scots pine in mixed forests (Schwarzwald = Black forests); Drescher (1965) - a yield history of mixed spruce + beech and spruce + fir + beech stands in southern Hochschwarzwald; Fiedler (1966), (1969) - yield of Douglas-fir in northwestern Germany.

Kasa (1972) - yield studies on Scot pine + spruce mixed stands in different plain sites; Petri (1972) - influencing density in beech + spruce mixed stands; Bechter (1977) - spruce growth in Baden; Kenk and Hradetzky (1984) - growth of Douglas-fir in Baden-Württemberg studies using a stand growth simulation model able to evaluate the effects of four thinning regimes on the basis yield, site index and related tables are presented.

Kenk (1992) - conclusions on growth and yield from long-term experimental plots in mixed stands of southern Germany.

Preuhsler and Mayer (1993) - growth of some predominant trees of different species in mixed stands of southern Bavaria; Röhle (1995) - growth of Norway (European) spruce on high yield sites in southern Bavaria and developed yield models.

Cited authors:

Abetz 1960, Albrecht 1960, Bechter 1977, Bergel 1969, Blanckmeister 1962, Crocoll 1957, Drescher 1959, 1965; Dieterich 1928, Engler 1904, Fiedler 1966, Firat 1941, Gunther 1955, Hamm 1963, Hink 1973, Hockenjoss 1968, Jaeger 1966, Kalble 1966, Kasa 1972, Kenk 1992, Kenk and Hradetzky 1984, Klamroth 1929, Klotz 1961, Koehler 1940, Künstle 1962, Kwasnitschka 1955, Lorey 1884, 1896, 1902; Magin 1954, 1959 a, 1959 b; Mang 1955, Mauve 1931, Mayer 1984, Mitscherlich G. 1952, 1953, 1955/1956, 1957, 1961; Moosmayer 1957, Petri 1960, 1966, 1972; Preuhsler 1992, Preuhsler and Mayer 1993, Prodan 1949, Rasul 1929, Rodenwaldt 1962, Röhle 1995, Schober 1953, Schulze 1972, Schwappach 1889, 1896, 1908, 1911; Seitschek 1967, Speidel 1889, Venselow 1937, Wätzig 1966, Weck 1948, Wiedemann

1923, Webst 1942, Wohnfahrt 1957, 1960; Zimmerle 1933, 1937, 1941, 1942, 1947/1949; Zimmermann 1958, 1960; Zundel 1960.

4.3. Determination of log and other primary products, volume and measurements of diameters, tree height and crown. Instruments

The similarity of stems (especially in the case of excurrent formed trees that have a definite central stem from the ground to the top) to geometric solids of revolution as the cone, paraboloid and neiloid (Fig. 4.3.-1.) was known for a long time.

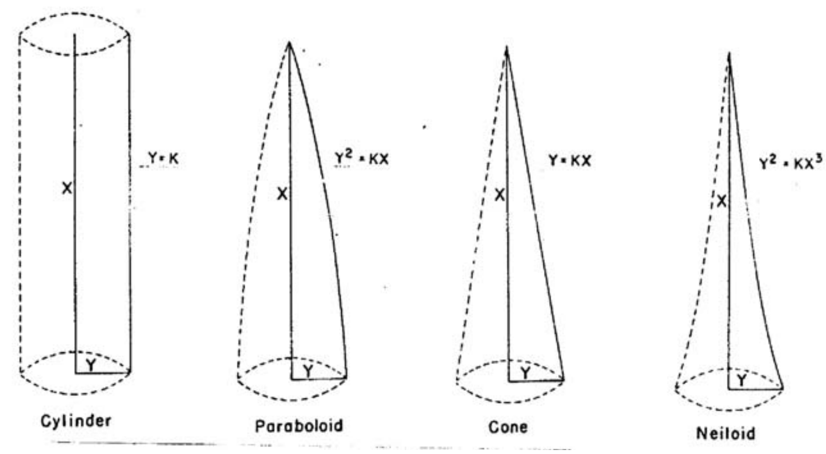


Fig. 4.3.-1. Solids of revolution descriptive of tree form

These solids are generated by the revolution about the *X* axis of a curve whose general formula is

$$Y^2=KX^r \quad \text{or} \quad Y=K\sqrt{X^r}$$

and the type of solid depends on the value of *r* exponent: zero for cylinder, 1 for paraboloid, 2 for cone and 3 for neiloid (Fig. 4.3-1). When the stem is separated into sections called logs or bolts the individual pieces are similar with different forms in according with their position in the tree. In fact the total stem of a tree represents a composite of these forms (Fig. 4.3.-2.): the butt log and stump looks like a neiloid, the central part of the stem is similar to the frustum of a paraboloid and the upper part of the stem looks like a cone or a paraboloid.

In Germany the theory of the solids of revolution was developed for forestry by Öttelt (1765), Krunitz (1781), Hossfeld (1812), Smalian (1837), Riecke (1840), König (1835, 1864) and Prodan (1944).

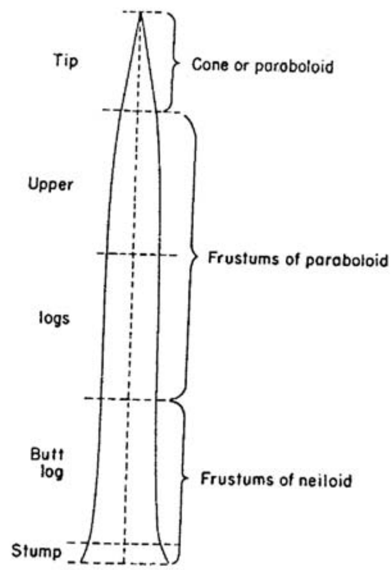


Fig. 4.3.-2. Geometric forms assumed by portions of a tree stem
SOURCE: Husch, B., Forest men suration, p. 85 Ronald Press Company New York, 1953

The best-known formulae for log volume belong to the Germans:

Huber (1828): $V = l \; g_{1/2}$

Smalian (1837): $V = l \; \frac{(g_b + g_s)}{2} = l \frac{\pi}{4}\left(\frac{d_b^2 + d_s^2}{2}\right)$

Hossfeld (introduced in 1849 according to Prodan et al. 1997, p. 63):

$$V = \frac{l}{4}(3g_{1/3} + g_b)$$

Newton's formula known as Newton-Rieke formula was introduced in 1849 (Prodan et al. 1997, p. 65):

$$V = \frac{l}{6}\left(g_b + 4g_{1/2} + g_s\right)$$

Additionally, Prodan (1965) proposed the following formulae:

$$V = 0.25 \; l \; (g_0 + g_s + 2g_{0.5})$$

$$V = 0.333 \; l \; (g_{0.167} + g_{0.5} + g_{0.833})$$

$$V = 0.125 \; l \; (3g_{0.167} + 2g_{0.5} + 3g_{0.833})$$

$V=0.25\ l\ (2g_{0.167}+g_{0.5}+g_{0.883})$

$V=0.125\ l\ (g_0+2g_{0.25}+2g_{0.75}+g_s)$

where V = log volume

l = length of the section of stem (length of log)

$g_0 = g_b$ = area of the section at the larger extremity (d_b)

g_s = area of the section at the smaller extremity (d_s)

$g_{0.5} = g_{1/2}$ = area of the section at the middle length of the log

$g_{1/3}$, $g_{1/4}$, $g_{0.167}$, $g_{0.833}$, $g_{0.25}$, $g_{0.75}$ area of the section situated at 1/2, 1/4, 0.167, 0.833, 0.25, 0.75 from the larger extremity of the log.

In fact the formula of the area of middle section of the log (named in Germany Hubert's formula, inspector in a Bavarian salt mine who introduced it in 1828) was known in France and Germany in the 17[th] and 18[th] centuries; in Germany was used by Kästner (1785) and Krunitz (1781) - according to Prodan et al. 1997, pp. 59, 62).

Determination of felled wood volume was investigated by E. Heyer (1861), Baur (1879), bark and stacked wood included, Cotta's tables of round barked and unbarked wood cut in pieces were reprinted in 1897. Behm (1896) developed tables for pitrops timber.

Kunze (1912) completed investigations on error of the use of the middle section formula in the case of logs and whole stem.

In 1920, Ganghoffer developed a practical reckoner for computation of the measurement data.

Guttenberg and Müller (1927) provided a complete demonstration of Hossfeld formula for the whole stem

$$(V=\frac{3}{4} l \cdot g_{1/4})$$

Investigations on the bark of pine have been developed by Klump (1930) and Wiedemann (1932). Zohrer et al. (1973 - reference by Laar and Akça 1997) used the reverse relation of Meyer's (1942, USA, Forest mensuration) relation $k = d_{ub}/d_{ob}$ i.e. $k=d_{ob}/d_{ub}$ (d_{ob} = diameter over bark and d_{ub} = diameter under bark); Meyer assumed a linear relationship between the over and under bark diameter which implies a linear relationship between bark thickness and dbh defined by the factor k as k_{ub}/k_{ob}.

Influence of frost on wood (swelling) was investigated by Fabricius (1929) in the case of Norway spruce and beech. Wood contraction affecting the measurement of logs and woody material was determined by Kollman (1951) for European species (mean values: longitudinal contraction 0.1-0.6 %, radial 2.3-6.8 %, tangential 6.0-11.8 % and volumetrical 8.5-18.8 %) and by Mayer Wegelin (1953) for German beech. Kern (1961) underlined the necessity of distinguishing between fluctuations due to swelling and shrincage of the stems and real growth.

In the German system HOMA (1936) on timber assortment, in the second part there are included recommendations on measurement and log volume determination.

The rules applied in Germany for locating breast height diameter are shown in Fig. 4.3.-3.

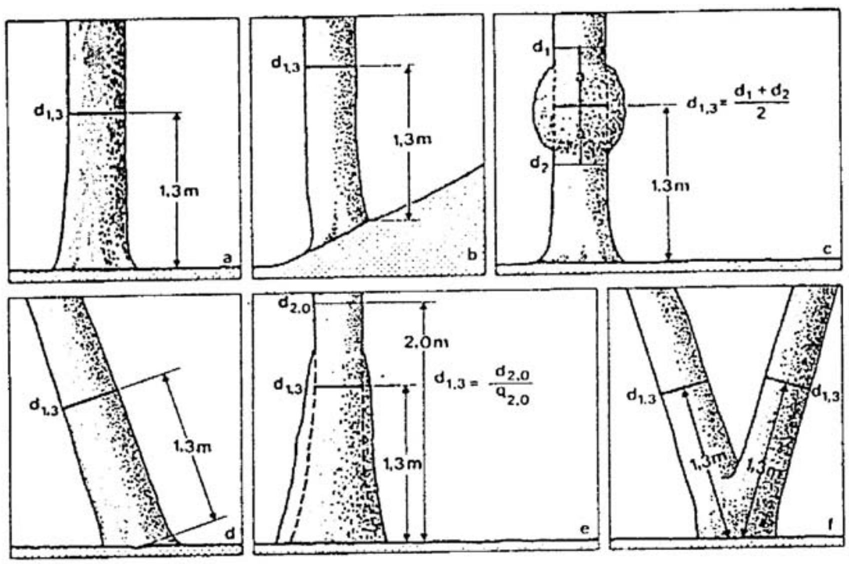


Fig. 4.3.-3. The rules applied in Germany for locating breast height diameter
SOURCE: A. van Laar and A. Akça 1997, Forest mensuration, p. 84, Cuvillier Verlag, Göttingen

For tree volume determination (or long logs) Schöpfer (1976 - reference by van Laar and Akça 1997, p. 95) recommended the measurement of two stem diameters: dbh and 50 % of tree and in this way the upper stem section will be represented by a paraboloid and its volume estimated accordingly, for the central section it will be used Smalian's formula while the butt section might be approximated as a cylinder. Van Laar (1984) investigated the accuracy of upper stem measurement with Wheler's pentaprism and Finnish optical caliper. In 1996 Akça, and Sangen-Emden concluded that the additional measurement of an upper-stem diameter did not significantly improve the accuracy of volume estimates in hardwoods.

The cross sectional area shape of the trees, especially the isoperimetric deficit of the estimated basal area was studied by G. Müller (1958). Kennel (1959) reported on the accuracy of tape and caliper in estimating the tree basal area and established that the caliper produced estimates with a mean difference of 2.14 % below that obtained with the diameter tape. The accuracy of basal area estimates obtained from stem discs and increment cores have been investigated by Smaltschinski (1986).

Researches on crown biometrics were developed by Röhle and W. Huber (1985) who determined the accuracy of the estimation of horizontal crown projection of a tree using the measurements of 2, 4, 8, 16, 32 radii under conditions of a supposed different spatial distribution of trees and concluded that 4-8 radii per tree are sufficient for the estimation of the crown projection for the whole stand, while 8-16 radii per tree are necessary to obtain reliable estimates for individual trees. Other researches on crown biometrics were completed by Dong and Kramer (1985 - crown surface area); Röhle (1986 - comparison between plumb-line projections and subjective visually controlled projections); Huber, W. (1987 - horizontal crown projection using 8 instead of 4 directions). Biometrical data on tree crown are given in the Assmann's (1961) "Waldertragslehre".

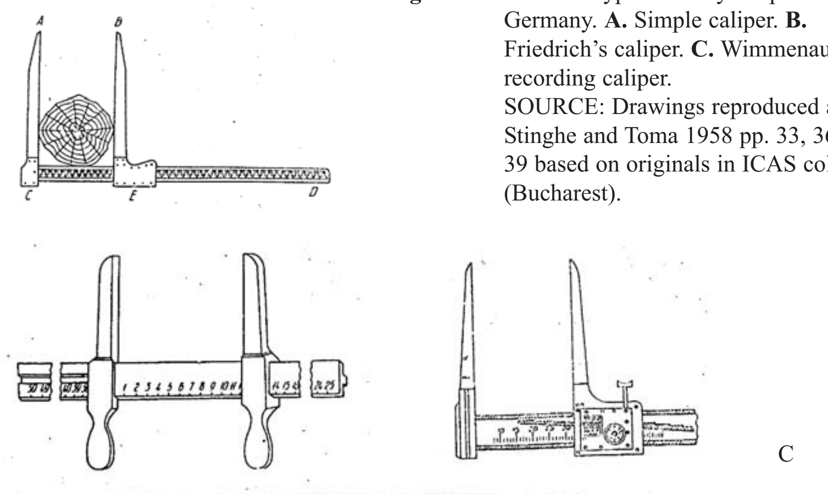
For the measurement of diameters are used calipers or dendrometers, tape for measuring girths and hypsometers for determination of heights. An early detailed work on diameter and height mensuration was published by E. Heyer in 1870 at Giessen. In 1880, Weise designed a caliper indicating directly the section area instead of diameter.

Different kinds of calipers and hypsometers have been described in detail by Müller in his "Lehrbuch der Holzmesskunde (1899, 1915, 1923) and later by Tischendorf (1927) in "Lehrbuch der Holzmassenermittlung". Some calipers are constructed to supply directly data on volume depending on the class length of logs; such a type was introduced in Württemberg in 1865 by Waldraff (Müller 1899).

Hypsometers used in Germany in the 19th century are based on geometric (Faustman, Weise, Klaussner, Christen), or on trigonometric principle (Abney hand level and clinometer). The geometric principle of similar triangles and the trigonometric principle of measuring angles are presented in any standard forest mensuration book. Among other early hypsometers will be mentioned that constructed by Fricke, Nasenkreuz, Stötzer, Ed. Heyer, Bose and Mayer.

A sample of early calipers and hypsometers are presented in Figs. 4.3.-4.-4.3.12.

A



B

C

Fig. 4.3.-4. Different types of early calipers used in Germany. **A.** Simple caliper. **B.** Friedrich's caliper. **C.** Wimmenauer's recording caliper.
SOURCE: Drawings reproduced after Stinghe and Toma 1958 pp. 33, 36 and 39 based on originals in ICAS collection (Bucharest).

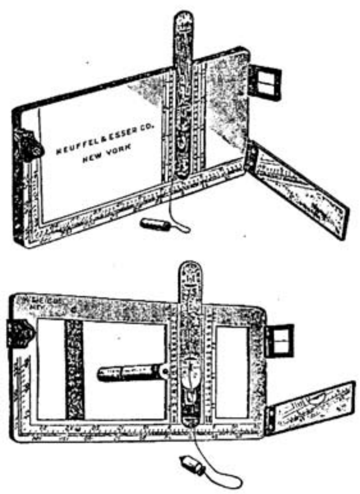


Fig. 4.3.-5. The Faustman hypsometer.
SOURCE: H. S. Graves, Forest mensuration 1910, p. 123, fig. 16.

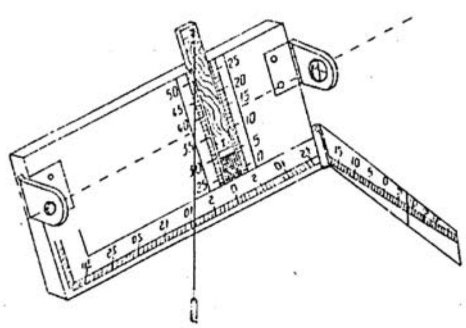


Fig. 4.3.-6. The Faustman hypsometer in working position
SOURCE: Stinghe and Toma, Dendrometrie 1958, p. 46, fig. 41

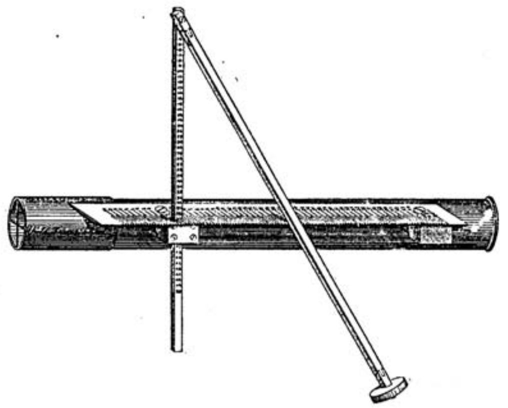


Fig. 4.3.-7. The Weise hypsometer.
SOURCE: H. S. Graves, Forest mensu ration 1910, p. 129, fig. 21

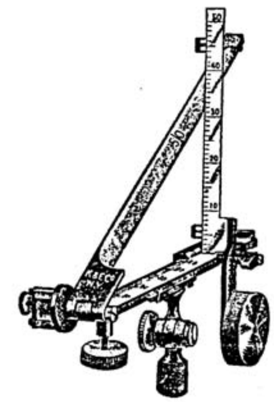


Fig. 4.3.-8. The Klaussner hypsometer.
SOURCE: H. S. Graves, Forest men suration 1910, p. 134, fig. 24.

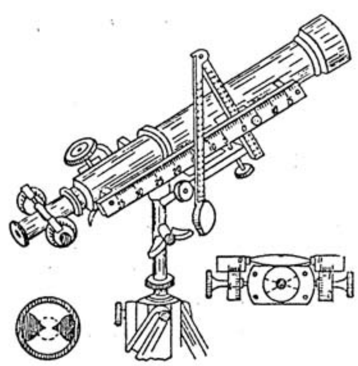


Fig. 4.3.-9. The Wimmenauer hypsometer.
SOURCE: Stinghe and Toma, Dendrometrie 1958, p. 53, fig. 54.

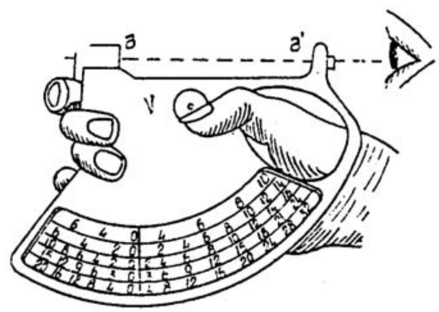


Fig. 4.3.-10. The Blume-Leiss hypsometer.
SOURCE: Stinghe and Toma, Dendrometrie 1958, p. 50, fig. 49.

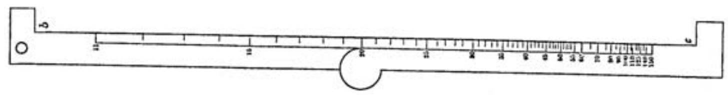


Fig. 4.3.-11. The Christen hypsometer.
SOURCE: H. S. Graves, Forest mensuration 1910, p. 131, fig. 22

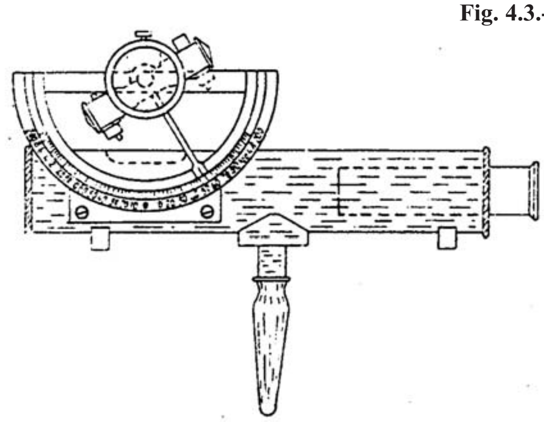


Fig. 4.3.-12. The Abney hypsometer (level).
SOURCE: Stinghe and Toma, Dendrometrie 1958, p. 51, fig. 52.

It is interesting to mention the opinion of two outstanding foresters on the error (%) of the most used hypsometers:

Hypsometer	Udo Müller (1915)	Tischendorf (1927)
Faustman	-3.4	2
Weise	+0.7	4
Abney	+1.5	4-5
Christen	-6.5	6
Klaussner	-0.1	
Wimmenauer	-1.0	

The error of the Blum-Leiss hypsometer, used on a large scale in the 1940s and 1950s, was appreciated at ± 1 % (Prodan 1951).

In 1936, Zimmerle proposed the measurement of stem diameter at 5 m height for the determination of a form quotient (which kept his name: $k_z = d_5/d$, d = dbh), and improvement of tree volume estimation of standing trees. For $d_{0.5h}$ determination simple and cheap devices have been built for the measurement of stem diameters at different heights (upper stem diameters) as d0.5h: Wimmenauer's Baummesser (for full description see Allgem. Forst- und Jagd-Zeitung 1896, p. 222 and Muller's Holzmesskunde, p. 182). Later there were used optical devices such as Zeiss Teletop (Schneider 1938) and Bitterlich's relaskop and telerelaskop (instruments for determination of diameters, heights and plot's basal area), whose errors were studied by Abetz and Merkel (1962).

In 1949, Hohenadl mentioned introduction of recording calipers (Registrierkluppe). In the 1970s, Kyritz constructed a recording caliper in which the data have been registered on punched tapes ready to be processed by the computer (Binder 1972).

The differences between the measurements of diameters of the stems at dbh with and without bark in the case of Norway spruce were analyzed by Erteld (1954).

Information on the measurement of stacked wood as stere (Raummeter) on the level of the 1950s and 1960s were given by Hensler (1951) and Gläser and Zieger who used photography for the determination of solid wood (Prodan 1965). On the other hand, it should be underlined that converting factors of solid content in stacked wood (Aufstellungsfaktor) and converting factors of stacked wood in solid content (Kubierungsfaktor) represent procedures determined a long time before (in the middle of the 19^{th} century).

In the 1970s, determination of the trees and stand heights using photogrammes (Akça et al. 1971, 1973) became a common procedure.

In 1982, Hradetzky presented a procedure for the measurement of round wood (volume) stacked in geometrical figures.

Dehn et al. (1985) proposed a photographic method using perspective transformation for measurement of stems system. "This method involves attaching to the stem, parallel to its main axis, a 4-5 m long aluminium road, the reference-point pole on which there are three equally-spaced reference points. Data are analyzed by computer and accuracy of ± 6 cm in height and ± 2 cm in diameter at 30 m height can be obtained".

An ultrasonic set (ELP manufacturer in Germany) was used in 1986 by Köhl and Meke to measure distances in forest.

In 1996, electronic calipers and mobile data-recording instruments have been tested with good results but some problems appeared after wet-weather testing (Ruppert and Kurzdorfer 1996).

In 1997, there are in use three models of LEDHA (LEDHA 100, LEM 300 W and LEDHA Geo), a laser dendrometer "with a weight of 2.2 kg which operates on the base of travel-time measurements of laser pulses by diffuse backscathering of such pulses. The instrument is suitable for stationary as well as mobile applications and had a storage capacity of 4000 measured values which are delivered to a printer or personal computer. It has the capacity to measure azimuths, distances, vertical angles, and heights and was developed and marketed by the optical firm Zeiss." (van Laar and Akça 1997, p. 79).

Cited authors:

Abetz and Merkel 1962, Akça and Sangen-Emden 1986, Akça et al. 1971, 1973; Assmann 1961, Baur 1879, Behm 1896, Binder 1972, Bitterlich 1958 (Austria), Blume-Leiss 1936, Cotta 1897, Dehn et al. 1985, Dong and Kramer 1985, Erteld 1954, Fabricius 1929, Ganghoffer 1920, Graves 1910 (U.S.A.), Guttenberg-Müller 1927, Hensler 1951, Heyer Ed. 1861, 1870; Hradetzky 1982, Hossfeld 1812, Huber 1828, Huber W. 1987, Husch 1963 (U.S.A.), Kästner

1785, Kenner 1959, 1964, Köhl and Mecke 1986, Kollmann 1951, Klump 1930, König 1835, Krünitz 1781, Kunze 1912, Laar 1984, Laar and Akça 1997, Mayer-Wegelin 1953, Müller G. 1958, Müller U. 1899, 1915; Prodan 1951, 1965; Riecke 1840, Röhle 1986, Röhle and Huber W. 1985, Ruppert and Kurzdörfer 1996, Smalian 1837, Schneider W. 1938, Schöpfer 1976 (reference by Laar and Akça 1997), Smaltschinski 1986, Stinghe and Toma (Romania) 1958, Tischendorf 1927, Weise 1880, Wiedemann 1932, Zimmerle 1936, 1950; Zohrer et al. 1993.

4.4. Tree form

Stem profile of a tree (Fig. 4.4.-1.) presented a decrease of stem diameter with increasing height above the base of the tree and three sections of the stem are distinct: base section, central section and upper-stem section. In figure 4.4.-1. the diameters d_i ($d_{0.1}$, $d_{0.3}$ etc.) located at 0.1, 0.3 ... of height are shown . The rate of decrease of the stem diameter per unit increase in height is called taper. "Taper is closely related to the growing space available to the individual tree and is extremely high for solitaries. Competition amongst trees reduced the rate of diameter growth, but has a negligible effect on height growth, with the exception of overcrowded stands. A relatively high rate of decrease can, therefore, be expected in widely spaced and heavily thinned stands. Taper is also affected by the application of fertilizers, which tend to stimulate radial growth in the upper part of the stem section ... and tends to produce a more cylindrical stem form" (van Laar and Akça 1997, p. 88).

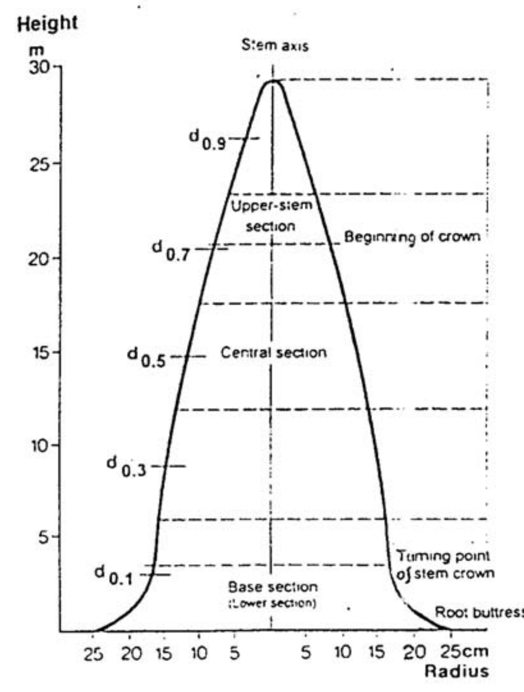


Fig. 4.4.-1. Stem profile
Reproduced after van Laar and Akça, Forest Mensuration, 1997, p. 87

In connection with stem form theories in Germany it should be mentioned Metzger`s (1894) mechanical theory and Hohenadl's opinion (1923). Metzger considered that the stem shape is determined by lateral pressures centred at a fixed focal point located within the crown. Metzger's hypothesised that the relationship between stem diameter and height above ground may be expressed by the taper line $d^3 = b_o + b_1h$. In other words the stem form is controlled by wind pressure. Hohenadl considered that crown weight represents the dominant factor which controls the stem form. Other opinions expressed in other countries are mentioned in van Laar and Akça (1997) textbook (p. 88-89); Newnham (1962, 1965, Canada); Burkhardt et al. (1985-U.S.A.) - both of them refer to geometrical models as quadratic or cubic paraboloids; Labyak et al. (1954 U.S.A. - importance of foliage); Jaccard (1912, Switzerland - water conduction theory); Larson (1963, U.S.A. - hormonal theory); Gray (1956, Australia - quadratic paraboloid).

For a long time the form factor was considered as one of the most important indicators of the tree form and is defined as the ratio of the volume of a tree or stem to the volume of a geometrical solid of the same diameter and same height. The form factor can be described according to the geometrical solid used, such as cylindrical or conical form factors. Form factors are the result of the fact that in the 19th century it was recognized that the form of tree stems approached that of the solids of revolution (see Fig. 4.3-1) and their volumes could be approximated by the formulas of solids of the same diameter and height. Another classification is based on the position of the basal diameter (d_i):

d_i taken at ground level: absolute form factor;

d_i taken at 1.3 m (or 4.5 ft): breast height form factor or "false form factor";

d_i taken at an arbitrary point such as 5 or 10 or 20 % of the height of the tree: normal form factor or true form factor.

If the merchantable length of stem is used, than merchantable form factor is produced. Another type of form factor called frustum form factor is similar to the merchantable form factor but uses the volume of the frustum of a cone as its standard. A good account of the theory of form factors is given by Müller (1923) and in the U.S.A. by Graves (1906), Meyer (1953), Husch (1963).

As far as we know, in Germany cylindrical form factors have been used (Fig. 4.4.-2.):

$$f_j = \frac{volume\ of\ tree}{volume\ of\ cylinder} = form\ factor\ (Formzahl)$$

with diameter $d_{1.30}$ for $f_{1.3}$ (false or breast height form factor); $d_{0.1h}$ for the true form factor, also known as Hohenadl's form factor; d_0 (at ground level) for f_R, the Riniker (1873) form factor, d at 0.3 m for Speidel (1889, 1893, 1894) form factor. In the case of absolute form factor it is possible to consider the stem cut at 1.30 m and volume of the piece under this section determined by other method without using Riniker form factor which has only a theoretical significance.

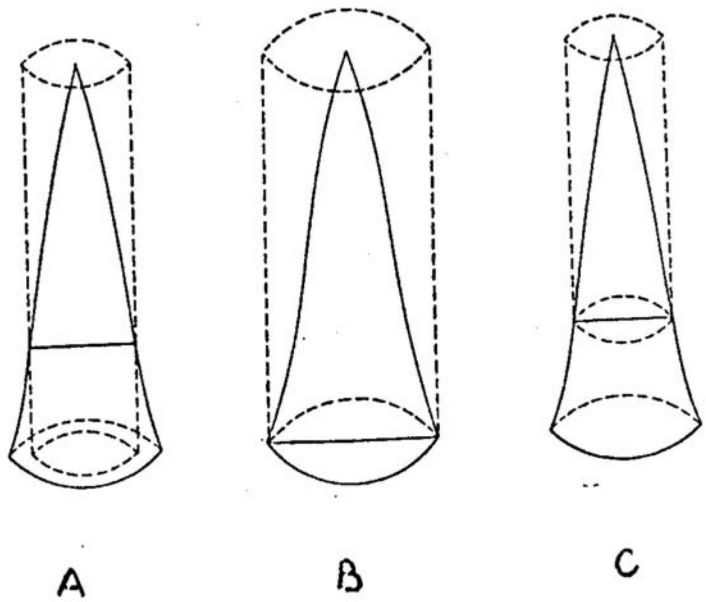


Fig. 4.4.-2. Form factors; **A**: breast height or false or artificial form factor; **B**: absolute form factor; **C**: normal or true form factor

Form factors have been introduced in forest literature by Paulsen (1795 and 1800), Hossfeld (1812) and König (1813) but Klauprecht (1846) developed and published the form factor theory. In the same year Bavarian volume tables (based on 40,200 trees), which contain also breast height form factors for different species, were published. An example of this early form factors for fir and larch is given in Table 4.4.-1.

At the end of the 19th century and the beginning of the 20th century form factors tables were constructed by Behm (1886), Schwappach (1890, 1905), Horn (1893). A sample of these tables is presented in this book in tables 4.4.-2. - 4.4.-5. for historical reason because they represented for many years the basis for construction of volume tables in Germany. On the other hand, form factors tables may be used for the comparison of the tree's form in different regions and site conditions.

TABLE 4.4.-1. Breast height form factors for fir and larch

FIR unexploitable		FIR exploitable				LARCH unexploitable		LARCH exploitable	
Dbh	Tree height 6-34 m	Dbh	Tree height 6-44 m	dbh	Tree height 6-44 m	Dbh	Tree height 3-29 m	Dbh	Tree height 3-29 m
cm	form factor	cm	form factor	cm	form factor	cm	form factor	cm	form factor
-	-	-	-	66	0.450	-	-	-	-
8	0.507	-	-	68	446	8	0.492	-	-
10	562	10	0.584	70	443	10	487	10	0.523
12	556	12	579	72	440	12	481	12	515
14	550	14	574	74	437	14	476	14	507
16	545	16	569	76	434	16	471	16	499
18	539	18	564	78	430	18	466	18	491
20	533	20	559	80	427	20	460	20	483
22	528	22	554	82	424	22	455	22	475
24	522	24	550	84	421	24	450	24	466
26	517	26	22	86	418	26	445	26	458
28	511	28	24	88	415	28	439	28	451
30	506	30	26	90	413	30	434	30	441
			28						
32	500	32	30	92	410	32	428	32	431
34	495	34	524	94	407	34	423	34	425
36	489	36	519	96	404	36	418	36	418
38	484	38	514	98	402	38	(413)	38	411
40	478	40	509	100	400	40	(408)	40	403
42	472	42	504	102	398	42	(403)	42	394
44	466	44	500	104	396	-	-	44	386
46	461	46	495	106	394	-	-	46	379
48	456	48	489	108	392	-	-	48	371
50	450	50	484	110	390	-	-	50	362
52	444	52	479	112	388	-	-	52	354
54	439	54	475	114	386	-	-	54	346
56	434	56	470	116	384	-	-	56	338
58	428	58	466	118	383	-	-	58	330
60	423	60	462	120	382	-	-	60	322
-	-	62	458	-	-	-	-	-	-
-	-	64	454	-	-	-	-	-	-

SOURCE: Anonymous. 1846. Massentafeln zur Bestimmung des Inhaltes der vorzuglichsten teutschen Waldbäume. (Volume tables for the principal German forest trees. München, 50 pp.)

TABLE 4.4.-2. Stem form factors of spruce over 90 years old

Diameter Breast-high, (cm)	Form Factor	Diameter Breast-high, (cm)	Form Factor	Diameter Breast-high, (cm)	Form Factor	Diameter Breast-high, (cm)	Form Factor
10	.559	34	.466	58	.414	80	.370
12	.544	36	.462	60	.410	82	.367
14	.532	38	.457	62	.406	84	.365
16	.522	40	.453	64	.401	86	.363
18	.513	42	.449	66	.397	88	.361
20	.505	44	.444	68	.393	90	.3595
22	.498	46	.440	70	.388	92	.358
24	.492	48	.436	72	.384	94	.3565
26	.486	50	.431	74	.380	96	.355
28	.480	52	.427	76	.376	98	.354
30	.475	54	.423	78	.373	100	.3535
32	.470	56	.419				

SOURCE: Behm 1886, Masseltafeln zur Bestimmung des Gehaltes stehender Bäume

TABLE 4.4.-3. Form factors of scotch pine in north Germany
(based on the volume of wood above 7 centimeters.)
SOURCE: Schwappach 1890, Formzahlen und Massentafeln für die Kiefer

Height, (m)	Diameter Classes (cm)							
	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60
	Form factors							
12	.500							
13	.495							
14	.491	.492						
15	.487	.488						
16	.483	.484	.487					
17	.479	.480	.483					
18	.475	.476	.479	.477				
19	.471	.473	.475	.474				
20	.468	.470	.472	.471	.470	.465		
21	.465	.467	.469	.467	.466	.463		
22	.462	.464	.467	.465	.463	.461	.457	
23	.459	.461	.465	.463	.462	.460	.457	
24	.456	.459	.463	.462	.461	.459	.456	.455
25	.453	.457	.461	.461	.460	.459	.456	.455
26	.450	.455	.460	.460	.459	.458	.456	.455
27	.449	.454	.459	.459	.458	.458	.457	.456
28	.448	.454	.458	.459	.458	.458	.457	.457
29	…	.453	.457	.458	.458	.458	.458	.457
30	…	.453	.456	.457	.458	.458	.458	.458
31	…	….	.455	.457	.457	.457	.458	.459
32	…	…	.455	.457	.457	.458	.459	.460
33	…	…	…	.457	.458	.459	.460	.460
34	…	…	…	.457	.459	.460	.461	.461
35	…	…	…	…	.459	.461	.462	.461
36	…	…	…	…	.460	.461	.462	.461

TABLE 4.4.-4. Form factors of european beech (based on the volume of wood above 7 cm)

Height, Meters.	Diameter at Breast-height in Centimeters.															
	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
9	.257	.379	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	.255	.383	.435	.455	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	.253	.387	.436	.456	.464	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	.256	.392	.438	.457	.465	.469	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	.265	.395	.441	.458	.466	.470	.470	.474	.....	.....	.....	.....	.....	.....	.....	.....
14	.265	.397	.443	.459	.467	.470	.471	.475	.476	.....	.....	.....	.....	.....	.....	.....
15	.262	.398	.445	.460	.468	.470	.473	.476	.476	.477	.....	.....	.....	.....	.....	.....
16	.262	.400	.447	.461	.468	.470	.474	.477	.477	.479	.480	.....	.....	.....	.....	.....
17	.....	.402	.449	.462	.468	.472	.476	.477	.478	.480	.481	.483	.485	.488	.....	.....
18	.....	.404	.450	.463	.469	.474	.477	.478	.480	.481	.483	.485	.487	.490	.493	.....
19	.....	.406	.452	.464	.469	.476	.478	.479	.481	.483	.484	.486	.488	.492	.494	.496
20	.....	.408	.453	.465	.470	.477	.479	.480	.482	.485	.486	.488	.490	494	.496	.498
21	.....	.410	.454	.466	.472	.478	.480	.482	.484	.486	.487	.489	.492	.495	.497	.500
22	.....	.....	.456	.467	.474	.479	.482	.484	.485	.487	.489	.491	.494	.496	.498	.502
23	.....	.....	.457	.467	.477	.481	.483	.486	.487	.489	.490	.493	.495	.498	.500	.503
24	.....	.....	.458	.468	.478	.483	.484	.487	.488	.490	.491	.493	.497	.499	.502	.504
25	.....	.....	.....	.468	.480	.484	.486	.489	.490	.491	.493	.496	.498	.500	.503	.505
26	.....	.....	.....	.....	.482	.486	.488	.490	.491	.493	.495	.497	.500	.502	.504	.507
27	.....	.....	.....	.....	.....	.488	.490	.492	.493	.494	.496	.498	.501	.503	.506	.508
28	.....	.....	.....	.....	.....	.489	.491	.493	.494	.495	.497	.499	.502	.505	.507	.509
29	.....	.....	.....	.....	.....	.490	.493	.494	.495	.497	.499	.501	.503	.506	.508	.510
30	.....	.....	.....	.....	.....	.....	.494	.496	.497	.498	.500	.502	.505	.507	.509	.510
31	.....	.....	.....	.....	.....	.....	.495	.497	.498	.500	.501	.504	.506	.508	.510	.511
32	.....	.....	.....	.....	.....	.....	.496	.498	.500	.501	.502	.505	.507	.509	.511	.511
33	.....	.....	.....	.....	.....	.....	.....	.500	.501	.502	.503	.506	.508	.510	.511	.512
34	.....	.....	.....	.....	.....	.....	.....	.....	.503	.504	.505	.507	.509	.511	.512	.513
35	.....	.....	.....	.....	.....	.....	.....	.....	.504	.505	.506	.509	.510	.512	.513	.514
36	.....	.....	.....	.....	.....	.....	.....	.....	.505	.506	.508	.510	.511	.512	.513	.515
37	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.512	.513	.514	.516
38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.512	.514	.515	.517

SOURCE: L. W. Horn 1893. Formzahlen und Massentafeln for beech (Form factor and tree volume tables for beech

The absolute or real form factors were recommended in Germany at the end of the 18th century and later by Smalian (1837). An expert in mathematics applied to forest mensuration, Gottlob König (who "did not have the benefit of a university education; his views were largely influenced by Cotta" – N. D. G. James 1996, p. 19) developed the problems of form factors (1835) and in the 1864 edition of his "Die Forst-Mathematik mit Anweisung zur Forstvermessung" (revised by Dr. Grebe) he published tables for Norway spruce and fir form factors average values for trees of different heights with no regard to the diameters. In 1864 in König's text there is a proposal to make separate tables of form factors for the following classes of trees: (1) slim with narrow crowns, in crowded stands; (2) tree growing in the stands of moderate density; (3) trees with full crowns in rather open stands; (4) trees with heavy crowns, and (5) trees standing singly.

In 1886, Behm constructed form factor and volume tables for different species. In the case of Norway spruce (Table 4.4-2) fir, larch over 90 years old form factor tables are constructed on the basis of the average form factors of trees of different diameters without regard to height; for silver fir, and larch 60 to 90 years the tables are constructed in the same way.

TABLE 4.4.-5. Form factors of european oak (based on the volume of wood above 7 centimeters)
SOURCE: Schwappach 1905. Formzahlen und Masseltafeln für die Eiche

Height Meters	Diameter at Breast-height in Centimeters.								Diameter at Breast-height in Centimeters.										
	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
	Form Factors								Form Factors										
6	.285																		
7	.298	.506																	
8	.316	.500	.553																
9	.338	.495	.538	.548															
10	.361	.491	.429	.542	.555														
11	.378	.488	.524	.538	.550	.557													
12	.395	.486	.520	.534	.544	.551	.565												
13	.409	.484	.514	.530	.540	.545	.559	.564											
14	.424	.482	.512	.526	.435	.541	.555	.560	.565	.570	.575								
15	.437	.481	.507	.523	.431	.536	.550	.556	.560	.566	.570	.575							
16	.448	.479	.506	.521	.528	.533	.546	.553	.556	.563	.566	.571	.570						
17	.454	.478	.504	.519	.525	.530	.543	.550	.553	.560	.563	.567	.571	.576					
18	.460	.477	.502	.517	.523	.528	.541	.548	.550	.557	.560	.564	.568	.572	.580				
19	…	.476	.501	.515	.521	.526	.537	.545	.547	.554	.557	.561	.565	.569	.576	.585			
20	…	.475	.500	.513	.519	.524	.534	.542	.545	.551	.554	.558	.562	.566	.571	.576			
21	…	.474	.499	.511	.517	.523	.531	.538	.542	.548	.551	.555	.559	.563	.567	.572	.577		
22	…	.474	.498	.510	.516	.522	.529	.535	.539	.545	.548	.551	.556	.560	.564	.569	.574	.586	
23	…	…	.497	.509	.515	.521	.527	.532	.536	.542	.544	.549	.554	.558	.562	.567	.572	.584	.595
24	…	…	.496	.508	.514	.520	.526	.530	.534	.539	.542	.547	.552	.556	.560	.565	.570	.581	.591
25	…	…	.495	.505	.513	.519	.524	.528	.532	.537	.541	.545	.550	.555	.558	.563	.569	.577	.587
26	…	…	.496	.503	.511	.518	.523	.527	.531	.536	.540	.544	.549	.554	.557	.562	.568	.574	.582
27	…	…	…	.501	.510	.517	.522	.526	.530	.535	.539	.543	.548	.555	.556	.560	.566	.571	.578
28	…	…	…	.497	.508	.516	.521	.525	.529	.534	.538	.542	.547	.551	.554	.559	.564	.568	.573
29	…	…	…	.494	.506	.514	.520	.523	.528	.532	.537	.541	.545	.550	.552	.557	.561	.566	.571
30	…	…	…	.491	.504	.512	.519	.522	.526	.531	.535	.539	.543	.548	.551	.555	.559	.564	.568
31	…	…	…	.488	.502	.510	.518	.521	.526	.530	.534	.537	.542	.546	.549	.554	.556	.562	.566
32	…	…	…	…	.500	.509	.516	.520	.524	.529	.533	.536	.540	.544	.547	.552	.555	.560	.564
33	…	…	…	…	.498	.507	.514	.519	.523	.527	.531	.534	.537	.542	.545	.550	.553	.558	.562
34	…	…	…	…	.497	.504	.511	.516	.521	.525	.530	.533	.535	.541	.543	.548	.551	.555	.560
35	…	…	…	…	.495	.502	.509	.513	.519	.523	.528	.532	.534	.539	.542	.546	.549	.553	.556
36	…	…	…	…	.493	.500	.505	.511	.516	.521	.526	.530	.533	.538	.541	.544	.547	.550	.553
37	…	…	…	…	…	.497	.503	.508	.514	.519	.524	.528	.531	.536	.538	.542	.544	.547	.549
38	…	…	…	…	…	.495	.500	.505	.511	.516	.522	.526	.529	.533	.536	.539	.541	.544	.545
39	…	…	…	…	…	.493	.498	.503	.509	.514	.519	.524	.527	.530	.531	.532	.534	.530	.538
40	…	…	…	…	…	.490	.496	.501	.507	.512	.517	.522	.526	.529	.530	.531	.533	.535	.537

The table of tree form factors for Scots pine is constructed on a basis of height with no regard to diameters; the tables for beech over 90 years old are based on diameters and heights, while those for beech 60-90 years old depend on heights alone (information from Graves 1910, p. 180).

Baur (1890) proposed that separate tables of form factors should be constructed for different age classes having 40 years each.

Klauprecht (1842, 1846) established a method for computing the false and true form factors and the relation existing between them:

$$f_{1.3} = f_{0.1} \cdot \frac{g_{0.1}}{g_{1.3}} = f_{0.1}\left(\frac{d_{0.1}}{d}\right)^2 = \frac{f_{0.1}}{\left(\frac{d}{d_{0.1}}\right)}$$

where $g_{1.3}$ and $g_{0.1}$ are stem section areas and d and $d_{0.1}$ the stem diameters at 1.3 m above ground and 0.1 h height above ground.

Form factors remain present in the works of Pressler (1865) in his "Gesetz der Stammbildung" (Laws of stem building, Pressler and Kunze (1873), Riniker (1873), Horn (1898), Schwappach (1890, 1905), Speidel (1889, 1893, 1894).

The normal form factor was defined by Pressler (1865) as:

$$f_n = \frac{\textit{tree volume}}{\textit{tree height} \quad \textit{sectional area at a height in fixed proportion to the height of the tree which is generally assumed as } 1/20}$$

$$= \frac{V}{h * g\left(\textit{taken at } \frac{h}{20}\right)} \quad or \quad f_n = \frac{V}{h \quad g_{h/20}}$$

Among special procedures of form factor determination should be mentioned:

• Philipp's method, designed in 1896 by Karl Philipp of Baden, is based on the formula $Y^{2n} = px^{m-n}$. Using this formula the form factor is based on the volume and height of the stem above dbh (= 1.3 m) and is expressed by the fraction n/m. If the form factor is 0.46 respectively 46/100, then n = 46 and m = 100 and the equation is $y^{92} = px^{54}$. The equation $Y^{2n} = px^{m-n}$ represents a mathematical expression of all forms of the stem of trees and is given by the relation

$$\frac{n}{m} = \frac{1}{1 + 2\frac{\left(\log\frac{D}{2} - \log\frac{d}{2}\right)}{(\log H - \log h)}}.$$

where D = dbh and *d* the diameter of the point on the stem representing a fixed and arbitrary proportion of height (usually 0.4 of the height; H is the height above dbh and h the distance from the point where d is measured to the top (after Graves 1910, p. 185).

• Another method was published by Nossek and Shaal in "Allgemeine Forst- und Jadt-Zeitung in August 1885.

The relations between Kunze's (1873) form factor (reference diameter measured at 1/20 height) species, stem height and age can be examined in table 4.4.-6. for pine spruce and beech. In this period the first height form (hf) tables have been constructed.

TABLE 4.4.-6. Kunze's form factors: reference diameter 1/20 h

Medido a/ Measured at 1/20 h	Altura fustal/ Stem height	Edad, años/ Age, years					
		21-40	41-60	61-80	81-100	101-120	121-140
		Factor de forma de la madera de fuste/ Form factor of stem wood					
Pino/ Pine	0,75 h	0.419	0.421	0.426	0.433	0.456	0.462
	0,55-0,75 h	0.410	0.416	0.428	0.443	0.450	0.455
	0,35-0,55 h	0.397	0.398	0.429	0.443	-	
Picea/ Spruce	0,75 h	0.517	0.518	0.524	0.523	0.510	0.523
	0,55-0,75 h	0.503	0.512	0.522	0.516	0.508	0.513
	0,35-0,55 h	0.478	0.492	0.511	0.508	0.500	0.502
	0,15-0,35 h	0.446	0.461	0.497	0.485	0.460	-
Haya/ Beech	0,75 h	0.460	0.458	0.482	-	0.492	0.519
	0,55-0,75 h	0.458	0.460	0.474	0.497	0.501	0.490
	0,35-0,55 h	0.444	0.447	0.459	0.461	0.480	0.484
	0,15-0,35 h	0.376	0.400	0.441	-	-	-

ORIGINAL SOURCE: Kunze 1873, Lehrbuch der Holzmesskunst; cited by Müller 1899. Reproduced after Prodan et al., Mensura forestral, p. 47.

Hengst (1959 a, 1959 b) investigated later the relation of artificial (false) form factor with dbh and height in the case of *Pinus strobus* (Fig. 4.4.-3., 4.4.-4., 4.4.-5.).

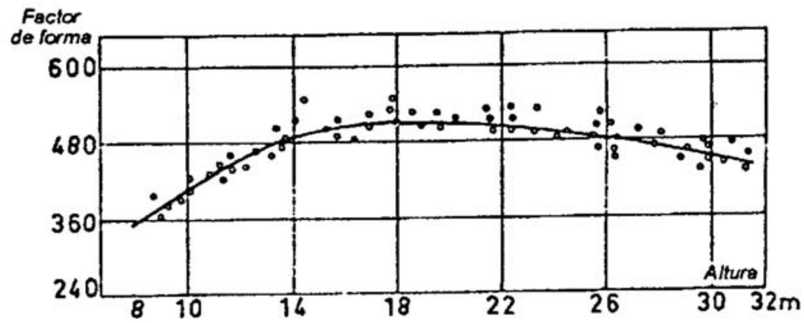


Fig. 4.4.-3. Relation of artificial form factor with height (altura)
SOURCE: Reproduced after Prodan et al. 1997, Mensura forestal, p. 339, fig. 3-33.

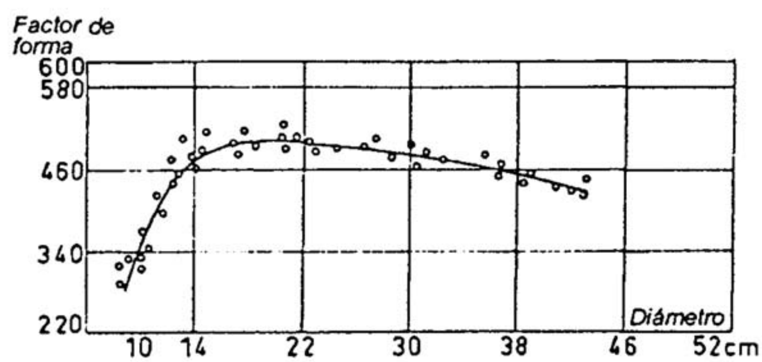


Fig. 4.4.-4. Relation of artificial form factor with diameter (dbh)
SOURCE: Reproduced after Prodan et al. 1997, Mensura forestal, p. 339, fig. 3-34

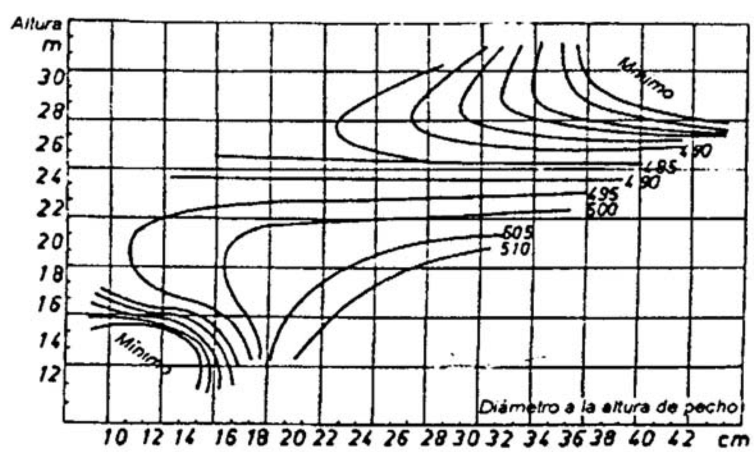


Fig. 4.4.-5. Relation of artificial form factor with dbh and height.
SOURCE: Reproduced after Prodan et al. 1997, Mensura forestal, p. 339, fig. 3-35.

In 1891, Kunze published the results of a detailed study of the form of the stems of the Norway Spruce and Scots pine with regard to the relationship between dbh and diameter measured at 0.5 height ($d_{0.5h}$). Some 10,000 spruce and over 8,000 pines were measured, but aside from demonstrating the entire probability of using this factor $d_{0.5h}$/dbh in determining the form factor (f) of stems Kunze failed to suggest any important practical application (Judson, C-Park U.S.A., Forestry Quaterly vol. I 1902/1903, p. 9).

Kunze (1891) established the following formula for breast height form factor:

$$f_{1.3} = 0.903k_s - 0.15 + \frac{0.27}{h}$$

where $k_s = k_{1/2} = \frac{d_{0.5}}{d}$

d = dbh, $d_{0.5}$ = diameter at 0.5 height (h) which is in fact a form quotient that Kunze used it without named it as “form quotient” as Schuberg (1898) and Schiffel (1899) did late in Austria. Form a historical point of view Kunze has priority over other authors.

Officially the form quotient (Formquotient) concept was introduced into forest literature almost at the same time by K. Schuberg (1898) in Germany, and Schiffel (1899) in Austria.

In Schuberg’s conception form quotient (q) represented the ratio:

$$Q = \frac{\textit{diameter at certain height above ground}}{\textit{diameter at breast height}}$$

The concept of the form quotient explained by Austrian Schiffel (1899) used the diameter at half height ($d_{0.5}$) as the numerator and was called the normal form quotient which is the same with Kunze’s k_s. It ought to be verified if in his original work Kunze used “k_s” or $d_{0.5}$/d because “s” is a subscript for Schiffel (!).

By introducing the form quotient began a new period in the history of form factors related to the form quotient and form quotients and tapering.

In 1907, Kunze used an idea expressed by Heinrich Ritter von Strzelecki (a Galician forester who published interesting papers in Centralblatt für das gesammte Forstwesen 1883) and proposed the well-known relation:

$f_{1.3} = f_f = q_2 - c$ where $f_{1.3}$ is false form factor $q_2 = k_s$ and c is a parameter whose values are 0.20-0.22 and depends on species.

Tree form was studied by Hohenadl between 1920 and 1939. Apart from the 1924 mentioned theory on mechanical construction of stem Hohenadl divided it into five sections (Fig. 4.4.-6.) and introduced the term “natural form quotients”

$k_H = \frac{d_i}{d_{0.1}}$ which represents a series generated by different d_i values.

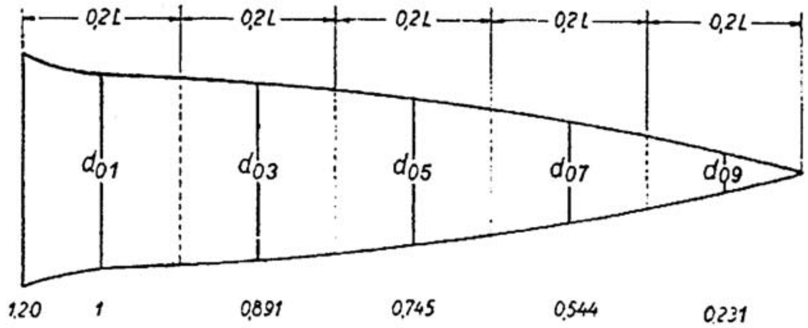


Fig. 4.4.6. Hohenadl's division of the stem in five parts
SOURCE: Hohenadl 1936, s: 61-61, and Prodan et al. 1997, Mensura forestal, p. 34, fig. 2-17.

The terms of series have thus a common basis $d_{0.1h}$ (diameter at the height 0.1 h):

$$k_{0.1} = \frac{d_{0.1}}{d_{0.1}} = 1,\ k_{0.3} = \frac{d_{0.3}}{d_{0.1}},\ k_{0.5} = \frac{d_{0.5}}{d_{0.1}},\ k_{0.7} = \frac{d_{0.7}}{d_{0.1}},\ k_{0.9} = \frac{d_{0.9}}{d_{0.1}}$$

where $d_{0.1}$, $d_{0.3}$, $d_{0.5}$, $d_{0.7}$ and $d_{0.9}$ represent the diameters at 0.1 h, 0.3 h, 0.5 h, 0.7 h and 0.9 h respectively the diameters on the middle of the five mentioned sections. Stem volume with l height (length) and five sections of 0.2 l is determined with Hohenadl's formula:

$$V = \frac{\pi}{4} \bullet l \bullet \left(d_{0.3}^2 + d_{0.3}^2 + d_{0.5}^2 + d_{0.7}^2 + d_{0.9}^2\right)$$

factorizing d and replacing l with 0.2 h Hohenadl obtained the relation:

$$V = \frac{\pi}{4} d_{0.1}^2 \bullet h \bullet 0.2 \left(1 + k_{0.3}^2 + k_{0.5}^2 + k_{0.7}^2 + k_{0.9}^2\right)$$

The expression :

$$\frac{\pi}{4} \bullet d_{0.1}^2 \bullet h = w_{0.1}$$

represents the volume of a cylinder having diameter $d_{0.1}$ and height = h which means the xpresion:

$$0.2\,(1+k_{0.5}^2+k_{0.7}^2+k_{0.9}^2)=f_{0.1}$$

where $f_{0.1}$ is the real form factor named by Hohenadl real or true form factor.

An alternative to the $k_{0.1}$ series is the series of false or artificial form quotients whose reference diameter is dbh (noted with d) and the general form is

$$k_j=\frac{d_j}{d}$$

where d_j is the d = dbh in cm and k_j is the false form quotient at j distance from tree base. A special case is Hohenadl's form quotient (qH) defined as

$$q_H=\frac{d_{1.3}}{d_{0.1}h}$$

which is greater than 1 for trees with a height of less than 13 m. However, because breast height diameter is measured at a fixed and $d_{0.1h}$ at Hohenadl's form quotient, is useful for converting the true factor of a tree into its false form factor.

Form factors and form quotients have been analyzed by Wiedemann and Buchholz (1929).

In 1936, Zimmerle considered the form quotient

$$k_z=\frac{d_5}{d}$$

where d_5 is diameter measured at five meters from the tree base (ground level) and d = dbh. In Zimmerle opinion k_z characterized better the tree form (paper reprinted in 1950).

Zieger (1939) proposed formulae of $f_{1.3}$ depending on height and dbh:

$$\log f_{1.3}=b_0+b_1\log d+b_2\log h \text{ and}$$

$$f_{1.3}=b_0+\frac{b_1}{g}=b_1+\frac{b^2}{d^2}$$

In 1942, Mitscherlich developed researches on form factor of the wood with diameter more than 7 cm at the top end, recommended measurement of diameters at upper sections of the stem and proposed the general form function:

$$f_{1.3}=f\,(d_{1.3}, d_5, H, A, B)$$

where A = age, B = site class (quality) and H = height

The stem form can be expressed using form factors, form quotients or equation of the stem curve which is the best way adopted in other countries, especially in Sweden and the U.S.A. The Germans preferred for a long time the first two alternatives. In connection with the form factors, H. Arthur Meyer, professor of forestry at the Pennsylvania State College wrote in 1953: “In the past, when geometrical considerations methods were more widely employed in mensurational problems than today, much space was devoted in text of forest mensuration to the theory and application of form factors. Much of that literature is today of historical interest only” (Forest Mensuration, Penns. Valley Publishers Inc. p. 110).

In 1944, Krenn and Prodan established a strong statistical relation ($r = 0.974$) between $f_{0.1}$ (true form factor) and $k_{0.5}$ form quotient ($k_{0.5} = d_{0.5}h/d_{0.1}h$) which is valid for all species with a continuous stem (Table 4.4.-7.):

$$f_{0.1} = 0.894k_{0.5} - 0.126$$

TABLE 4.4.-7. Spruce series of form quotients determined with the general regression equation $f_{0.1} = 0.894k_{0.5} - 0.126$ ($r = 0.994$), $k_{0.1} = 1.0$
SOURCE: Prodan et al. 1997, Mensura forestal, p. 46 Table (Cuadro 2-12.) based on Krenn and Prodan 1944, Die Bestimmung der echten Schaftholzformzahl und achungsreihe aus dem echten Formquotienten. Mitt. d. Akad. d. deutsch.Fw. Bd. 8.

$k_{0.2}$	$k_{0.3}$	$k_{0.4}$	$k_{0.5}$	$k_{0.6}$	$k_{0.7}$	$k_{0.8}$	$k_{0.9}$	$f_{0.1}$
0.903	0.805	0.702	0.600	0.503	0.406	0.301	0.196	0.442
904	808	706	605	508	411	304	197	445
906	810	710	610	513	416	307	198	448
907	813	714	615	519	421	310	199	451
908	816	718	620	524	426	313	200	454
910	819	722	625	529	431	316	202	458
911	821	726	630	534	436	319	203	460
913	824	730	635	539	441	323	204	464
914	827	734	640	544	446	326	206	467
915	829	738	645	550	451	329	207	470
917	832	742	650	555	456	332	209	473
918	835	746	655	560	461	336	211	477
919	838	750	660	565	466	339	212	480
921	840	754	665	570	471	343	214	483
922	843	758	670	576	476	346	216	487
923	846	762	675	581	481	349	218	490
925	848	766	680	586	486	353	220	493
926	851	770	685	591	491	356	222	497
928	854	774	690	596	496	360	224	500
929	857	778	695	601	501	363	226	504
930	859	782	700	607	506	367	228	507

They determined also volumetrical structure of the stem based on series of form quotients depending on $f_{0.1}$ values. In the same year, Prodan (1944) constructed another relation:

$$f_{0.1} = 0.58k_{0.5}^{2} + 0.23$$

and proposed other statistical relation for the determination of $f_{0.1}$ depending on dbh and h.

Krenn and Prodan (1944) related the true form factor to the true form quotient $d_{0.5}h/d_{0.1}h$. For single trees they established the relation

$$\lambda = -0.038 + 0.777 \left(\frac{d_{0.5}h}{d_{0.1}h}\right)$$ where λ is form factor $f_{0.1}$.

Relations between the true form quotient $k_{0.5}$ and series of quotients $k_{0.8}$, $k_{0.7}$, $k_{0.6}$, $k_{0.4}$, $k_{0.2}$ and $k_{0.1}$ in spruce determined by Prodan (1965) are shown in Fig. 4.4.-7. and that between $f_{0.1}$ and $k_{0.5}$ (for Norway spruce) based on the equation

$$f_{0.1} = 0.3333 - 0.21867 \quad k_{0.5} + 0.6667 \cdot k_{0.5}^{2}$$

are shown in Fig. 4.4.-8.

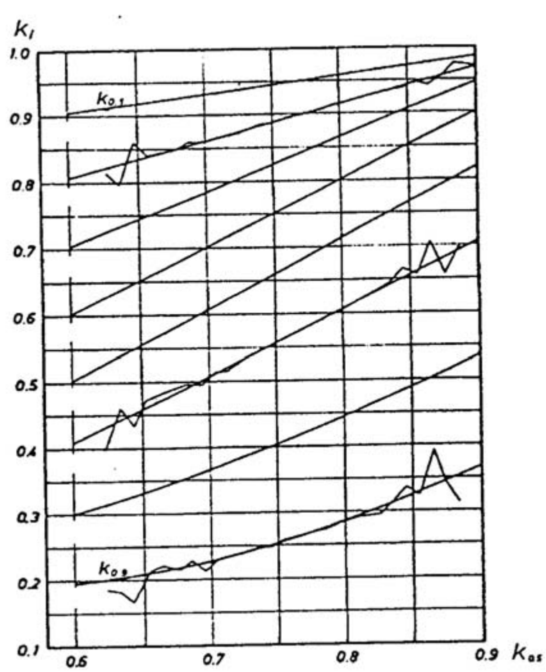


Fig. 4.4.-7. Relation between the true form quotient $k_{0.5}$ and series of quotients $k_{0.8}$, $k_{0.7}$, $k_{0.6}$, $k_{0.4}$, $k_{0.2}$, $k_{0.1}$ in spruce.
SOURCE: Prodan 1965, Holzmesslehre

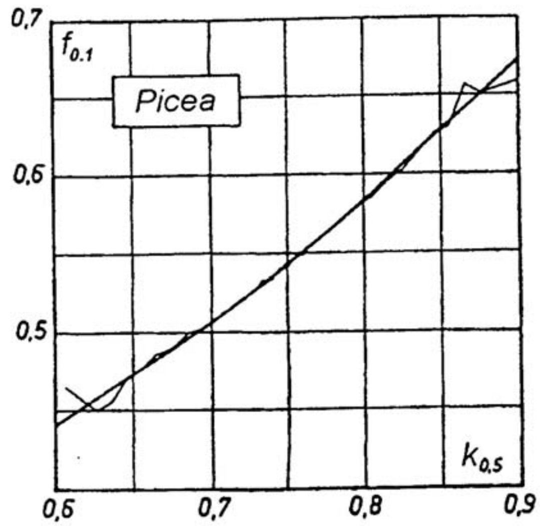


Fig. 4.4.-8. Relation between $f_{0.1}$ and $k_{0.5}$ in spruce, equation $f_{0.1} = 0.3333 - 0.21867k_{0.5} + k$.
SOURCE: Prodan 1965, Holzmesslehre

Prodan developed Hohenadl's studies in an original way. Like Hohenadl, he divided the tree stem into five portions equal in length and measured the diameters of the middle of this sections, but the relative distance is considered from the top to the base of the stem (inversely compared with Hohenadl) and the volume will be:

$$V = \frac{\pi}{4} \; h \cdot 0.2 \left(d_{0.9}^2 + d_{0.7}^2 + d_{0.5}^2 + d_{0.3}^2 + d_{0.1}^2\right)$$

factoring $d_{0.9}^2$ and noting the ratios $\frac{d_{0.i}}{d_{0.9}}$ with η_i the formula becomes

$$v = \frac{\pi}{4} \cdot d_{0.9}^2 \cdot h \quad 0.2\left(1 + \eta_{0.7}^2 + \eta_{0.5}^2 + \eta_{0.3}^2 + \eta_{0.1}^2\right)$$

Prodan noted: $W = \frac{\pi}{4} \; d_{0.9}^2 \cdot h$ and $\lambda_{0.9} = 0.2\left(1 + \eta_{0.7}^2 + \eta_{0.5}^2 + \eta_{0.3}^2 + \eta_{0.1}^2\right)$

then $V = w_{0.5} \cdot \lambda_{0.9}$ and $\lambda_{0.9} = \frac{v}{w_{0.9}}$

which is considered as a good condensed expression of the tree form. If d_i values are expressed in percentages of $d_{0.9}$ ($d_{0.9}$ = 100 %) it is easy to establish if two compared stems have the same form. If a $\lambda_{0.9}$ table is available, the operator will be able to compute $w_{0.9}$. This technique is precise and characterizes very well any stem form.

According to German researchers in order to obtain stem form curve it is important to determine the relationships between $k_{0.5}$ and the series of decreasing indices k_i (established by Krenn-Prodan (1944), Altherr (1953), Prodan (1965).

Altherr (1953) used the true form quotient series for stem form and volume determination of different species (individual values and mean values for stands) such as Norway spruce, Oregon pine and Japanese larch. In the same year, Altherr (1953) determined assortments of resinous species using true tapper coefficients. Dittmar (1956) performed investigations on form factors for the determination of stem form and growth. G. Müller (1954) determined Norway spruce stem volume and vertical profile using solids of revolution and form factors.

The series of form quotients permit the determination of relations concerning volumetrical structure of the tree stems by dimensional classes: Eidman 1956, Speidel (1955). Hausser (1956) completed a study on volume and stem form taper, form quotient series and assortment tables for Douglas-fir planted before in Germany. The series of form quotients and the "laws" of volumetrical structure of stem based on form quotients represents the subject of Brabaender's (1957) doctoral thesis.

Using the data from northern Germany and statistical methods Dittmar (1958) constructed tables with quotient form series, form factors (for trees and stands), decrease factors and determined also the mean value of felled wood contraction that represents according to his data 0.2-0.5 % of the sectional area and depends on the felling season, storage time and slope orientation.

G. Müller (1958) developed researches on the deviations of the stem transversal sections and new formulae for $f_{1.3}$:

$$f_{1.3} = b_0 + b_1 h = \frac{b_2 h}{d} \quad \text{and} \quad f_{1.3} = b_0/(b_1 + b_2 d)$$

where d = dbh and h = height. Stem forms of *Pinus strobus* were investigated in Germany by Hengst (1959 a and 1959 b).

Taper tables were constructed in Germany by a few authors, but only some of them will be mentioned here: Mitscherlich (1939), for spruce, Zimmerle (1949), for spruce in Württemberg; Bergel (1981), spruce in northwestern Germany; Böckmann and Kramer (1990), *Tilia cordata* in northwestern Germany used the stem diameter at intervals of $1/10^{th}$ of the tree height and a sixth-degree polynomial with the stem diameter in the 1^{st} position as the dependent variable and dbh as the predictor variable.

In 1963 Altherr established statistical relationships between the real form quotient ($k_{0.5}$) and false form factor ($f_{0.1}$) and among k_i values for fir (*Abies alba*):

$$k_{0.3} = 0.456398 + 0.560k_{0.5}$$

$$k_{0.7} = - 0.275158 + 1.132k_{0.5}$$

$$k_{0.9} = - 0.284332 + 0.714k_{0.5}$$

$$f_{0.1} = 0.0792 + 0.8342k_{0.5}$$

The same type of relations were computed by Prodan (1965) for Norway spruce:

$$k_{0.2} = - 0.739 + 0.2733k_{0.5}$$

$$k_{0.3} = 0.479 + 0.5433k_{0.5}$$

$$k_{0.4} = 0.222 + 0.800k_{0.5}$$

$$k_{0.6} = - 0.119 + 1.0366k_{0.5}$$

$$k_{0.7} = - 0.194 + 1.000k_{0.5}$$

$$k_{0.8} = 0.175 - 0.17667k_{0.5} + 0.64444k_{0.5}^2$$

$$k_{0.9} = 0.544 - 1.35333k_{0.5} + 1.28889k_{0.5}^2$$

$$f_{0.1} = 0.03334 - 0.21867k_{0.5} + 0.6667k_{0.5}^2$$

Pollanschütz (1961, 1967) introduced a new form quotient

$$k_p = \frac{d_{0.3h}}{d} \qquad \text{(h=height and d=dbh)}$$

and a new function “Form- bzw. Kubierungsfunktion”.

In 1962, Wenk referred to the mathematical formulation of form height (hf), form factor and volume curves.

In 1970 (2nd edn. 1978) Mitscherlich published a textbook on form and growth of trees and stands.

In 1976 Roico-Jokela constructed an equation in order to determine the assortments of standing Norway spruce trees.

The functions of stem form were used also by Schmidt-Haas for the construction of assortment tables.

For the determination of stem profile Tietze and Pofahl (1979) applied locally fitted spline function and with similar purpose Saborowski (1981) used the cubic spline function.

Brink and von Gadow (1986) used decay functions for modelling stem profiles. Their model was improved in 1995 by Riemer, von Gadov and Sloboda, by introducing a conditioned function which ensured that estimated stem diameter is zero at the tree top and equal to dbh at 1.3 m height (van Laar and Akça 1997, p. 182).

Stem form modelling of spruce and beech was completed in 1996 by Trincado to obtain "Grades Magister der tropischen Forstwirtschaft" at the Georg-August University, in Göttingen.

A comprehensive review of the different indicators of tree form are presented in the remarkable "Mensura Forestal" (Forest mensuration) written by Prodan, Peters, Cox and Real and published in 1997 in Spanish by Instituto Interamericano de Cooperacion para la Agricultura (UCA) and Deutsche Gesellschaft für Technische Zusammenarbeit (G.T.Z.) GmbH.

Cited authors:

Altherr 1953 a, 1953 b, 1963; Baur 1890, Bavarian volume and form factor tables 1846, Behm 1886, Bergel 1981, Böckmann and Kramer 1990, Brabaender 1957, Brink 1986, Burkhart and Walton 1985 (U.S.A.), Clark, J. F. 1902/1903 (Canada), Dittmar 1956, 1958; Eidmann 1956, Gray 1956 (U.S.A.), Graves 1910 (U.S.A.), Grundner 1898, Hausser 1956, Hausser and Bolsinger 1956, Hengst 1959a, 1959b; Hohenadl 1924, 1936; Horn 1893, 1898; Hossfeld 1812, Hush 1963 (U.S.A.), Jaccard 1912, James N. D. G. 1996 (U.K.), Klauprecht 1842, 1846; Krenn and Prodan 1944, König 1853, Kunze 1873, 1889a, 1889b, 1891, 1907; Laar and Akça 1997, Labyak and Schumacher 1954, Larson 1963 (U.S.A.), Metzger 1893, 1894; Meyer 1953 (U.S.A.), Mitscherlich 1939, 1942, 1970; Müller G. 1954, 1958; Müller Udo 1899, Newnham 1965 (Canada), Paulsen 1795, Philipp 1896, Pollanschutz 1961, 1967; Prodan 1944a, 1944b, 1951, 1965; Prodan et al. 1997, Pressler 1865, Pressler and Kunze 1873, Riemer et al. 1995, Riniker 1873, Roiko-Jokela 1976, Saborowski 1981, Schmidt-Haas 1976, Schuberg 1891, 1898; Schwappach 1890, 1905; Smalian 1837, Speidel E. 1889, 1893; Speidel G. 1955, Tietze and Potahl 1979, Trincado 1996, Weise 1881, Wenk 1962, Wiedemann and Buchholz 1929, Zieger 1939, Zimmerle 1936, 1949, 1950.

4.5. Tree volume tables and equations

The first suggestion for the construction of volume tables belongs to H. Cotta and was expressed in his "Systematische Anleitung zur Taxation der Waldungen" published in 1804. Cotta's idea was developed on a large scale by the Bavarian government and completed in 1846. Using the data from 40,220 trees and graphical methods in values compensations, the tables have been constructed for beech, oak, birch, Norway spruce, silver fir, Scots pine and larch. An average of 5,750 trees have been used per species. Today, by the application of modern statistical methods, the construction of reliable volume tables on the basis of 100-200 trees is possible.

Bavarian tables containing also the form factors tables were later (1872, 1896) translated by Ganghoffer from the old Bavarian foot and inch measure into the metric system. The entry characteristics of these tables are: age class (as a rule under 90 and over 90 years), height and dbh.

Volume tables are not used and not intended for the use in volume determination of a single tree because the trees having the same dbh and height, growing side by side in the same stand, may vary in cubic content sometimes more than ± 20 %. The volume tables have been constructed for stands. To overcome the weakness of a table based on height, dbh and age classes - which are not able to adapt itself to any variation in the average form - Schuberg (1891) constructed "correlation tables in which a percentage has to be added to or deducted from the value in his volume tables for silver fir (based on 1,352 trees) according to the form of stem (more or less cylindrical). This variation was determined by comparing the relation between dbh (d) and the diameter at the middle of the stem $d_{0.5}h$/dbh which is in fact a form quotient which was expressed by Schuberg as a percentage. It should be underlined that Schuberg was the first he discovered that the middle point of the stem height is the most critical for the second measurement of diameter and "is capable of expressing any variation in form due to any factor or combination of factors such as site, age or silvicultural conditions" (Judson F. Clark 1902/1903, p. 9).

The next important volume tables were published by Franz Baur in Munich in 1890 and used data from 55,874 stems of Norway spruce. In 1898 appeared the first edition of Grundner-Schwappach tables (141,150 trees used) whose 10^{th} edition was printed in 1952. They are probably the most used German tables of conventional (classical) type (Table 4.5-2).

A sample of German volume tables is presented in Table 4.5.-1.

A special type of volume tables were constructed in 1948 by Krenn. In Krenn's volume tables (Table 4.5.-3.) or tariffs the volume of stand average tree is given. The volume given by the table depends on the mean diameter and mean height of stand because they have been constructed on the basis of yield tables. The originality of these tables consists in the fact that they offer the possibility to determine the current increment of stands if they are constructed for different thinning intensities.

From the volume of average stand tree given by tables, the stand volume is determined with the formula V = N•v (N = number of trees, v = volume given by the table). As a rule, for every species three tariffs have been constructed: superior (O), medium (M) and inferior (U) (Table 4.5.-3.).

TABLE 4.5.-1. A sample of German conventional tree volume tables

Publishing year(s)	Author(s)	Species	Remarks
1846	Bavarian government	Beech, oak, birch, Norway spruce, silver, fir, Scots pine, larch	Entry: age class, dbh and height. Original in old Bavarian foot and inch measure. Vol . ($dm^{3)}$ in metric system.
1870	G. Pabst		Tables for volume determination
1871 (1898)	M. R. Pressler	Different species. Metric system	Edition 1898 revised by M. Neumeister
1872, 1896	A. von Ganghoffer	Different (as Bavarian tables)	Entry: age class, h, dbh. Represents a translation of Bavarian tables in metric system
1882	Tuisko Lorey		
1890	A. Schwappach	Scots pine	Entry: dbh, h
1891	K. Schuberg	Fir	Volumes and form factors
1896,1924,1931	K. Philipp	Norway spruce	Entry: h and diameter class
1896,1906, 1913,1919, 1922,1928,1938,1942, 1952 (10th edn.)	Grundner-Schwappach	Main species	Entry: age class
1900	A. Schwappach	Scots pine	
1890	Franz Bauer	Norway spruce	Entry: age class, dbh and h, region. Volumes and form factors
1905	A. Schwappach	Oak (*Q. robur*)	Volumes and form factors
1949	H. Zimmerle	Norway spruce	Entry: age class, dbh and height.
1952	R. Schober	Different	
1956	K. Hausser	Douglas-fir	Entry: height and dbh, based on 5,000 trees
1956	J. Soest	Douglas-fir	
1968	F. Zöhrer	Norway spruce, larch	Entry: dbh, h and crown length
1969	R. Kennel	Beech and Norway spruce	Entry: h and dbh
1973	D. Bergel	Different	Vol. I, entry: h, dbh
1974	D. Bergel	Different	Vol. II, entry: h, dbh
1989	M. Röös T. Bockmann	*Tilia cordata* *Prunus avium*	North-western Germany
1995	K. W. Lockow	*Alnus glutinosa* (common alder)	Northeastern Germany, Low plains (Macklenburg, Pomerania).

TABLE 4.5.-2. Schwappach-Grundner volume tables for Norway spruce. Stems at upper end ≤ 7 cm and > 60 years (extract)
Beispiel einer Massentafel Derbholz-Massentafel für Fichte nach Grundner-Schwappach. b) Altersklasse über 60 Jahre

(height) Scheitel-Höhe m	Stammdurchmesser in 1.3 m Höhe über dem Boden: cm (dbh)										
	30	31	32	33	34	35	36	37	38	39	40
	Festmeter (m^3) solid wood										
11	-	-	-	-	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-	-	-	-	-
14	0.48	-	-	-	-	-	-	-	-	-	-
15	0.52	0.55	0.58	0.61	0.65	-	-	-	-	-	-
16	0.55	0.58	0.62	0.65	0.69	0.73	0.77	0.80	0.84	-	-
17	0.59	0.62	0.66	0.70	0.74	0.77	0.81	0.85	0.89	0.93	0.98
18	0.62	0.66	0.70	0.74	0.78	0.82	0.86	0.90	0.95	0.99	1.04
19	0.66	0.70	0.74	0.78	0.83	0.87	0.91	0.95	1.00	1.05	1.10
20	0.69	0.73	0.78	0.82	0.87	0.91	0.96	1.01	1.06	1.10	1.15
21	0.73	0.77	0.82	0.87	0.92	0.96	1.01	1.06	1.11	1.16	1.21
22	0.77	0.81	0.86	0.91	0.96	1.01	1.06	1.11	1.17	1.22	1.27
23	0.80	0.85	0.90	0.95	1.00	1.05	1.11	1.16	1.22	1.27	1.33
24	0.84	0.89	0.94	0.99	1.05	1.10	1.16	1.21	1.27	1.33	1.39
25	0.87	0.92	0.98	1.03	1.09	1.15	1.21	1.27	1.33	1.39	1.45
26	0.90	0.96	1.02	1.08	1.14	1.20	1.26	1.32	1.39	1.45	1.51
27	0.94	1.00	1.06	1.12	1.18	1.24	1.31	1.37	1.44	1.50	1.57
28	0.97	1.03	1.10	1.16	1.23	1.29	1.36	1.43	1.50	1.56	1.63
29	1.01	1.07	1.14	1.20	1.27	1.33	1.40	1.47	1.55	1.62	1.69
30	1.04	1.10	1.17	1.24	1.31	1.38	1.45	1.52	1.60	1.67	1.75
31	1.07	1.14	1.21	1.28	1.35	1.42	1.50	1.57	1.65	1.73	1.81
32	1.11	1.18	1.25	1.32	1.39	1.46	1.54	1.62	1.70	1.78	1.86
33	1.14	1.21	1.29	1.36	1.44	1.51	1.59	1.67	1.76	1.84	1.92
34	1.17	1.24	1.32	1.40	1.48	1.55	1.63	1.72	1.81	1.89	1.97
35	1.21	1.28	1.36	1.44	1.52	1.60	1.68	1.77	1.86	1.94	2.03
36	1.24	1.32	1.40	1.48	1.56	1.64	1.73	1.82	1.91	2.00	2.09
37	1.27	1.35	1.43	1.51	1.60	1.68	1.77	1.86	1.96	2.05	2.14
38	1.30	1.38	1.47	1.55	1.64	1.73	1.82	1.91	2.01	2.10	2.19
39	-	-	1.51	1.59	1.68	1.77	1.87	1.96	2.06	2.15	2.25
40	-	-	1.54	1.63	1.72	1.81	1.91	2.01	2.11	2.20	2.30
41	-	-	1.58	1.67	1.76	1.85	1.95	2.05	2.16	2.25	2.35
42	-	-	-	-	-	-	-	-	2.21	2.31	2.41
43	-	-	-	-	-	-	-	-	-	-	-
44	-	-	-	-	-	-	-	-	-	-	-

Source: Grundner-Schwappach 1922, Masseltafeln zur Bestimmung des Holzgehalts stehender Waldbäume. 6. Aufl., Berlin.

TABLE 4.5.-3. Extract from Krenn's tariff
SOURCE: Krenn 1948: Tarife zur Massenberechnung von Bestanden, Heft 6, Freiburg, Forstliche Versuchsanstalt

Average diameter cm	Amplitude of heights for tariff M	Tariff	Fractions in cm of average diameter					Small wood (<7cm)
			.0	.2	.4	.6	.8	
			Volume per tree (wood with diam. ≥ 7 cm)					
1	2	3	4	5	6	7	8	9
15	18.5-16.0	O	0.1520	0.1584	0.1648	0.1712	0.1776	31
		M	0.1357	0.1414	0.1470	0.1527	01583	
		U	0.1194	0.1243	0.1292	01342	0.1391	
16	19.0-17.0	O	0.184	0.191	0.198	0.206	0.213	28
		M	0.164	0.170	0.177	0.183	0.190	
		U	0.144	0150	0.156	0.161	0167	
17	20.0-17.5	O	0.220	0.228	0.236	0.244	0.252	26
		M	0.196	0.203	0.210	0.218	0.225	
		U	0.173	0.179	0.185	0.192	0.198	
18	20.5-18.0	O	0.260	0.269	0.278	0.286	0.295	24
		M	0.232	0.240	0.248	0.255	0.263	
		U	0.204	0.211	0.218	0.225	0.232	
19	21.5-19.0	O	0.304	0.314	0.324	0.333	0.343	23
		M	0.271	0.280	0.289	0.297	0.306	
		U	0.239	0.247	0.255	0.262	0.270	
20	22.5-19.5	O	0.353	0.363	0.374	0.384	0.395	22
		M	0.315	0.324	0.334	0.343	0.353	
		U	0.278	0.286	0.294	0.303	0.311	

Sometimes stand volume may be affected by errors due to the reduced number of tariffs (height classes) established for each diameter. Using Krenn's tables, it is not possible to determine volume by diameter categories.

Prodan (1951) developed volume tables for fir and spruce in selection forest (Plenterwald) with dbh and tariff number as entries. Tariff number is determined for each species depending on dbh and height using a sample (Table 4.5.-4.). Prodan (1952) underlined the influence of site (elevation, species composition) on tariff number.

TABLE 4.5.-4. Prodan's volume tables for fir and spruce in selection forest (Plenterwald)
Provisorische Massentarife für Tannen und Fichten (Plenterwald) nach Prodan

	Massen in fm (volume in m^3)				
$D_{1.3}$	I	II	III	IV	V
10	0.030	0.026	0.023	0.021	0.018
12	0.063	0.057	0.052	0.048	0.043
14	0.107	0.099	0.091	0.084	0.077
16	0.163	0.151	0.139	0.129	0.118
18	0.232	0.215	0.199	1.183	0.168
20	0.312	0.290	0.268	0.247	0.226
22	0.404	0.375	0.347	0.320	0.292
24	0.508	0.472	0.436	0.401	0.367
26	0.624	0.580	0.536	0.492	0.449
28	0.753	0.699	0.645	0.593	0.541
30	0.893	0.829	0.765	0.702	0.640
32	1.045	0.970	0.895	0.821	0.747
34	1.209	1.121	1.034	0.948	0.863
36	1.385	1.284	1.184	1.085	0.987
38	1.573	1.458	1.345	1.232	1.120
40	1.772	1.643	1.515	1.387	1.260
42	1.984	1.840	1.695	1.551	1.409
44	2.208	2.047	1.885	1.725	1.566
46	2.444	2.265	2.086	1.908	1.735
48	2.692	2.494	2.287	2.097	1.905
50	2.951	2.734	2.517	2.301	2.087
52	3.232	2.985	2.748	2.511	2.267
54	3.506	3.248	2.989	2.731	2.476
56	3.802	3.521	3.240	2.960	2.682
58	4.110	3.805	3.501	3.198	2.897
60	4.429	4.100	3.772	3.445	3.120
62	4.761	4.407	4.053	3.701	3.352
64	5.104	4.724	4.345	3.966	3.591
66	5.459	5.053	4.646	4.241	3.839
68	5.827	5.392	4.958	4.525	4.095
70	6.206	5.743	5.280	4.818	4.360
72	6.597	6.104	5.611	5.120	4.633
74	7.000	6.477	5.953	5.431	4.913
76	7.415	6.860	6.305	5.752	5.203
78	7.843	7.255	6.668	6.081	5.500
80	8.282	7.661	7.040	6.420	5.806
82	8.733	8.077	7.422	6.768	6.120
84	9.196	8.505	7.815	7.125	6.442
86	9.671	8.944	8.217	7.492	6.773
88	10.232	9.462	8.693	7.924	7.163
90	10.656	9.854	9.056	8.252	7.458

Höhen in m für die Abstufung in den Tarifen.*

	Fichte (Spruce)					Tanne (fir)				
30 cm	25.0	22.8	21.0	19.3	18.0	24.3	21.6	19.7	18.1	16.8
50 cm	34.1	31.0	28.5	26.3	24.3	32.4	28.8	26.1	23.9	21.9
70 cm	39.1	34.7	31.2	28.3	26.1	37.0	32.9	29.5	26.9	24.7

SOURCE: Prodan 1951: Messung der Waldbestände, p. 160, table 54. Sauerländer's Verlag, Frankfurt a.M.

* Height in m for determination of tariff heights are given by the tariff's category and dbh.

Laer and Spiecker (1951) constructed volume tables for different species which give volume series depending on dbh and the number of tariff which is determined depending on dbh of average tree and the height of this tree (Table 4.5.-5.).

TABLE 4.5.-5. Extract from Laer and Spieker's volume tables for beech
2.5.-5.-A Tariff's determination (Table I); 2.5.-5.-B Volume series (Table II)

A

Beech dbh of average tree, cm	Height of average tree									
	26	27	28	29	30	31	32	33	34	35
	Tariff number									
40	66	69	72	74	77	80	83	86	88	90
-	-	-	-	-	-	-	-	-	-	-
41	65	68	71	74	77	80	83	85	88	90
42	65	68	71	73	76	79	82	85	87	89
43	65	68	70	73	76	79	82	85	87	89
44	64	67	70	73	75	78	82	84	86	89
45	64	67	70	73	75	78	81	84	86	88
46	64	67	70	72	75	78	81	84	86	88
47	63	67	69	72	74	77	81	83	85	88
48	63	66	69	72	74	77	80	83	85	87
49	63	66	69	71	74	77	80	83	85	87
50	63	66	69	71	74	77	80	82	85	87

B

Beech dbh cm	Tariff number				
	B 75	B 76	B 77	B 78	B 79
	cubic meters				
38	1.67	1.69	1.71	1.73	1.75
40	1.88	1.90	1.93	1.95	1.98
42	2.09	2.12	2.15	2.18	2.21
44	2.33	2.36	2.39	2.42	2.45
46	2.57	2.61	2.64	2.68	2.71
48	2.84	2.87	2.91	2.95	2.99
50	3.11	3.15	3.19	3.23	3.27
52	3.38	3.43	3.47	3.52	3.56
54	3.68	3.72	3.77	3.81	3.86
56	3.97	4.02	4.07	4.13	4.18
58	4.28	4.33	4.39	4.45	4.50
60	4.59	4.65	4.71	4.77	4.83

SOURCE: von Laer and Spiecker 1951. Massenberechnungstafeln Zur Ermittlung von Vorrat und Zuwachs von Waldbeständen J. D. Sauerländer's Verlag, Frankfurt a. M.

Tables have been completed also for series of form heights (hf). Laer and Spieker's tables can be used for determination of stand growth because if a stand is included in a tariff number it remains in this tariff a relatively long period of time.

A classical volume table for Douglas-fir plantations in Germany was developed by Hauser in 1956 (Table 4.5.-6.).

TABLE 4.5.-6. A classical volume table for standing Douglas-fir plantations in Germany (Volume in m^3 with bark and more than 7 cm at upper end)
SOURCE: Hausser 1956, Inhalt und Schaftform der Douglasie, Mitteilungen der Württembergischen forstlichen Versuchsanstalt, Stuttgart

Tree height m	Diameter at breast height, cm												
	10	15	20	25	30	35	40	45	50	55	60	65	70
7	0.02	0.06											
8	0.02	0.06											
9	0.03	0.07											
10	0.03	0.08	0.14										
11	0.03	0.09	0.15										
12	0.04	0.09	0.17	0.25									
13	0.04	0.10	0.18	0.27									
14	0.05	0.11	0.19	0.30	0.41								
15	0.05	0.12	0.21	0.32	0.44								
16	0.05	0.13	0.22	0.34	0.47								
17	0.06	0.14	0.24	0.36	0.50	0.66							
18	0.06	0.14	0.25	0.38	0.53	0.70							
19	0.07	0.15	0.27	0.41	0.56	0.74							
20	0.07	0.16	0.28	0.43	0.59	0.78	1.00						
21	0.07	0.17	0.30	0.45	0.62	0.82	1.05						
22		0.18	0.31	0.47	0.66	0.86	1.10						
23		0.19	0.33	0.50	0.69	0.91	1.15						
24		0.20	0.34	0.52	0.72	0.95	1.20	1.49					
25		0.21	0.36	0.54	0.75	0.99	1.26	1.55					
26			0.37	0.57	0.78	1.03	1.31	1.61	1.96				
27			0.39	0.59	0.82	1.07	1.36	1.68	2.04	2.45			
28			0.41	0.61	0.85	1.12	1.41	1.74	2.12	2.55			
29			0.42	0.64	0.88	1.16	1.47	1.81	2.20	2.64	3.14		
30			0.44	0.56	0.92	1.20	1.52	1.87	2.28	2.73	3.25	3.80	4.40
31				0.69	0.95	1.25	1.58	1.94	2.36	2.83	3.36	3.93	4.56
32				0.71	0.99	1.29	1.63	2.01	2.44	2.92	3.47	4.07	4.71
33				0.73	1.02	1.34	1.69	2.08	2.52	3.02	3.59	4.21	4.87
34				0.76	1.06	1.38	1.75	2.15	2.61	3.12	3.70	4.34	5.03
35					1.09	1.43	1.81	2.22	2.69	3.22	3.82	4.48	5.19
36					1.13	1.48	1.86	2.30	2.78	3.32	3.94	4.61	5.35
37					1.17	1.53	1.92	2.37	2.86	3.42	4.05	4.75	5.50
38					1.21	1.58	1.99	2.44	2.95	3.52	4.17	4.88	5.66
39					1.25	1.63	2.05	2.54	3.03	3.63	4.29	5.02	5.81
40					1.29	1.68	2.12	2.59	3.12	3.73	4.41	5.15	5.97
41						1.74	2.18	2.66	3.21	3.84	4.53	5.29	6.13
42						1.80	2.25	2.74	3.30	3.94	4.66	5.43	6.29
43							2.32	2.82	3.39	4.05	4.78	5.58	6.45
44								2.90	3.49	4.16	4.91	5.73	6.62
45								2.99	3.58	4.27	5.04	5.88	6.79

It is useful to summarize the entry types of volume tables:

h, dbh:	Schwappach (1890), Hauser (1956), Kennel (1969), Bergel (1973)
age class, h, dbh:	Bavarian volume tables (1846), Ganghoffer (1872, 1896); Grudner-Schwappach (1898, 1952) 10th edn., Zimmerle (1849).
h, diameter class:	Philipp (1896, 1924, 1931).
dbh, h, crown length: age class, height, dbh, region:	Zohrer (1968) Baur (1890)
dbh, unique height volume curve:	Spiecker (1948), valid only for mature stands
dbh and height for tariff number (or category), determination and dbh and tariff number for volume determination:	Laer and Spiecker (1951), Prodan (1951), for selection forest

Among approximate German formulae for tree or log volume estimation should be mentioned:

Hossfeld's method:

$$V = \left(3g_{1/3} + b\right)\frac{h}{4}$$

and for the entire stem when b=0:

$$V=\frac{3}{4}\left(g_{1/3} \cdot h\right)$$

where V is tree volume, $g_{1/3}$ = the sectional area of the top and h = the length of the log or height of the tree.

Pressler's method (1855, after Graves 1910, p. 155) called "director point or height procedure for standing trees"

$$V=\frac{2}{3}B\left(H+\frac{M}{2}\right)$$

where V = tree volume, B = sectional area measured just above butt swelling, H is the distance from the stump to the point of the stem where the diameter is one half that measured of the butt and M is the distance from the stump to the point where ß is measured. As a rule B is taken at dbh.

Frankhauser's (1889) formula:

$$V = \left(\frac{6}{10}dbh\right)^2 \bullet \frac{h}{100}$$

where V = volume in m^3, dbh is in dm and the height in m.

Denzin's (1929) formula:

$$V = \frac{(dbh)^2}{1000}$$

where V is the tree volume in m^3 and dbh is given in cm.

The first function adopted in Germany for the tree volume and applied for construction of tree volume and volume tables was Kopezki`s (1899) and Gerhardt`s (1901) function:

$$V = b_0 + b_1 g = a_0 + a_2 d^2 = b_0 + b_i g \qquad \text{or}$$

$$V = a + bx^2$$

which is preferred and known as the KG volume line (Kopezki-Gerhardtsche Massenline) where d is dbh and g the section area at dbh. This equation was used especially for local volume tables and was generally preferred in Germany (Dittmar 1958).

Other equations used for local volume table were proposed by:

Hohenadl (1936) and Krenn (1944): $V = b_0+b_1d+b_2d^2$ d = dbh

Berkhout (reference by Müller 1915): $V=b_0 d^{b_1}$

Wenk (1962): $V = g\left(h^2 / b_0\sqrt{d} + b_1\sqrt{d}\right)$, d = dbh, h = height, g = basal area at dbh.

Honer (1965 - reference by Prodan et al. 1997, p. 98):

$V = d^2/(b_0+b_1h^{-1})$ d = dbh, h = height

Müller G. and Zahn (1958) proposed a good function for compensation during construction of volume tables.

Schmitt and Schneider (1959) described the use of the least squares method in the developement of tree volume tables. In 1960 G. Müller proposed for Norway spruce construction of volume tables (tariffs) for different site types.

Prodan (1965 a) recommended the following regressing equations:

$$\log V = a_0 + a_1 \log d + a_2 \log^2 d + a_3 \log h + a_4 \log^2 h \quad \text{(standard error} \pm 7\text{-}10\ \%)$$

$$V = kd^a \cdot e^{-b/a}$$

$$\log V = b_0 + b_1 \log d + b_2 \log^2 d$$

$$\log V = b_0 + b_1 \log d + b_2 \bullet \frac{1}{d}$$

$$V = b_0 + b_1 d^2 + b_2 e^{-b_3 d_2} \qquad d = \text{dbh}$$

and proposed (1956 b) a simplification of the tariff system.

Lockow (1977) proposed equations with ln(V) and ln(form factor) as dependent variables and functions of ln(d) and ln(h) as independent variables.

Wagner (1982) recommended a volume function with log transformed volume as dependent variable, log-transformed dbh, height and diameter at 30 % of the tree height as predictor variables.

In 1990, Böckmann and al. proposed a five parameter non-linear model for *Tilia* species stem volume

$$V = b_1\left(b_2 d^2 h + b_3 dh + b_4 h\right)^{b_5} \qquad d = \text{dbh},\ h = \text{tree height}$$

Cited authors:

Anonymous (Bavarian volume tables) 1846, Baur 1890, Bergel 1973, 1974; Cotta 1804, Denzin 1929, Dittmar 1958, Frankhauser 1889, Ganghofer 1872, 1896, Gerhardt 1901, Graves 1910 (U.S.A.), Grundner-Schwappach 1898, 1952; Hausser 1956, Hohenadl 1936, Clark 1902/1903-U.S.A., Kennel 1969, Kopezki 1899, Krenn 1944, 1948; Laer and Spiecker 1951, Lockow 1977, 1995; Lorey 1882, Müller G. 1960, Müller G. and Zahn 1958, Pabst 1870, Philipp 1896, Pressler 1871, Prodan 1952, 1965a, 1965b; Röös and Bockmann 1989, Schwappach 1890, 1900, 1905; Schmitt and Schneider 1959, Schober 1952, Schuberg 1891, Soest 1956, Spiecker 1948, Wagner 1982, Wenk 1962, Zimmerle 1949, Zohrer 1968.

4.6. Tree growth

According to Prodan (1961), among the early (the earliest?) growth (y) functions should that proposed by Hossfeld be mentioned

$$Y = \frac{ax^2}{b_0 + b_1 x + b_2 x^2} \quad \text{and } y = \frac{x^n}{a + bx^n} \quad ,\ x = \text{age},\ y = \text{growth}$$

and Hossfeld IV:

development: $y = t^c/(b + t^c/a)$ with the first derivative (increment)

$y^1 = bct^{c-1}/(b + t^c/a)^2$ (Prodan et al. 1997, p. 465).

used for construction of yield tables after a modification in order to use the minimum squares method. Since Hossfeld's proposals and that of E. A. Mitscherlich (1919) we have not noticed any other work on tree growth with reference to functions.

In 1853, Schneider, professor of the first school at Eberswalde, proposed for tree growth determination the formula:

$$p = 400/n\ D$$

where p = the rate of growth percent, D = dbh, n = the number of annual rings in the last centimetre (or inch).

Schneider's formula (whose demonstration may be found in other forest mensuration books) assumes that there is no change in height and form factor that is the case of mature or nearly mature trees, when it gives satisfactory results. In the same conditions satisfactory results are given by Pressler's formula:

$$\mathrm{P} = \frac{D^2 - d^2}{D^2 + d^2} \cdot \frac{200}{n}$$

where D = dbh now, d = dbh n years age, p = percentage of growth. Pressler designated D-d as "a" and D/a called the relative diameter designed as q. Then the above-mentioned formula becomes:

$$\mathrm{P} = \frac{q^2 - (q-1)^2}{q^2 + (q-1)^2} \quad \frac{200}{n}$$

and Pressler constructed a table showing the values of the expression

$$E = 200(q^2 - (q - 1)^2)/(q^2 + (q - 1)^2$$

and for p determination one measures D = dbh and its growth for n years, divides D by "a" to obtain q and looks up the table of E corresponding to known q which is divided by n and gives the rate of growth percentage in volume. Schneider's and Pressler's formulae may be used to approximate the percentage of growth volume of the whole stand but the result is very inaccurate.

In 1866, Pressler constructed the increment borer (Zuwachsbohrer) whose best types have been made in Sweden.

For the rate of growth percentage Stoetzer (1880) proposed the formula p = k/nd, (n = number of years for which d is measured), and if z = increment of form factor is zero ($z_f = 0$) and $Z_h/h = Z_d/d$ then $p_h = p_d$ (zh and zd are increment in height and diameter) and

$$p_v = 2p_d = p_h = 2p_d + p_d = 3p.$$

The constant k is located between 200 and 600:

$$p_d = \frac{200^d}{nd} \quad \text{and } p_v = \frac{600}{nd}$$

In 1880, Tuisko Lorey described in detail how to perform stem analysis (Stammanalysen) which are able to determine the tree growth characteristics (diameter, height, volume, basal area) during its life.

The relationship between current and mean increment was demonstrated for the first time by K. Meyer in 1883 (Prodan 1951 p. 184, 185; Prodan et al. 1997 p. 437). The curves of current and mean increment are presented in Fig. 4.6.-1.

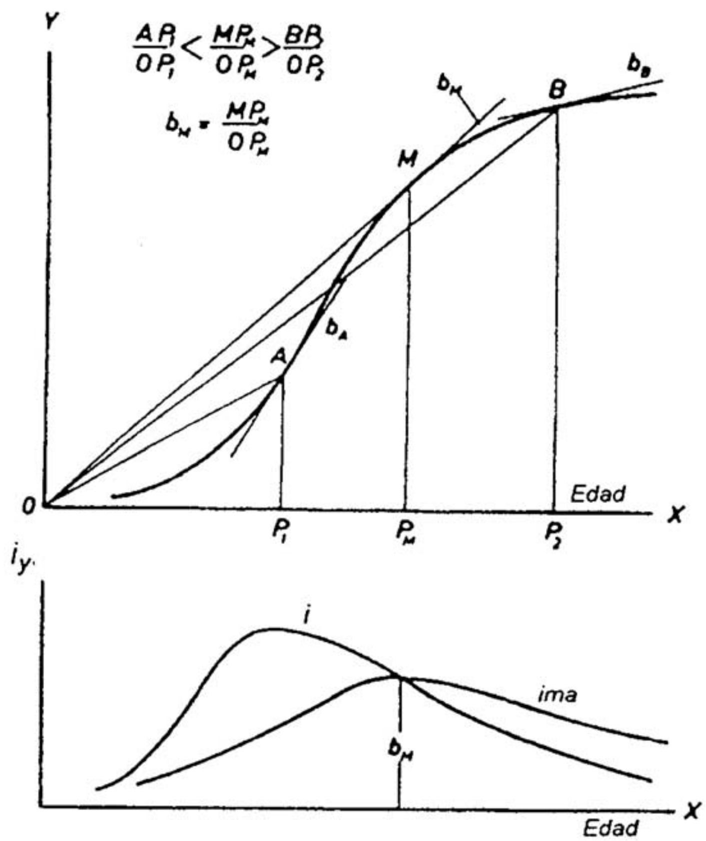


Fig. 4.6.-1. The relation between annual current increment (i) and annual average (mean) increment (ima) and cumulative curve of growth development x=age (edad)
SOURCE: Prodan 1951 and Prodan et al. 1997, p. 435. The last book contains different demonstrations, that of Heyer`s (1883) included

Growth percentage has been analyzed also by Gustav Kraft (1885). Jaccard (1916) developed the hypothesis of pipe model considering the tree stem as a pipe and connected this theory with the tree form and growth.

Tree growth was considered to be influenced by (1) individual tree growth potential which determines the level of growth in the absence of other factors or under "open growth" stand conditions, and (2) a competition (term which scales the growth of a tree from "1" under open growth conditions towards "0" as a tree begins to become overtoped in a dense stand. This concept seems to have been satisfactorily applied in several modelling efforts and was formalized as a general growth "law" in the early 1900s (Baule 1917).

In 1919, E. A. Mitscherlich developed for plant growth the so-called monomolecular function:

$$Y = a\,(1 - ce^{-bt}) \qquad y^1 = abce^{-bt}$$

where y = growth, t = age (time), a, b, c = parameters, y = first derivative

This equation represents in fact the generalized form of the Bertalanffy equation with α value non-restricted, and was used by German foresters during the 1950s, e.g. Weck 1951 (Vanclay 1994). The generalized form of Bertalanffy equation (α not constrained) is sometimes called the Chapman-Richards equation because of Richards` studies (1959) on plant growth and by Chapman (1961) with fish population" (Vanclay 1994, p. 109). In fact the Chapman-Richards equation

$$\left(y = a\left(1 - e^{-bt}\right)^c\right)$$

is not identical with that developed by E. A. Mitscherlich.

The investigation of physiological similarities of growth processes was developed by A. Pütter (1920) who in our opinion may be considered as aprecursor of Bertalanffy, if not even more than that.

Between Pütter (1920) and Bertalanffy (1941) we should be mention the works of: Busse (1930), the use of photography for growth determination; Meyer J. (1939), crown convexity and growth variability of Scots pines in northern Germany; Peschel's (1939), growth function which was used by Waren in 1980 in Canada in the field of dendrochronology; Topcuoglu (1940), researches on annual growth distribution along the stem (the same annual ring becomes larger toward the top of the stem). A special mention for Hugershoff (1938) who proposed the equation $y = ax^m e^{-kx}$ and "combined the characteristics of a second degree equation without a linear term with the exponential model y = exp (-kA) to express the rate of growth (y) as a function of age (A):

$$\frac{dy}{dt} = b_0 A^2 e^{-b_1 A}$$

A logarithmic transformation of the growth function ensures that ordinary least squares can be applied to estimate the two parameters" (Laar and Akça 1997, p. 228). For A = 0 the function y = 0 and the maximum rate of growth is than $A = 2/b_1$ and the cumulative growth function can be obtained by integration.

In his researches on the laws of growth and types of metabolism (1941), 1942/1951: "Teoretische Biologie", 1949: "Problems of organic growth", and 1968: "General System Theory", L. von Bertalanffy presented a hypothesis according to which the growth of an organism could be represented as the difference of two processes: anabolism (synthesis) and catabolism (degradation).

"These assumptions were attributed to Pütter (1920) could be expresses as allometric functions of mass (Y) and thus growth (dY/dt) would approximate:

$$dY/dt = \beta_1 Y^{\alpha} - ß_2 Y^{\delta}$$

where α and δ are the constants of anabolism and catabolism respectively" (Vanclay 1994, p. 108/109).

In 1949 and 1968 Bertalanffy`s papers considered that α could vary from 2/3 to 1 and did not propose any value of α. In the case of diameter (d) growth (Δd) in trees Bertalanffy equation is:

$$\Delta d = ß_1 d^{\alpha} - ß_2 d = ß_2 d \left\{ \left(\frac{d_{\max}}{d} \right)^{1-\alpha} - 1 \right\}$$

where d_{max} is the maximum attainable diameter.

The Bertalanffy equation may be written in the generalized form (in order to be compared with other growth and yield models, presented by Prodan et al. 1997, p. 465):

$$Y = a(1- e^{-bt})^3 \qquad y' = 3abe^{-bt}(1- e^{-bt})^2, \qquad t = \text{time, age.}$$

Another important function with biological motivation of growth was proposed by G. Backmann in 1943 and is frequently used in forestry:

$$\log y = k \log^2 t$$

where y = growth, k = constante always negative and t = "organic time" which corresponds to the logarithm of physical time.

In fact, Backmann introduced the concept of "organic time" which represents the age divided by the age at maximum growth rate and organic growth rate, defined as the rate of growth divided by the maximum growth rate. The original Backmann's growth model is represented by the expression:

$$\log \left[\frac{dy/dt}{(dy/dt)\max} \right] = b \log^2 \left(\frac{A}{A_{\max.}} \right)$$

where t = time and A = growth rate.

After some algebraic changes the following growth equation was obtained:

$$\log \left(\frac{dy}{dt} \right) = b_0 + b_1 \log A + b_2 \log^{2A}$$

The parameter b_0 depends on the maximum growth rate, b_1 depends on b and the age at which the growth rate is maximum, whereas b^2 = b.

A detailed discussion on the Backmann function was published in 1962 by Thomasius.

In 1956, Mitscherlich constructed a model to described Liebig's law of diminishing returns expressed by the differential equation:

$$\frac{dy}{dA} = k\ (B - y)$$

where the parameter B represents the upper asymptote of the size variable y whereas k expresses the rate of which the organism reaches the asymptotic. The solution of this equation is

$$Y = B - b_0 e^{-b_1 A}$$

and if y = 0 for A = 0 than b_0 = B and the equation can be rewritten:

$$Y = B(1 - e^{-b_1 A}).$$

In this model the growth curve has no inflection point and the age A_i is proportional to the difference between the upper asymptote of y and A_i (Laar and Akça 1997, p. 229).

Different other equations of growth and yield developed in other countries are presented in a generalized form by Prodan et al. (1997, p. 465).

In 1947, Prodan published data on diameter increment in managed selection forests (Plenterwaldbestand). On the other hand, Pfeilsticker (1950) constructed the German growth hammer as an alternative to Pressler`s increment borer.

An important chapter referring to growth of trees and stands is included in Prodan's (1951) "Messung der Waldbestände" (Measurement of forest stands).

In 1951, Vanselow analyzed the relationships between crown and growth in the spruce trees grown in pure even-aged sands, and Magin (1959) performed the similar thing in the Bavarian selection forest.

Measurement of the influence of different factors on radial growth were completed by Sostrzionek and Grossmann (1961) and Kern (1961). Volume and diameter increment were determined in accordance with the height growth by Weck (1961).

In 1961, Prodan proposed the following equation for growth curve:

$$Y = b_0 x^{b_1} e^{b_2 x} \quad \text{or } \log y = b_0 + b_1 \log x + b_2 x$$

where y = growth, x = age, b_0, b_1, b_2 = coefficients of regression.

By the integration of growth functions it results the development functions.

Prodan (1961) noted that growth functions with satisfactory results can be obtained using Pearson's system of equations.

Two outstanding books have been published in a rather short period: Assmann's (1961) "Waldertragslehre" translated into English in 1970 (The principles of forest yield study), a book that contains a lot of information on tree growth and Prodan's (1965) "Holzmesslehre" (Wood science, forest mensuration). Prodan designed a special chapter for the determination of tree and stand growth (chapter X).

Diameter growth and the use of dendrographs for its determination was the subject of the papers written by Abetz (1966), Hildebrandt (1966), G. Mitscherlich et al. (1966), Klemmer (1969), Geissler (1970), and for height by Tiihonen (1967).

In 1971, Sloboda developed an investigation of growth processes using first order differential equations for the growth of height (this equation was used in Mexico by Aguire in 1989 for *Pinus pseudostrobus*. Generalized forms of this equation are the following:

$$Y = ae^{-be^{ct^{d}}} \qquad y' = bcdyt^{d} e^{ct^{d}}$$

A mathematical formulation of growth processes in forestry based on the determination of the growth percentage was completed in 1978 by Wenk.

Mathematical and stochastical models for the description of static and dynamic of trees and stands with a special account on growth and development as a stochastic process determined by environment were presented by Sloboda at Freiburg in 1976. The influence of weather, especially temperature on growth of beech trees was studied by Kramer (1982).

In 1982, methods of stem analysis are described by Nagel and Athari with a computer program for evaluating results that can be presented in tabular or graphical form.

Akça (1984) estimated growth using crown measuring.

In 1985, Nagel constructed a model for mountain maple growth (*Acer pseudoplatanus*). Kramer (1986) assessed the effects of air pollution on growth and established that volume growth per unit crown surface is a valuable target variable.

A synthesis on growth of some predominant trees of different species in a mixed stand of southern Bavaria was presented at IUFRO Centennial by Preuhsler (1992).

An inventory study on individual growth of forest trees in relation to natural and anthropogenetic influences was completed in 1994 by Kramer and Kätsch and this work revealed the great variability in growth development between individual trees of Norway spruce and beech.

Nagel (1994) developed a growth model for an individual tree of sessile oak.

Vogel (1994) used RMI girth tapes for automatic recording of girth at 3-4 intervals on Norway spruce; these automatic precision measurements of radial increment offer the possibilities of interpreting short-term fluctuations in the measured values, and radial changes could be deduced from the measured value with an accuracy of ± 1μ.

Cited authors:

Abetz 1966, Aguire 1989, Akça 1984, Assmann 1961, 1970; Backmann 1943, Baule 1917, Bertalanffy 1941, 1942, 1951, 1949, 1957, 1968; Busse 1930, Chapman 1961, Geissler 1970, Grossmann 1961, Heyer K. 1883, Hildebrandt 1966, Hilf 1930, Hugershoff 1938, Jaccard 1916, Kern 1961, Klemmer 1969, Kraft 1885, Kramer 1982, 1986; Kramer and Katsch 1994, Krenn 1948, Künstle 1962, Loetsch 1952, Lorey 1880, Magin 1959, Mayer 1939, Mitscherlich E.A. 1919, 1956, Mitscherlich G. 1952, Mitscherlich G. et al. 1966, Peschel 1939, Nagel 1985, 1994; Nagel and Athari 1982, Pheilsticker 1950, Pressler 1865, 1866, 1867,1883,1898; Preuhsler 1992, Prodan 1947, 1951, 1961, 1965a, 1965b); Prodan et al. 1997; Pütter 1920, Richards 1959-U.K., Schöpfer 1962, Schneider 1853, Sloboda 1971, 1976; Sostrzionek 1958, Thomasius 1962, 1965; Tiihonen 1967, Topcuoglu 1940, Vanselow 1951, Vanclay 1994, Vogel 1994, Waven 1980 (Canada), Weck 1951, 1961; Wenk 1978.

4.7. Timber assortments

The oldest German methods for the determination of assortments in a stand were based on sample trees (Draudt 1860, Urich 1860, Hartig 1847) and supplied data only for large categories of wood such as log-wood, small wood, branches, fuel wood (staked or in piles). Early data on assortment percentage in stands of different species such as oak, poplar, ash, beech, birch, pine, spruce and fir were used in southern Germany. These tables were of Austrian (Schindler 1876, Hempel 878) or Swiss origin (Flury 1916, published in Switzerland in 1916 for spruce, beech and fir - based on 3,125 stems).

One of the earliest German tables containing assortment percentage for trees were constructed by Wimmenauer, in 1907, and for stands by Schwappach (1889).

In 1884, Gustav Kraft published his tree classification according to the position of trees in the canopy (I: emergents, II: dominants, III: codominants, IV: overtopped and partially suppressed, V: deadly suppressed, dying) which is based on silvicultural criteria, but at the same time it is a guide for the potential assortment structure of a tree.

Among the early German works on timber assortment it will be mentioned:

Haehnle (1905) assortment tables for spruce ± even-aged stands thinned regularly in Württemberg; assortments and its value in spruce and fir (Gayer E. 1912); Hausser's (1933) assortment table for Douglas-fir.

In 1936 (first October) official rules for wood division into sections, measure and assortments, so called HOMA, were published: Bestimmungen über die Ausformung, Messung und Sortenbildung des Holzes in den deutschen Forsten" - or "Reichshoma".

HOMA represented a new synthesis of rules applied during the last 100 years in Central Europe, developed and presented in a new form (Prodan 1965, p. 4).

The main criteria of timber classification in the HOMA system are (1) diameter size and (2) the utilization purpose. According to diameter size the timber is classified in:

(a) Derbholz = big size timber having more than 7 cm diameter over bark at upper end (top);

(b) Nichtderbholz = upper top diameter under 7 cm;

(c) Schaftholz = stem timber (timber under 7 cm diameter included);

(d) Baumholz = all timbers of a tree.

After utilization:

(a) Nutzholz = (unbarked) round timber for work:
- (1) Langholz = long timber
  - (a) Stämme sind Langnutzhölzer = logs having more than 14 cm diameter (over bark) 1 meter from the lower butt;
  - (b) Stangen = poles.
- (2) Schichtnutzholz = stacked timber for work;
- (3) Rinde = bark when used for other purposes than fuelwood.

(b) Brennholz = fire wood (fuel wood).

More details can be found in Prodan's forest mensuration (1965, p. 4-17) and HOMA 1950 for transformation factors and units of measurement.

Characteristic to the Homa assortments is the fact that: (1) they have been established for an optimal tree form based on decreasing indices of the stem, by species; (2) there is an average relationship between the size of individual trees and the percentage of different assortments within their stem volume (see Table 4.7.-1.).

TABLE 4.7-1. Table with percentage of long timber (Heilbronner classes in stem timber (Schaftholzmasse)
SOURCE: Mitscherlich 1939. Mentioned in Schmidt-Vogt, 1986:Die Fichte, p. 173

Scheitelhöhe in m *	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
	cm Brusthöhendurchmesser **																							
36											91	82	85	87	90	92	93	79	82	85	87	89	90	91
34								80	86	88	91	82	85	88	90	92	93	79	82	86	87	89	90	91
32							70	80	85	88	91	82	85	88	90	92	93	93	83	86	87	89	90	92
30						85	88	81	86	89	91	92	86	88	90	92	93	93	94	86	87	89	90	92
28					80	86	89	83	87	90	92	93	93	89	91	92	94	95	95	96	96	97	91	92
26				83	80	87	90	93	88	90	92	94	95	96	97	93	94	95	96	96	97			
24			76	85	89	87	91	93	94	91	92	94	95	96	97	98	98	98						
22		92	78	85	90	94	91	93	94	96	97	97	95	96	97									
20	87	93	78	86	90	94	97	94	95	96	97	97	98	98										
18	87	93	94	87	91	93	95	96	96	97	97													
16	87	93	97	98	91	94	97																	

* Total height in m Kl. 1, Kl. 2, etc. = Heilbronner classes
** dbh, cm

For grading logs from a dimensional point of view, there are two main systems in Germany: (1) based on mid diameter of the log and contains the classes L0-L6 with divisions within the classes L 1, L 2 and L 3, and; (2) the Heilbronner classification based on minimum length and minimum top diameter. (Table 4.7.-2.). On the other hand timber is classified in four qualitative classes: A, B, C and D which indicate wood defects.

TABLE 4.7.-2. Grading long-length logs and Heilbronner grading in Germany
SOURCE: van Laar and Akça 1997. Forest mensuration, p. 119, table 4.4.

Long-length logs		Heilbronner classes		
Class	diameter under bark (cm)	Class	Minimum length (m)	Minimum top diameter (cm)
L0	<10	H1	8	10
L1a	10-14	H2	10	12
L1b	15-19	H3	12	14
L2a	20-24	H4	14	17
L2b	25-29	H5	16	22
L3a	30-34	H6	18	30
L3b	35-39			
L4	40-49			
L5	50-59			
L6	> 59			

The transition from the quantity on assortments by diameter categories to the stand assortments is performed on the basis of correlation between dbh and height of stand (height curve). Such assortment tables have been developed by Lang (1938), for spruce in Württemberg; Vogel (1939), for oak and beech; Mitscherlich (1939), for spruce, Scots pine, beech and oak, who used the theoretical form of solids of rotation; Schober and Wiedemann (1957), Wiedemann (1969).

In 1989, Schöpfer and Dauber published stand assortment tables 1982/1985 for spruce, fir, Scots pine, larch, beech and oak, and a sample of these tables (for spruce) is presented in Table 4.7.-3. Other assortment tables were constructed in Baden (1952), and by Krenn (1952), Harder (1954), Schilling (1960).

TABLE 4.7.-3. Assortments tables for spruce stands in southern and northern Germany

Süddeutschland

Best.-Mittel	Stamm-Klassen H							Stammteile-Klassen HL											H+HL	IL	S	X	NV
$d_{1,3}$ cm	1 %	2 %	3 %	4 %	5 %	6 %	1–6 %	0 %	1a %	1b %	2a %	2b %	3a %	3b %	4 %	5 %	6 %	0–6 %	%	%	%	%	%
12	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	45	46	5	3
15	5	11	3	1	0	0	20	0	1	1	0	0	0	0	0	0	0	2	22	34	34	3	7
20	5	25	19	9	1	0	59	0	1	1	1	1	0	0	0	0	0	4	63	18	11	2	6
25	2	16	25	24	6	1	74	0	0	1	2	2	1	1	0	0	0	7	81	6	6	3	4
30	0	6	17	33	18	4	78	0	0	1	2	3	2	1	1	0	0	10	88	3	4	3	2
35	0	3	8	27	30	10	78	0	0	1	2	3	3	2	2	0	0	13	91	2	3	2	2
40	0	1	4	18	35	20	78	0	0	1	1	3	3	3	3	1	0	15	93	1	3	2	1
45	0	1	2	10	30	34	77	0	0	1	1	2	2	3	5	1	1	16	93	1	3	2	1
50	0	0	1	6	22	46	75	0	0	0	1	2	2	3	5	3	2	18	93	1	3	2	1
55	0	0	0	3	14	56	73	0	0	0	1	1	2	2	7	4	3	20	93	1	3	2	1
60	0	0	0	1	8	61	70	0	0	0	0	1	1	2	7	6	6	23	93	1	3	2	1

Norddeutschland

Best.-Mittel	Stammklassen L											IL	S	X	NV
$d_{1,3}$ cm	0 %	1a %	1b %	2a %	2b %	3a %	3b %	4 %	5 %	6 %	0–6 %	%	%	%	%
12	0	1	0	0	0	0	0	0	0	0	1	67	22	7	3
15	0	5	4	2	0	0	0	0	0	0	11	40	36	5	8
20	0	2	19	11	3	1	0	0	0	0	36	49	4	4	7
25	0	1	21	28	13	5	1	1	0	0	70	20	2	3	5
30	0	0	11	32	26	12	4	2	0	0	87	6	1	3	3
35	0	0	4	23	30	20	9	5	1	0	92	2	1	3	2
40	0	0	2	12	29	27	15	9	1	0	95	1	1	2	1
45	0	0	1	6	20	28	21	16	3	0	95	1	1	2	1
50	0	0	0	3	12	25	24	24	7	1	96	1	1	2	0
55	0	0	0	2	8	18	24	30	11	3	96	1	1	2	0
60	0	0	0	1	5	13	21	35	16	6	97	0	1	2	0

H = Heilbronner Sortierung; HL = Stammteile innerhalb der Heilbronner Sortierung; L = Mittenstärkensortierung; IL = Industrieholz lang; S = Schichtholz; X = X-Holz (im Bestand liegenbleibendes krankes Holz des unteren und mittleren Stammbereiches); NV = nicht verarbeitetes Derbholz

H = Heilbronner grading, HL = Stem Heilbronner classes and inner subclasses, L = Grading according to mid diameter, IL = industrial wood, S = stacked wood, NV = not working wood, X-Holz = other wood.
SOURCE: Schöpfer and Dauber, 1985. Bestandessortentafeln 1982/1985. Reproduced after Schmidt-Vogt 1986, Die Fichte, p. 175

A short history of timber assortments especially from theoretical point of view, till HOMA establishment (1936), it was written by Platte (1936). In the countries of the European Community a system of classification called Rohholz-Handelsklassen, that replaced the German HOMA (Loetsch et al. 1973), has been used since 1969.

Altherr examined the accuracy of assortment determination (1960) using decrease factors in the case of resinous species (1953) and discussed the connection between stem form and dimensional assortments (1954) and in 1978 (Altherr et al. 1978) the use of statistics in bark determination of stem timber of Norway spruce, fir, Douglas-fir and Sitka spruce. Data on volume assortments and value of Norway spruce have been determined by Schober (1979/1980).

A regression equation of stem form of Norway spruce was used by Roiko-Jokela (1976) for the determination of dimensional assortment in standing trees. Roiko-Jokela in the same way like Schmidt Hass (1976) used dynamic programming to establish the optimum variant of timber grading (sorting).

In 1982, Saborowschi developed a biometrical model for assortment prognosis. Another model for assortment planning and simulation is based on Michailoff's function

$$h = 1.3 + (h_m - 1.3)\ e^{\left[a_1\left(1-d_q/d\right)+a_2\left(1/d_q-1/d\right)\right]}$$

Gaffrey (1996) developed a stand assortment and growth simulation model based on intraspecific competition for Douglas-fir.

Wegard et al. (1997) introduced a new method of quality assessment of standing oak trees (*Quercus petraea*), called the butt log method, in which the assignment of quality classes is based on several quality criteria that are measured in the field.

In their "Mensura Forestal" Prodan, Peters, Cox and Real (1997, p. 143), used assortment functions that can be applied on stand level:

$$V_{p_i}\% = a_0(1\text{-exp } a_1 Dg)$$

$$V_{p_i}\% = b_0\left(b_1 + b_2 D_g + b \log D_g + b_4 D_g^2\right)$$

where $V_{p_i}\%$ = a given assortment percentage of total timber volume per hectare, D_g = average diameter corresponding to stand basal area, cm.

These models are flexible and can be used as components in a stand growth-yield computerized model.

Cited authors:

Altherr, 1953, 1954, 1960; Altherr et al. 1978, Baden 1952, Draudt 1860, Gaffrey 1988, 1996; Gayer 1912, Gayer-Fabricius 1935, Haehnle 1905, Harder 1955, Hartig Th. 1847, Hausser 1933, Hempel 1978, HOMA 1936, 1950; Kraft 1884, Krenn 1952, Laar and Akça 1997, Lang 1938, Loetsch et al. 1973, Mitscherlich 1939, Platte 1936, Prodan et al. 1997, Roiko-Jokela 1976, Saborowschi 1982, Schilling 1960, Schindler 1876 (Austria), Schmidt-Haas 1976, Schober 1946, 1979/1980; Schober and Wiedemann 1957, Schöpfer and Dauber 1989, Schwappach 1889, Urich 1960, Vogel 1939, Weiman 1969, Wiegard et al. 1997, Wimmenauer 1907.

4.8. Evaluation of forest site quality

There are different possibilities for the evaluation of forest site (land) quality which is its capacity to produce wood.

Prodan et al. (1997) defined site quality as the "totality of environmental factors which exert an influence on plant growth" (p. 370).

Evaluation of site quality can be performed by: (1) direct measurement or estimation of site characteristics such as soil and climate; (2) by the means of indicator plants (ground vegetation); (3) measurement of the effects on forest vegetation for height or volume per unit area of a given age, growth mean, current or total volume increment per unit area at a given stand age (50 or 100 years).

In 1765, K. C. Oettelt proposed the stand average height at a given age as a criterion for classification of site, evaluation of its quality respectively. This notable criterion was adopted 112 years later by Baur (1877)

Before Baur (1877), Pressler (1878) used total yield in cubic measure as an indicator of site quality in the so-called "Baur's method of strips (bands)".

The total yield in cubic measure of each stand is plotted on one cross-section paper whose ordinates represents final yield of the main crop in cubic measure and whose abscissae represent the average age of the stand. Each point (value of plot) is plotted. The number of the valuation survey is also entered near it. Then regular curves are drawn through the maximum and minimum points, confining all the points in a comet-shaped band whose outer edges represent the maximum and minimum yield. Then the ordinates at each decade lying between these curves are divided into five equal parts and the dividing points are connected by curves that separate the points representing the yield of the different plots into five divisions. The points lying in a single band indicate plots which belong to the same quality of site. A modification of the method just described uses heights instead of volumes to determine the quality of the site. This method used on construction of Baur's and similar yield tables is based on the principle that the height of an even-aged stand is a reliable index of the quality of site" and sometimes the average height of the stand is used, but some authors advocate the determination of the quality of site by means of maximum height (after the English text of Graves 1910, Forest Mensuration p. 325, 326).

Stand volume per unit area was used in Pressler's (1878) yield tables used in Saxony up to 1924. Baur's tables had not been easily accepted because even the Union of Forest Experimental German Stations decided in 1888 the construction of yield tables with five site classes based on normal volume per unit area under condition of low intensity thinnings which was considered then as an optimum. This normal volume represents the total volume production at 100 years of age as a standard of site productivity.

The total volume of a stand with a closed canopy was used also by Philipp (1893/1896) as an indicator of site quality.

Recommendations for site classification have been established by Eberhard (1916): "Tafel zur Bonitierung und Ertragsbestimmung". The importance of stand volume for site evaluation was underlined again by Reinhold (1926).

Ground vegetation was used in Germany for site evaluation on the basis of Braun-Blanquet plant sociology principles (1928, 1959), but as far as we know, not on a large scale. Humboldt's (1806) ideas on physiognomy of plants, in which forest plants are included, should not be forgotten.

In his "Forstliche Zuwachs- und Ertragskunde" (Science of forest growth and yield) published in 1948 (2^{nd} edn. 1955), J. Weck considered that the first way to classify the sites according to their productive capacity is the direct investigation on their characteristics, but no one characteristic of site is determinant in all cases and only the complex of all characteristics of a given site can be determinant for its classification because some factors could compensate the actions of others. In our opinion evaluation of a site should be performed in connection with a given species because a site may be proper for species A and inadequate for species B (the similar thing is valid in the case of soil classification and mineral nutrition).

In 1949, Prodan established productivity classes (site classes) in selection forest (Plenterwald) of spruce mixed with fir using dbh and height based on compensate height curves which have been constructed for this species and type of structure (Table 4.8.-1.).

Based on Prodan's idea (Prodan proposed a classification of selection forest sites depending on the number of trees with dbh ≥ 50 cm and their growth diameter), Mitscherlich 1952 constructed a table for site evaluation depending on the above-mentioned characteristics (Table 4.8.-2.).

TABLE 4.8.-1. Determination of site class in fir and spruce selection forest using compensate height-diameter curve
SOURCE: Prodan 1949. Normalisierung des Plenterwaldes? Forstliche Versuchsanstalt, Heft 7.

Diameter cm	Species	Yield class				
		I	II	III	IV	V
		Height, m				
40	fir	27.3	24.3	22.2	21.4	19.8
	spruce	29.9	27.4	25.5	23.2	21.7
50	fir	32.4	28.8	26.1	23.9	21.9
	spruce	34.1	31.0	28.5	26.3	24.3
60	fir	34.9	31.0	28.0	25.6	23.4
	spruce	36.9	33.1	30.2	27.7	26.0
70	fir	37.0	32.9	29.5	26.9	24.7
	spruce	39.0	34.7	31.2	28.3	26.1
80	fir	38.7	34.4	-	-	-
	spruce	40.7	-	-	-	-

TABLE 4.8.-2. Determination of site class in fir and spruce selection forest using compensate height-diameter curve
SOURCE: Mitscherlich 1952. Der Tannen-Fichten-(Buchen)-Plenterwald.Versuchsanstalt Freiburg, Heft 8.

Number of trees/ha with diameter over 50 cm	Fir					Spruce				
	Yield class					Yield class				
	I	II	III	IV	V	I	II	III	IV	V
	Growth in diameter, mm:									
5	10.9	9.7	8.4	7.1	5.9	7.4	6.5	5.7	4.8	4.0
10	10.3	9.1	7.9	6.7	5.5	7.0	6.2	5.4	4.6	3.8
15	9.7	8.5	7.4	6.3	5.2	6.7	5.9	5.2	4.4	3.6
20	9.1	8.0	7.0	6.0	4.9	6.5	5.7	5.0	4.2	3.5
25	8.5	7.5	6.6	5.6	4.6	6.3	5.5	4.8	4.1	3.4
30	7.9	7.0	6.1	5.2	4.3	6.1	5.4	4.7	4.0	3.3
35	7.4	6.5	5.7	4.8	4.0	6.0	5.3	4.6	3.9	3.2
40	6.9	6.1	5.3	4.5	3.7	5.9	5.2	4.5	3.8	3.1
45	8.5	5.7	5.0	4.2	3.5	5.8	5.1	4.4	3.8	3.1
50	6.1	5.4	4.7	4.0	3.3	5.7	5.1	4.4	3.7	3.1
55	5.8	5.1	4.5	3.8	3.1	5.6	4.9	4.3	3.7	3.0
60	5.6	4.9	4.3	3.7	3.0	5.6	4.9	4.3	3.7	3.0
65	5.4	4.8	4.2	3.6	2.9	5.5	4.8	4.2	3.6	2.9
70	5.3	4.7	4.1	3.5	2.9	5.4	4.8	4.2	3.6	2.9
75	5.3	4.7	4.1	3.5	2.9	5.3	4.7	4.1	3.5	2.9
80	5.2	4.6	4.0	3.4	2.8	5.3	4.7	4.1	3.5	2.9

In connection with the structure of European section forest should be mentioned the works of Leibundgut (1972, 1982).

The problem of site evaluation was also discussed by Wiedemann (1950, 1951).

Vanselow and Rubens (1952) used mass species as indicators of site productivity in Norway spruce stands in southern Bavaria.

Weck (1955, 1960) mentioned the relationship between climate and the potential of forest production, proposing the following index:

$$i=\frac{N \cdot n \cdot (z-60)}{(T+10) \cdot 92}$$

where: N = accumulated precipitations in May, June and July (mm);
T = average temperature in centigrades for the same months;
n = the number of days in May-June-July with precipitations less than 0.1 mm;
z = the number of days in a year without frost.

Weck index cannot be used in the same way with Paterson`s index.

The problems of site evaluation are analyzed in detail by Assmann (1961) in his "Waldertragslehre" (Forest science).

Moosmayer published in 1962 a short review of literature in German on forest site productivity published after 1945.

New researches on relationships of main species growth and environmental factors (site types) were developed in 1962 by Werner.

Influenced by the American system of site indexes (in the U.S.A an absolute height was adopted: at the same age and average height stands have the same site index class; a reference age of 50 or 100 years was usually adopted. Assmann and Franz constructed yield tables for Norway spruce based on reference height, the dominant height at 100 years (1963, 1965, 1972). For site evaluation the criteria are average or dominant height or mean increment of total yield at the age of 100 years.

Kramer (1967) advocated the use of height as an indicator of site quality because the height attained by trees at the cessation of height growth (assuming that such an asymptote exists) is a good indicator of site productivity and attributed this observation to Oettelt (1765).

According to Vanclay (1994, p. 138) "… Stand height may be used as an estimator of site productivity if there are trees present in the stand that are sufficiently large to reflect the maximum potential height that the nominated species is likely to attain on that site. The concept is analogous to a site index (as used in the USA – our mention A.A.) with a very large index age."

The influence of site quality is very important in forest management for the reglementation of forest production (Moosmayer 1970).

Site productivity is analyzed in detail in the works of Franz (1971) and Mitscherlich (1971). Laar (1976) discussed single tree parameters of Norway spruce in relation to site and environmental parameters.

In 1973, Ravat developed a mathematical model for the site quality curves of seven important tree species in Bayern (Bavaria). This was the first work of this kind.

Air pollution and forest decline as the result of site conditions, especially on acid soils, was extensively analyzed in a textbook having Schulze E. D. et al. as editors (1981).

In 1986, Bergel constructed a new yield table for Douglas-fir in northwestern Germany and underlined that "site index is calculated in the usual way, at the top height at 100 years but stands were also placed in three productivity classes." It seems that the American site index system became frequent in Germany.

In 1992, Gochet developed a site oriented model for beech in Reinhausen forest.

Spieker (1995) referring to growth trends of European Forest railed the question: "Has site productivity changed?" Based on permanent research plots (installed by forest research organizations starting from the middle of the 19th century) and analyzing trees during forest inventories Spiecker concluded: "Recent investigations in European forests indicate positive as well as negative changes in forest site productivity. In contrast to intensive discussions\ about forest decline in the 1980s several growth studies show that actual forest growth may have increased on specific sites" (Tampere Congress 1995, Inviting Papers p. 272). The same question was formulated by Untheim (Tampere, 1995, PT, p. 133/134 and 1996) for a case study in the Swabian Alps spruce and beech forests in Germany and "Preliminary results show that height growth of both tree species has increased significantly during this century. The detection of causing factors is difficult" but "Nevertheless, it is likely that site productivity changes have occurred because (1) fertilization has never taken place on the investigated site unit (2) sudden changes in the genetic pool of beech can be excluded due to natural regeneration". In our opinion the contribution of S as a result of air pollution within a reasonable limit could contribute to growth amelioration because the majority of forest soils are deficient of available S forms.

Kahn (1994) modelled the development of height curves of forest species growing on slopes.

Based on detailed analyses of site and environmental factors and modern measurement techniques Moosmayer et al. (1996) developed new formulas for estimating the growth of spruce and beech based on site factors (new growth models).

Röhle (1997) presented a new site class system and discovered that after 1950 site class improved and production level changes in southern Bavarian Norway spruce stands. A comparison between advance successive generations of Norway spruce on the same site indicated that the younger stands have superior levels of productivity and site class indices improved.

Cited authors:

Assmann 1961, Assmann and Franz 1963, 1965, 1972; Baur 1877, Bergel 1986, Braun-Blanquet 1928, 1959; Eberhard 1916, Franz 1971, Gochet 1992, Graves 1910 (U.S.A.), Humbold 1806, Kahn 1994, Mitscherlich 1952, Oettelt 1765, Philipp 1883, Pressler 1878, Prodan 1949, Rawat 1973, Reinhold 1926, Rohle 1997, Schulze et al. 1981, Spiecker 1995, Vanclay 1994, Untheim 1995/1996, Vanselow and Rubner 1952, Weck 1948, 1955, 1960; Werner 1962, Wiedemann 1951.

4. 9. Stand structure

The major elements of stand structure are represented by species composition (pure or mixed stands), age (even-aged or uneven-aged), vertical structure (one storey or multistoried), density (expressed by different indices of density), competition and mortality, average height, stand volume and basal area per unit of ground area, average diameter (in even-aged or nearly even-aged stands. A very important element of structure is the repartition of trees (included in a stand per unit area) by diameter (d), height (h) or volume categories and the relationships between different characteristics of trees, especially the relationship between *d* and *h*.

In Germany Gustav Heyer was one of the first among forest scientists who established different relationships between variables such as diameter, height and volume, in his "Ueber die Ermittelungen der Masse, des Alters und Zuwachses der Holzbestände" published in Dessau, in 1852. In 1880, Weise proposed his quadratic mean diameter and the 60th percentile of the ordered set of diameters. Practically, the Weise average diameter

$$D_w=\sqrt{\frac{\sum_{i=1}^{n} d_i^2}{n}}$$

is obtained by counting the trees from small to big and the 60 % is the tree having D_w. Weise's average height (H_w) is the height of the tree representing 40 % of the counted trees from the biggest (maximum dbh) toward the small categories. Weise may be considered also as the author of the term "dominant" height. He divided the stand into five classes having the same number of stems and dominant height was considered as the average height of the class with the largest dbh. After Weise the dominant height became more frequently used.

The first classification of trees in a stand after positional criteria belongs to Gustav Kraft (1884) and was generalized almost in the entire Europe.

In 1888, F. Grundner determined the contribution of diameter classes to stand growth. Tuisko Lorey proposed the average height determined by the formula:

$$H_L = \frac{n_1 g_1 h_1 + n_2 g_2 h_2 + \ldots}{g_1 + g_2 + \ldots} = \frac{\Sigma n_i g_1 hi}{G}$$

where n_i = the tree included in the stand, g_1 = its basal area, h = its height. The average stand height $\overline{H}$ (Hohenadl), H_g the height of stand basal area average tree and H_w (Weise's height) are sensitive to thinning which is not the case of $H_{G1/2}$ (the height of average tree of central basal area of the stand) the reason for which it was recommended by Philipp in 1893, 1896, 1931, and Wiedemann in 1961.

Gerhardt (1901) and Kopezki (1902) established a statistical relation between the basal area (g) or diameter (d_1) and height (h) in the case of trees:

$$gh = b_0 + b_1 g \quad \text{or} \quad h = \frac{b_0}{g} + k = \frac{b_1}{d_1} + k$$

In 1904, Eichhorn published his "law" (in the original title he refers to interrelationship between height and volume of a stand): "Beziehungen zwischen Bestandeshöhe und Bestandesmasse". His "law" is based on the data of fir yield tables he constructed in 1902. This "law" (rule in fact), considered classical in forest mensuration literature, is expressed as follows: for a given average stand height corresponds the same volume per unit area (hectare) regardless the site class or age. The "laws" was in the sense that total yield stand (during its life) is a function of stand average height disregarding the site particularities. Later, as it was mentioned by Assmann (1955 and 1961) the Eichhorn "law" is valid only in the stands which belong to the same site class. Eichhorn's "law" was discussed also by Moosmayer (1957) (fig. 2.9.-1.) and Schober (1960).

In 1961, Assmann introduced the concept of basal area level which expresses current basal area and percentage of the species-specific maximum basal area a site can support at a given age. Laar and Akça (1997, p. 169) considered "the measure as consistent with the basic concept of stand density as a biological parameter, but in most real life situations, the maximum basal area per hectare, which is dependent of age, is unknown".

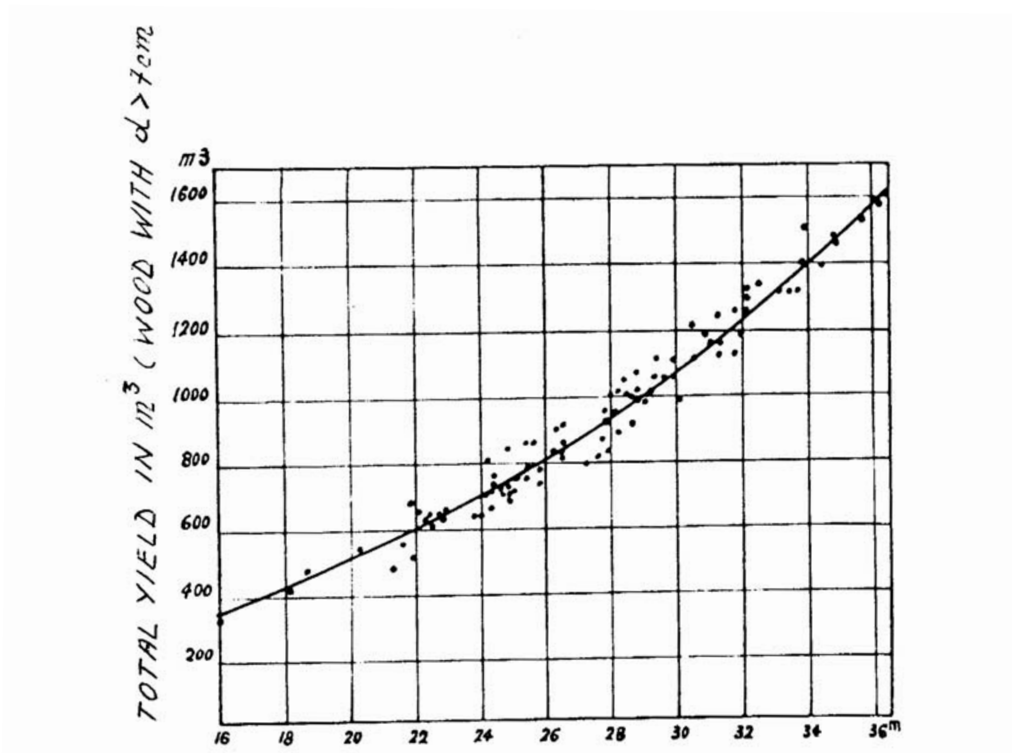


Fig. 4.9.-1. Relationship between average height in m and total yield for spruce in Schwabian SOURCE: Moosmayer 1957. Zur ertragskundlichen Auswertung der Standortsgliederung im Ostteil der Schwäbischen Alb. Mitt. Ver. Forstl. Standortskunde u. Forstpflanzenzücht., 7.

Data on the structure of natural stand were supplied in 1908 by Dingler in his report on the establishment of a forest reserve in the Spessart, Germany, consisting of natural stands of oak forest.

In 1923, Dietrich proposed the mean height of the dominant trees defined as those belonging to Krafts's classes 1 and 2.

Gerhardt presented in 1924 probably the first reliable information on the number of trees (per unit area) in young spruce stands. Vertical structure and development of stand and their importance for silviculture was a subject of a textbook written by Röhrl and published by Neuman (1927).

Diameter variability of fallen Norway spruce and beech stand was investigated by Fabricius in 1928 and Knuchel (1929) who discussed the problem of determination (establishment) of diameter categories for a forest inventory. Other proposals were expressed later by Lang (1941) who proposed not only diameter categories but a higher entity: diameter size class.

Assmann (1936) dedicated his dissertation at the Freiburg University to Kopetzki-Gerhardt line of volumes.

Relations between height (h) and diameter (d) of a stand were studied by Hohenadl (1936) and Krenn (1944), the curves of heights were represented graphically and the curve h-d relationship had the form of a parabola of second degree:

$$H = b_0 + b_1 d_n + b_2 d^2$$

Hohenadl (1939) established two average diameters in an average stand and used them for stand volume determination

$$D_- = \bar{D} - s$$

$$D_+ = \bar{D} + s$$

where $\bar{D}$ is the average arithmetical diameter and s is the standard deviation.

Hohenadl (1939) and Prodan (1951, p. 141, 1965) showed that the average of a stand characteristic (± even-aged) can be expressed in the form:

$Y = a_0 + a_1 d$ or $y = b_0 + b_1 d + b_2 d^2$ (Hohenadl's equation)

$$\bar{y} = \frac{y^- + y^+}{2} \qquad \bar{y} = \frac{\Sigma y_i}{N} = \frac{y^- + y^+}{2} = b + b_0\, \bar{D}_{1+\left(\bar{D}^2 + s^2\right)}$$

Krenn (1942) proposed a technique for approximation of average stand diameter: g = diam. of basal area G, $\bar{g} = \frac{G}{N} = \frac{\Sigma n_i g_i}{N}$

The errors of stand average diameter and basal area have been studied by Peschel (1936), Krenn (1944), Prodan (1951), and Prodan (1965).

The trees with *d*- and *d*+ have the following properties: average value Ag¬ of any characteristic *y* which can be expressed depending on diameter by linear or second degree parabola may be computed with the help of arithmetical mean of Hohenadl diameters *d*- and *d*+: $A_g = (y_- + y_+)/2$.

Wiedemann (1936) introduced standardized height curves in German forest mensuration for the purpose to rationalize the field work during forest inventories. Wiedemann (1936) and Lang (1938) constructed this type of tables which show how much should be added or deducted from the observed mean height to estimate the mean height if the diameter deviates a specific number of units of 1 or 2 cm from the mean. In order to use these tables it was necessary to estimate a limited number of tree heights, around the quadratic mean diameter (Laar and Akça 1997, p. 157).

Relationship between *h* and *d* established by Prodan (1944, 1950):

$h - 1.3 = d^2(b_0 + b_1 d_1 + b_2 d_2^2)$ can be transformed in a second degree

$d^2/(h - 1.3) = z = b_0 + b_1 h + b_2 h^2$

Homogeneity of stand was examined by Camino (1976).

Methodological aspects of the structure of mixed-stands were analyzed by Assmann (1953, 1954) and Schmidt-Vogt (1986), who presented different structural aspects of spruce stands mixed with other species such as larch, Scots pine, oak, fir, birken, beech. In 1992 Spellman presented concepts for mixed stand studies and underlined that the changing demands of society upon the forest in Germany call for a stronger orientation of forest production on ecological bases. Diverse structured mixed stands suited to the site are aimed at, in order to increase the number of species and reduce production risks.

The distribution of trees in a stand by diameter categories is a very important and attractive field of forest mensuration because it involves the use of mathematical and statistical categories: functions of distribution and probability. Fig. 4.9.-2. shows a symmetric unimodal distribution adjusted to normal distribution whereas Fig. 4.9.-3. and 4.9.-4. show the distributions of trees by diameter categories at different periods of time-distributions, which are asymmetrical.

The most known and used of these functions are normal function (Fig. 4.9.-2.), exponential, beta (Fig. 4.9.-5.-A), Weibull (Fig. 4.9.-5.-B), Johns (Fig. 4.9.-5.-C), logarithmic normal, gamma, inverse J-shaped, Charlier (Fig. 4.9.-3., 4.9.-4.), and well-known general system of the Pearson function in which many of the mentioned functions are included.

The following German contributions deserve a special mention in the field of the use of functions of distribution and probability: Mauve (1931) and Prodan (1944, 1949) used decreasing distributions in mixed uneven-aged stands (Table 4.9.-1., Fig. 4.9.-6. and 4.9.-7.) (decreasing distributions in ± virgin and selection forest, Krenn (1942), unimodal distribution compared with normal distribution (Fig. 4.9.-2.), tables of diameter distribution based on curves adjusted by graphical methods; Mitscherlich (1939), Prodan (1951, Charlier distribution), Zimmerle (1947), Schober (1949, 1953), Prodan (1949, 1953, 1961, 1965) have been constructed with trees repartition by diameter categories in the case of even-aged or ± even-aged stands (1953).

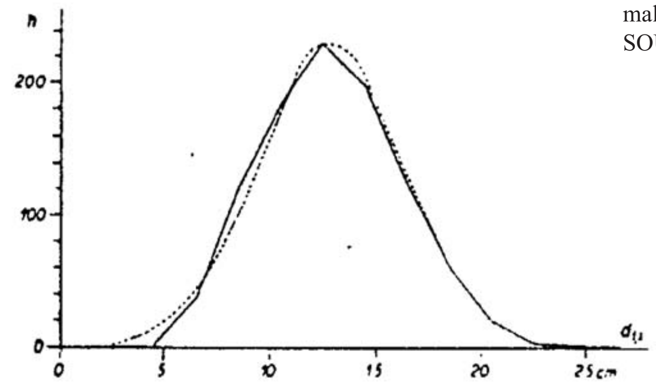


Fig. 4.9.-2. Unimodal distribution adjusted to nor mal distribution
SOURCE: Krenn 1942. AFJS Nr. 118

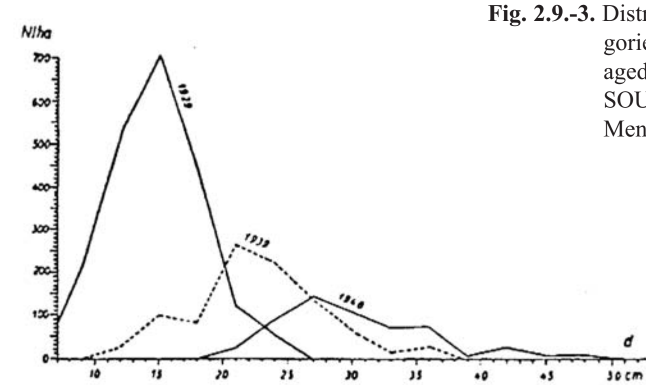


Fig. 2.9.-3. Distribution of trees by diameter cate gories in different periods of even-aged stand development
SOURCE: Prodan et al. 1997, Mensura Forestal, p. 410.

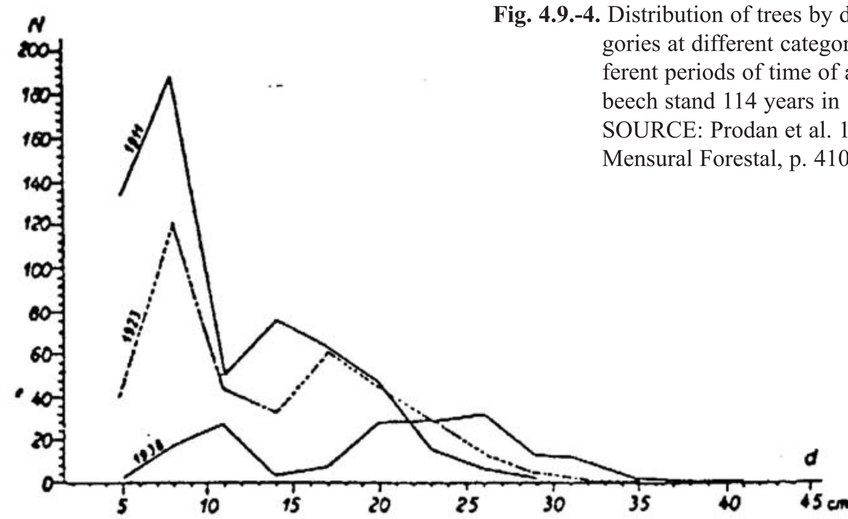
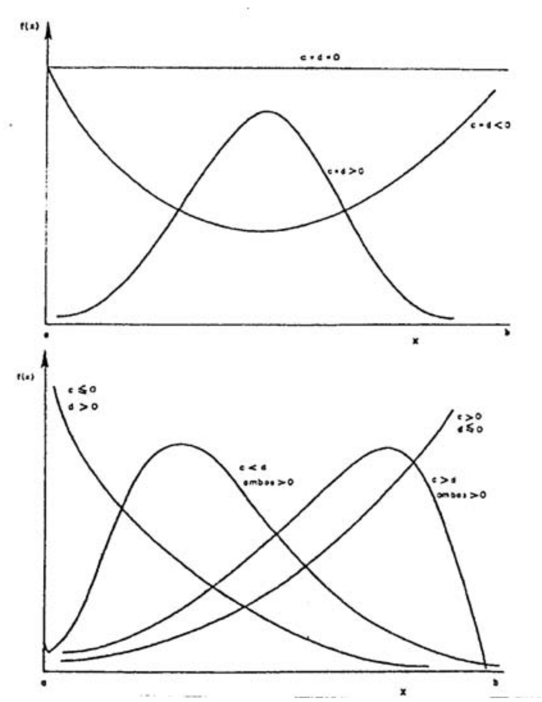
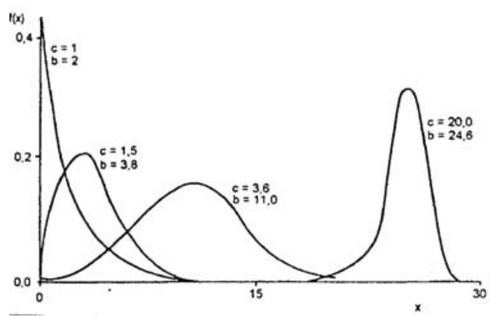


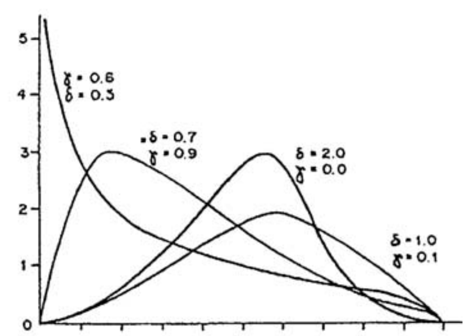
Fig. 4.9.-4. Distribution of trees by diameter cate gories at different categories in dif ferent periods of time of a 114 years beech stand 114 years in 1938
SOURCE: Prodan et al. 1997. Mensural Forestal, p. 410



A. Beta function



B. Weibull function



C. SB-Johns function

Fig. 4.9.-5. Different types of probability and density functions frequently used in German forest researches
SOURCE: Prodan et al. 1997. Mensura forestal, p. 425, fig. 5.20., p. 427 fig. 5.21. and p. 428 fig. 5.22.

A bimodal distribution of trees in a mixed stand (spruce, fir and Scots pine) is shown in Fig. 4.9.-8. (Prodan 1961).

TABLE 4.9.-1. Distribution of trees by diameter categories and forest types in German multi-aged stands
SOURCE: Original Prodan 1949, reproduced in Prodan et al. 1997, p. 417

d	I	II	III	IV	V
cm	N/10 ha				
10	831	1112	1299	1500	1768
14	556	672	824	980	1160
18	398	500	596	701	832
22	304	386	450	522	623
26	243	305	352	411	478
30	199	248	280	327	370
34	165	203	229	263	296
38	137	166	187	211	236
42	114	138	152	170	185
46	96	113	122	135	142
50	80	92	97	104	105
54	67	75	76	77	73
58	58	59	58	55	46
62	48	44	42	35	22
66	39	32	27	17	
70	30	21	13		
74	22	10			
78	14				
82	7				

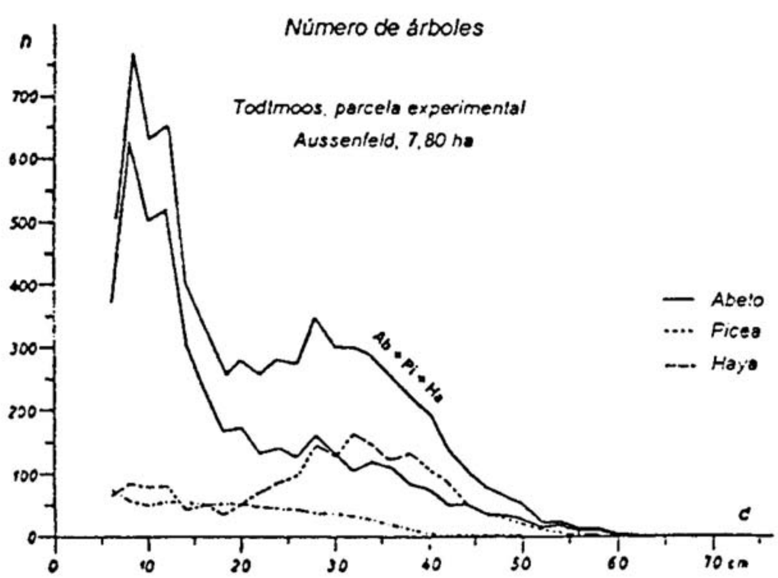


Fig. 4.9.-6. Decreasing distribution of stems by diameter categories in a mixed uneven-aged stand: fir, spruce and beech (haya)
SOURCE: Mauve 1931, Prodan 1944 and reproduced by Prodan et al. 1997, p. 413.

Fig. 4.9.-7. Decreasing distribution of trees by diameter categories
SOURCE: Prodan et al. 1997, p. 413

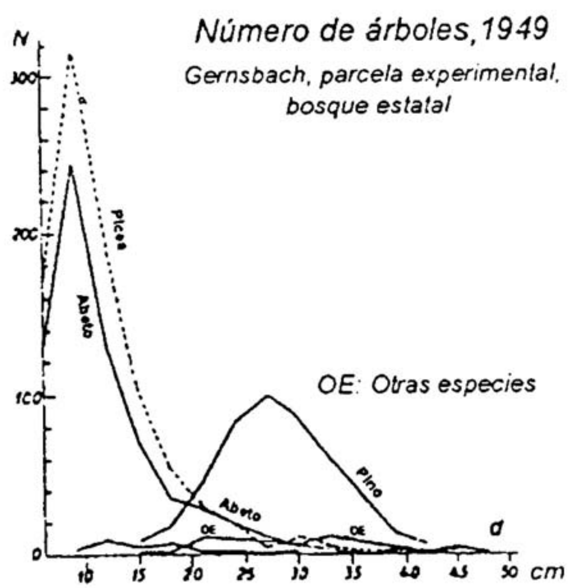


Fig. 4.9.-8. Bimodal distribution of trees by diameter categories in a mixed uneven-aged stand.
SOURCE: Prodan et al. 1997, p. 411.

In 1953, Prodan used the probability density function beta and determined the coefficient of asymmetry for tree distribution by diameter categories determining 25 types of asymmetric distributions for even-aged stands which represented almost all cases existing in Germany.

Before the studies based on the distribution function the procentual distribution of trees by diameter categories was performed depending on the stand average diameter for the first time by Schiffel (1905-Austria) and Fekete (1939 – in Hungary). Similar works were completed in Germany by Bauman (1955) and Weiss (1956).

In 1968, Prodan proposed the following function of relative diameter distribution (reproduced from Prodan et al. 1997, p. 425):

$$f(x) = ke^{bx_2}$$

Zohrer (1969) applied the beta function for best fit of stem diameter distribution in inventories of tropical forests.

Loetsch et al. (1973) advocated the use of Pearson's system of distribution functions, namely ß Weibull.

Gadov (1984) considered that SB-Jonson distributions seem to be the most appropriate for even-aged forest stands.

In 1992, Gerold completed a stand development model on the basis of diameter distribution and assortment simulator. According to Gerold, the above model called VESO is suitable for simulating a known stand development as well as for prediction of stand development which is based upon a definite stand treatment. The quantification of parameters (standard height curve, equation of stem form) was carried out for the tree species, namely: spruce, pine, beech, oak, alder and Weymouth pine. The distribution and assortment simulators have been tested for mixed stands of pine and beech.

Saborowski (1995) established minimum sample size, that is required to estimate the tree parameter of the Weibull distribution and considered that a sample with n=80 could be expected to produce satisfactory results.

Huy and von Gadow (1996) presented a new application on modelling of diameter distribution.

H e i g h t . Translocation with age of height-diameter curves in a stand (even-aged or ±uneven-aged) has been known since 1893 by E. Speidel and was investigated later by Assmann (1943), Krenn (1944) and Prodan (1965) – Figure 4.9.-9.

In 1936 Pescher measured all 840 heights in a stand of spruce 82 years old after cutting and height measurements were published by Assmann in 1943 and used by Peschel for the determination of different average height (Fig. 4.9.-10.)

whereas the relation height-diameter in a multistoried stand of spruce can be examined in Figure 4.9.-11.

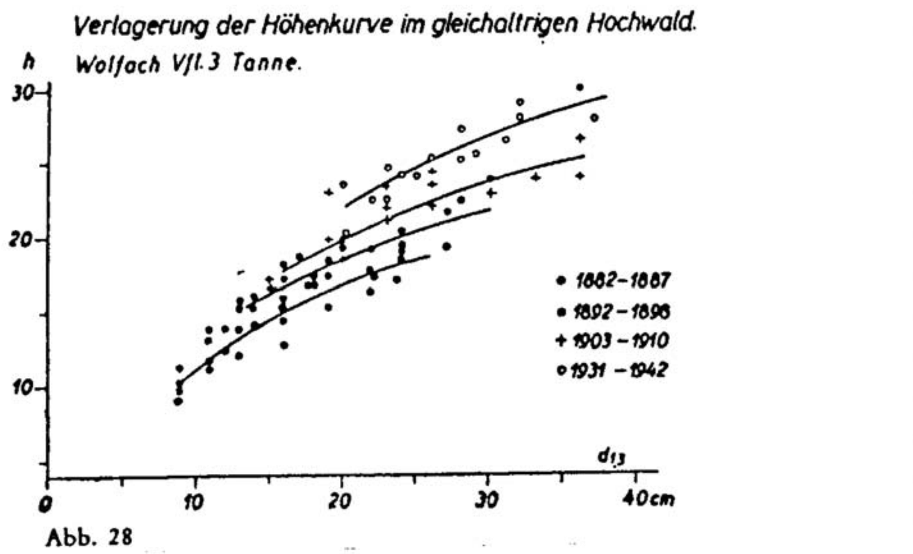


Fig. 4.9.-9. Translation with age of height-diameter in a stand. Phenomenon known by Speidel (1893) and Assmann (1943). The figure refers to fir and is reproduced after Prodan (1951), Messung der Waldbestände, p. 104, Sauerländer's Verlag, Frankfurt a. M.

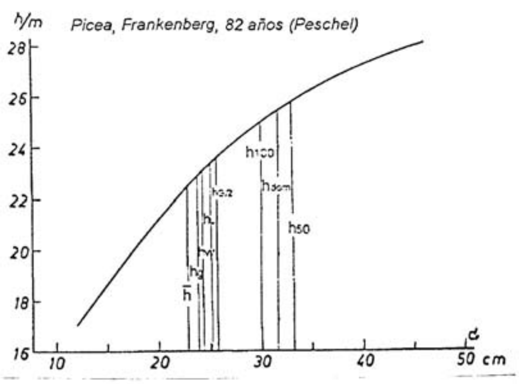


Fig. 4.9.-10. Relative position of different average heights.
SOURCE:Peschel 1936, Neuere Verfahren des Bestandes
Reproduced by Prodan et al. 1997, Mensura Forestal, p. 334, fig. 3.31.
H_w = Weise height $H_{G/2}$ = height of the tree of the basal central area: H, Hg, H_w; H_{dom}=dominant height,
H_{100} = predominant height.

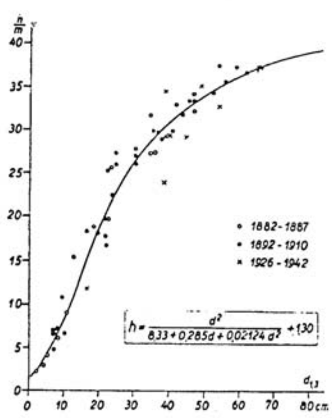


Fig. 4.9.-11. Relation height-diameter in a multistoried stand of spruce
SOURCE: Prodan et al. 1997, Mensura Forestal, p. 324, fig. 3.29

In 1938, Laer developed first series of form heights (Formhöhenreihen = hf) and Lang published (1938) types of height series in homogeneous stands, assortment tables, stand average height and d-h curve in stands.

Assmann (1943) and Krenn in 1944 completed studies on the investigations of the height curves of spruce stands and found a positive asymmetrical distribution of height in the stands and established the errors in the case when stand height curves are used for volume determination. Similar problems have been analyzed by Prodan (1944/1950) who proposed a function for stand dominant height:

$$H_{dom} = t^2/(b_0 + b_1 t + b_2 t^2)$$

where H_{dom} = total tree height minus 1.3 m and t^2 = age at 1.3 m (dbh) – model which was applied by Machado (1978) in young *Pinus taeda* plantations in the state of Parana, Brazil (Ph.D. Thesis Univ. of Washington). A new Assmann's investigation on the height curves of spruce was published in 1949.

Eckert (1957) used semilogarithmic paper for the representation of height-diameter curves. Kramer (1959) analyzed stands dominant height (a remarkable study with a consistent bibliography) and made distinctions between (1) "mathematical" definitions as average height of 100 trees of larger diameter per acre or 247 per hectare, and (2) dominant heights based on "biological" criteria.

In the 1960s (1961, 1962 and 1964), Kramer published other works on dominant height for the use of arrangement tables of h_{dom} for oak and Douglas fir (1962): $h_{dom} = b_0 + h_1 h_g$.

Schmidt A. (1967) fitted height curves of stands using a computer. Kennel (1971) published series of heights (depending on diameter) for beech stands.

Based on Assmann's (1943) or on the more precise date of Prodan (1951) concerning the translation of height-diameter curves according to time, Giurgiu, in his dissertation presented in the U.S.S.R. (1957) that he anticipated theoretically this thing which in fact happened a long time ago since it was known at the end of the 19th century.

Nagel (1991) constructed a height curve model for *Quercus petraea*. He compared standardized height curves, derived from the Petterson function with those based on Sloboda's function:

$$h = 1.3 + \left(h_m - 1.3\right) \quad e^{\left(b_0\left(1-d/dq\right)\right)} \quad , e^{\left(b_1\left(d/dq-1/d\right)\right)}$$

d = quadratic mean diameter. On the other hand, Petterson function implies the existence of an inflection point ($d_{infl.}$) which is a function of b_0 and b_1, $d_{inf} = b_1/b_0$.

It can be shown that
$$b_0=\frac{1+d_{\inf l.}/d}{\sqrt[3]{h-1.3}}$$

Thus $b_1 = b_0 d_{infl}$. and $h_i = (b_0 + b_1/d_i)^3 + 1.3$. Based on these considerations a system of standardised height curves should be preceded by a sampling study to estimate b_1 from age (compiled from Laar and Akça 1997, p. 154).

In 1993, Sloboda et al. developed a regional and local system of height-diameter curves.

Stand volume repartition by diameter classes was investigated in 1946 by Prodan in a Norway spruce stand and he found the following percentage of round wood with top diameter ≥7 cm out of total stem wood.

dbh (cm)	8	10	12	14	16	18	20	22	24	26	28	30
Round wood (%)	59	80	93	93	97	98	99	99	99	99	99.5	99.5

For stand tables a class width of 4 cm is customary for working plans in German forestry, whereas a class width of 20 cm is frequently used in tropical forests (Loetsch et al., vol. 2, 1973).

Sloboda (1988) studied representation and projection of diameter distribution regarding change of rank in indicative experimental plots.

Laar (1986) introduced age as an aditional predictor of height for improvement of these models.

Competition and distance between trees. In 1909, Paul Statz introduced the term *coefficient of distance = (average distance between trees)/(average diameter of the stand*) and considered that it reflects the competition and is important for stand tending. After that more syntheses on different categories of stand density indices and competition factors were summarized in many standard forest mensuration textbooks. An overview of the most important indices used on worldwide level is presented in Prodan's et al. ("Mensura forestal" 1997, p. 389-407). In the U.S.A. Spurr proposed a measure of point density. In the same year Hausburg (1962) confirmed that the distance between two trees is a good indicator of competition. This indicator was also confirmed by Stöhr (1963) and later by many American authors. Schinzel (1966) discussed about an optimum stand basal area in spruce stands in which the difference between real and optimum stand basal area (see 4.11) was involved. Cox (1971) referred to density considering the crown projection area and competition as a phenomenon which depends on distance between trees.

Adlard (1977) summarized the estimation of tree competition in forest stands.

Dippel (1988) investigated growth and mortality in southern Bergland stands of mixed beech and larch fitting the two- and three parameters of the Weibull function to distributions recorded in mixed beech-larch stands for each species separately.

The effects of competition on individual tree growth in spruce/fir/beech mountain forest was studied by Bachmann (1997) to find the most suitable competition indices for modelling individual tree growth. He used data from 61 permanent experimental plots in Norway spruce/fir/beech in mountainous region of Bayern and proposed different competition models whose performance was evaluated by non-linear increment models. Growth responses due to competition depend on tree species, height class and site specific effects. In conclusion Bachmann considered that "an adaptation of search algorithms for the effect of slope and aspect will improve the correlation between increment and competition".

Plantation schemes (which refer to distances among trees) influenced competition and trees development in a stand of Norway spruce (Vanselow 1942 b, 1950, 1956).

The influence on thinning – representing in fact an "artificial mortality" – on the competition and development of stands is mentioned in Berg (1846), for spruce and beech case; Wiedemann (1929), referred to heavy thinning and rapid growth management; Krenn (1946 a), criteria for thinnings in Norway spruce stands; Assmann (1950), basal area and volume growth of beech at different thinning research of the former Prussian Research Station; Pollanschüth (1971), completed tables and graphs which indicate the optimum number of trees per hectare in the case of a pole stand and stand with average dbh 14 cm.

Aspects of structure and forest dynamics were analyzed in different books signed by Metz and Diekmann (1986), "The dynamics of physiologically structured populations"; Bossel et al. (1991), "Simulation of forest stand dynamics using real structure process models"; Koop's (1989), "Forest Dynamics". At IUFRO Centennial Möller (1992) summarized major actual aspects of structure and dynamics of forest stands.

Pretsch (1994) analyzed trial of spatial reproduction of stand structure by structure generation model STRUGEN.

Degenhardt (1995) performed a study on the development of stand structure using modelling of random point process in plain regions. Daume et al. (1997) investigated thinning modelling in uneven-aged mixed stands.

Laar and Akça (1997) noted that "The social stratification, which follows after crown closure, is partly controlled by genetic variability. In clonal stands it is less pronounced than in stands grown from seedling" (p. 271).

A new approach to description of forest structures was developed by Pommerening, Gadow and Lewandowski, in 1997, and Gadow, in 1999.

Cited authors:

Adlard 1977, Assmann 1936, 1943, 1949, 1950 a, 1950 b, 1953/1954, 1955, 1961; Bossel et al. 1991, Buchmann 1997, Bauman 1955, Dingler 1908, Dippel 1988, Berg 1846, Camino 1976, Cox 1971, Daume et al. 1997, David 1988, Degenhardt 1995, Dietrich 1923, Eckert 1957, Eichhorn 1904, Fabricius 1928, Fekete 1939 (Hungary), Gadow 1984, Gadow and Levandowski 1997, Gadow 1999, Gehrhardt 1924, Gerhardt 1924, Gerold 1992, Giurgiu 1957 (Romania), Grundner 1888, Hausburg 1962, Heyer 1852, Hohenadl 1936, 1939; Huy and Gadowk 1996, Kennel 1971, Knuchel 1929, Koop 1989, Kopezki 1902, Kraft 1884, Kramer 1959, 1961, 1962, 1964; Krenn 1942, 1944, 1946, Laar 1986, Laar and Akça 1997, Laar 1938, Lang 1938, 1941; Loetsch et al. 1973, Lorey 1888, Machado 1978, Mauve 1931, Metz and Dieckmann 1986, Mitscherlich G. 1939, Möller 1992, Nagel 1991, Peschel 1936, Philipp 1893/1896/1931, Pretzsch 1994, 1997, Pollanschüth 1971, Prodan 1944a, 1944b, 1944/1950, 1946, 1949a, 1949b, 1951, 1953, 1961, 1965; Prodan et al. 1997, Röhrl 1927, Saborowski 1995, Schiffel 1903 (Austria), Schinzel 1966, Schmidt 1967, Schmidt-Vogt 1986, Schober 1949, 1953, 1960; Sloboda 1988, Sloboda et al., Speidel 1893, Spellmann 1992, Spurr 1962, Statz 1909, Stöhr 1963, Vanselow 1942, 1950, 1956; Weise 1880, Weiss 1956, Wiedemann 1929, 1936, 1961; Zimmerle 1947, Zohrer 1969.

4.10. Determination of stand volume

Stand volume determination represents a major problem of forest mensuration and during the last two and a half centuries different methods have been proposed and applied in this field. Among these techniques we should mention: sample plots with computation of tree volume using volume tables or tariffs, determination of stand volume using felled sample trees (such as Draudt, Urich, Hartig and other methods), sample tree method, volume curve method (Kopezki-Speidel), stand form factor, Metzger method, yield tables, expeditive methods, strip surveys, estimation by eye, sample point methods, aerophotogrammetrical techniques based on remote sensing and others.

Prodan classified and described the following methods for stand volume determination:

(I) Methods based on sample trees (corresponding to 3, S and W classes: Schmid-Haas and Winzeler 1981) that are considered as average representatives for a determinant number of trees:

(a) Empirical procedures (Draudt, Urich, Hartig);

(b) Combined procedures (Tischendorf and Neubaer 1949 – published in Austria, Speidel (1893) based on functional relationships between diameter and volume V=f(d) using d-v curve;

(c) Procedures based on theoretical deductions (Kopezki 1899, Gerhardt 1901 – volume line, Hohenadl 1936 technique based on two average trees).

(II) Methods based on tariffs, volume tables or general functions of tree volume (corresponding to 5, 6 and 7, S and W classes).

In 1981, Schmidt-Haas and Winzeler (S and W) classified the techniques of stand volume determination into seven classes depending on the following elements: (a) volume of standing trees measured directly or estimated; (b) measurement or estimation of a variable which is important for all trees of a sample (plot) or a part of a sample and; (c) the number of indicators (characteristics) used for volume estimation.

It should be mentioned that, as a rule, stand volume is determined for unit area (hectare) or for a given number of inventoried trees. In the case of a stand or forest the measurement of an area is compulsory, but the problem will be analyzed in the frame of "forest inventory" as a special branch of forest mensuration.

Form a historical point of view, the following use in time of stand volume techniques may be taken into account in Germany:

- eye estimation and other expeditive procedures;
- yield tables:at the end of the 18th century;
- techniques based on volume-diameter, h-diameter and fh-diameter relationships (Heyer 1852);
- volume tables: 1840s;
- sample trees: 1860s;
- volume equations: Kopezki-Gerhardt 1899-1901;
- stand form factors (Grundner and Schwappach since 1898).

The first yield tables were attributed by Th. Hartig (1847) to Paulsen (1795) and G. L. Hartig but the first well-known yield tables belong to F. Baur (1877).

In the 1860s a group of stand volume determination techniques emerged (which refer in fact to a given group of inventoried trees based on sample felled trees), techniques that permit the estimation of either volume and assortments, or both of them: Draudt (1810), Urich (1860), Hartig (1868). The characteristics of these techniques can be easily understood after the examples presented in tables 4.10.-1., 4.10.-2. and 4.10.3.

These methods have been considered as classical and have been applied in many European countries for a long time (in Romania, for instance, up to the 1950s).

Some aspects of stand volume were analyzed by Riniker (1873) especially in connection with form factors that can be determined not only for trees but also for stands as an average value of form factors of the component trees of a stand.

TABLE 4.10.-1. Volume determination by Draudt method
SOURCE: Original source U. Müller 1923, p. 293/294 based on Draudt: Ermittelung der Holzmassen. Giessen 1860 Reproduced after Prodan 1951, p. 137, tabl 41.

Massenberechnung nach dem Verfahren Draudt nach U. Mueller 1923, S. 293/94							
Verteilung der Probestämme N=420 Anzahl der Probestämme=12=0.0286 d. Stammz.							
$d_{1.3}$	N	ng	Zahl d. Probest.	der Probestämme			Berechnung d. Bestandesmasse
				$d_{1.3}$	g	Baumholz	
18	22	0.560	1	19.8	0.0308	0.384	
20	23	0.723		22.0	0.0380	0.447	$\frac{20.599}{0.6181}$ =33.32
22	60	2.281	2	23.2	0.0423	0.523	
24	92	4.162	3	24.0	0.0452	0.602	
26	150	7.964	4	25.1	0.0495	0.690	8287•33.32=
							276.12 fm
28	35	2.155	1	24.9	0.0487	0.645	
30	31	2.191	1	26.0	0.0531	0.730	
32	7	0.563	-	27.1	0.0577	0.754	gegenüber
				27.0	0.0573	0.760	$\frac{420}{12} \bullet 8.287 =$
				26.2	0.0539	0.732	
				28.6	0.0642	0.872	= 290.05 fm
				31.4	0.0774	1.148	
	420	20.599	12		0.6181	8.287	
1	2	3	4	5	6	7	8

Total number of trees N = 420; Number of sample trees 12; 1 = dbh, 2 = number of trees by dbh categories, 3 = total basal area by dbh categories, 4 = number of sample trees by ng, 5-7 sample trees 5 = dbh, 6 = basal area of sample trees and = wood for work, 8 = volume determination of N = 420 trees, The German text used comma for decimals.

Lorey (1877) considered the methods based on sample trees as adequate, today they belong to the history of the discipline.

Gerding-Borggreve proposed in 1880 a competitive technique for the estimation of volume having > 7 cm at top end in a stand. The method is valid only for mature stands with closed canopy. After the estimation of stand average height this is multiplied in medium by 16 for beech, 15 for oak, 18 for spruce, 20 for fir and 15 for pine.

Grundner (1882) underlined the importance of the determination of stand basal area (G), a basic element in stand volume (V) formula:V = G H F, (H = average height and F stand form factor of $f_{1.3}$ type).

In 1898, Grundner and Schwappach began to publish volume and $f_{1.3}$ tables for trees and form factors. In the 10^{th} edition (1952) there are F stand values for mature stands of oak, beech, Scots pine, spruce, larch, fir, alder and birch. F values refer to stands of 100-120 (160) years of age (except for alder and birch: 60-80 years). For each species 2-5 site classes and two categories are considered: wood with ≥7 cm top diameter (working wood) and for all wood (Table 4.10.-4).

TABLE 4.10.-2. Volume determination by Urich method
Fi-Bestand Frankenberg 139 c. (Peschel nach Krenn) Bestandesmassenberechnung nach dem Verfahren Urich

Durch-messer	Stamm-zahl	Klassen-stammzahl	Kreis-fläche	Klassen-kreis-flächen	des Klassenmittelstamms		
					Kreisfläche	Durchm.	Inhalt
d	n	(n)	g	(g)	g= (g)/(n)	d_m	V_m
cm			qm	qm	qm	cm	fm
1	2	3	4	5	6	7	8
12	4		0.015				
13	19						
14	25						
15	39						
16	40						
17	41	168	931	3,106	0,018488	15,34	0,18470
18	52		1,323				
19	49		1,389				
20	56		1,759				
21	11	168	0,381	4,852	0,028881	19,18	0,31789
21	37		1,282				
22	50		1,901				
23	55		2,285				
24	26	168	1,176	6,644	0,039548	22,44	0,45458
24	19		0,860				
25	55		2,700				
26	45		2,389				
27	38		2,176				
28	11	168	0,677	8,802	0,052393	25,83	0,61919
28	13		0,801				
29	37		2,444				
30	30		2,121				
31	11		0,830				
32	15		1,206				
33	16		1,368				
34	8		0,726				
35	12		1,155				
36	11		1,120				
37	4		0,430				
38	4		.454				
39	1		.119				
40	1		.126				
41	1		.132				
43	1		.145				
44	1		.152				
45	1		.159				
48	1	168	.181	13.669	0.081363	32.19	0.99045
	840	840	37.073	37.073			2.56681-168 431.22

1 = diameter, 2 = number of stems, 3 = stem classes, 4 = basal area, 5 = basal area by stem classes (5 classes), 6-8 = characteristics of average sample stem by stem classes: 6 = basal area, 7 = diameter, 8 = volume. Total trees: 840, total volume 431 fm. The German text used comma for decimals.
SOURCE: Reproduced after Prodan 1951, Messung der Waldbestände, p. 139, table 42

TABLE 4.10.-3. Volume determination by Hartig method
Fi-Bestand Frankenberg 139 c. (Peschel nach Krenn) Bestandesmassenberechnung nach dem Verfahren Hartig

Durch-messer	Stamm-zahl	Klassen-stammzahl	Kreis-fläche	Klassen-kreis-flächen	des Mittelstamms			Klassen-masse
					Kreisfläche	Durchm.	Masse	
d	n	N_I	g	G_1	$g_1 = \frac{G_1}{N_1}$	d_1	v_1	$v_1 \bullet N_1$
cm		qm	qm	qm	qm	cm	fm	Fm
1	2	3	4	5	6	7	8	9
12	4		0.045					
13	19		252					
14	25		385					
15	39		689					
16	40		804					
17	41		931					
18	52		1.323					
19	49		1.389					
20	51	320	1.602	7.420	0.023187	17.18	0.24493	78.378
20	5		0.157					
21	48		1.663					
22	50		1.901					
23	55		2.285					
24	31	189	1.403	7.409	0.039201	22.34	0.45014	85.076
24	14		0.633					
25	55		2.700					
26	45		2.389					
27	30	144	1.718	7.440	0.051667	25.56	0.60989	87.824
27	8		0.458					
28	24		1.478					
29	37		2.444					
30	30		2.121					
31	11		0.830					
32	1	111	0.080	7.411	0.066766	29.14	0.80338	89.175
32	14		1.126					
33	16		1.368					
34	8		0.726					
35	12		1.155					
36	11		1.120					
37	4		0.430					
38	4		.454					
39	1		.119					
40	1		.126					
41	1		.132					
43	1		.145					
44	1		.152					
45	1		.159					
48	1	76	.181	7.393	0.097276	35.19	1.19438	90.773
	840	840	37.073					431.23

1 = dbh, cm, 2 = number of stems, 3 = stem classes, 4 = basal area, 5 = stem class basal area, 6-8 = average stems: 6 = basal area, 7 = diameter, 8 = volume, 9 = stem volume by classes. Total stems 840, total volume 431.23 fm (Festmasse). The German text used comma for decimals.
SOURCE: Peschel (1936) and Krenn (1944). Reproduced after Prodan 1951, p. 142, table 145: Messung der Waldbestände.

TABLE 4.10.-4. Form factors and average height for pure and even-aged mature stands by Grundner and Schwappach (1942)

Species	Form factor of					Form factor of all wood					Age	Average height in meters				
	I	II	III	IV	V	I	II	III	IV	V		I	II	III	IV	V
Oak		0.53	0.54	0.55			0.58	0.6	0.62		100		26.7	22.7	18.9	
											120		28.5	24.7	20.9	
											160		31.7	27.9	22.6	
Beech	0.50	0.50	0.50	0.49	0.48	0.56	0.57	0.58	0.59	0.60	100	32.0	27.7	23.5	19.2	14.8
											120	35.4	30.8	26.3	21.8	17.1
Scots pine	0.45	0.46	0.46	0.47	0.49	0.49	0.50	0.52	0.55	0.60	100	28.0	24.1	20.3	16.3	12.5
											120	30.0	25.9	22.0	17.8	13.4
Spruce	0.46	0.47	0.50	0.50	0.51	0.50	0.53	0.56	0.58	0.61	100	33.3	29.3	25.0	21.0	17.2
											120	35.9	32.1	28.2	24.0	
Larch		0.44	0.45	0.46			0.47	0.49	0.51		100		34.0	29.5	25.0	
											120		35.9	31.3	26.6	
Fir	0.48	0.50	0.51	0.52		0.54	0.57	0.59	0.61		100	31.8	27.4	23.5	19.4	15.2
											120	34.0	29.5	25.5	21.5	17.2
Alder		0.48	0.48	0.49			0.51	0.54	0.55		60		24.7	20.7	16.7	
											80		27.7	23.4	19.2	
Birch		0.44		0.46			0.54		0.57		60		23.0		18.3	
											80		26.0		20.9	

I Site of high quality
II Site of good quality
III Site of medium quality
IV Site of low quality
V Site of very low quality

SOURCE: Grundner-Schwappach 1942: Massentafeln zur Bestimmung des Holzgehaltes stehender Waldbäume und Waldbestände. 9. Aufl. Hersg. von R. Schober, Berlin

Metzger (1894/1895) proposed the efficient formula:

$$V(\text{volume}) = N(\text{number of trees})\ ((V_{max}-V_{min})/10)$$

where V_{max} = volume of 3 most large trees (after dbh) and V_{min} = volume of 7 most small trees. It is possible that this idea influenced Hohenadl's (1936) procedure based on statistics and refering to two stand average trees.

In 1902, Jacob Weber proposed determination of stand volume using photography.

Gerhardt (1909) applied the basic Eichhorn's "law" to predict the yield of spruce, fir and Scots pine, but restricted the "law" to stands of a given site class.

In 1925, Tischendorf presented the results on precision of methods referring to stand volume determination.

Erich Ziegler (1928) published a work (probably one of the earliest) on measurement of stand volume from aerial photographs with Autokartograph (Hugershoff-Heydeschen Autokartograph). Neumann (1933) completed the observations on stock determination from aerial photographs.

Wielgosz (1935) analyzed the biometrics of tree groups and their importance in development of methods for stand volume determination.

In 1936, van Laer, based on Grundner-Schwappach's (1942) volume and heights, obtained from Wiedemann's (1936) yield tables, developed the concept "form height series for estimate stand volume and defined the form height of a stand as the average form factor multiplied by the mean height of the stand. In the same year, Peschel (1936) developed a new procedure for stand volume determination based on mathematical and statistical principles. Lang (1938) determined height form series for Württemberg region. Laer (1938) published tables with series of formheight (fh) and later constructed with Spiecker height form series depending on species and diameter by multiplying the "normal heights" with the form factor from Grundner-Schwappach tables.

Researches developed by Wiedemann (1936), Lang (1938) and Laer (1938) concluded that fitted height h-d curves that should be constructed in every case (stand) can be replaced by the so-called "normal curves" constructed once and for ever on the basis of correlation between dbh and height (h) after numerous measurements. These normal curves have been used by Laer as basis for height form curves (hf). The data for curve construction are given by tables as differences in plus or minus, compared with the hf of the average central tree. Due to the fact that for every value of average central tree there are values proper for the considered curve, these differences appeared as increasing series of numbers and this is why they are called tables of form height series.

In 1948, Spiecker introduced the volume series method which is closely related to the form height series method.

When HF is known, the volume will be given by the relation V = HF G, G (basal area) being obtained by tree measurement.

In 1951, Laer and Spiecker presented hf series depending on series number and diameter (Tables 4.10.-5. and 4.10.-6.) and based on *hf* series constructed (1951) volume series that are valid only in mature stands. It should be noted that a stand included in a series do not remain for ever in that series and a phenomenon of translation is under way earlier in even-aged than in multiaged selection forests. As a result of this relative stability volume series may be used for stand growth determination (as an indicative method).

Hohenadl (1939) observed that height-dbh curve or dbh-height curve in even-aged stands is very similar to an arc of a parabola of second degree and is expressed by the relation

$$h = -50d + 100\sqrt{d} - d \qquad \text{where h=model height and d=dbh.}$$

TABLE 4.10.-5. Example of table for identification of the height form series number or volume for beech

Average diameter (h)	Average height, m											
	14	15	16	17	18	19	20	21	22	23	24	25
	Series number											
15	49	52	56	59	63	67	-	-	-	-	-	-
16	47	51	54	58	62	66	70	-	-	-	-	-
17	46	49	52	56	60	64	68	72	-	-	-	-
18	45	48	51	55	58	62	66	70	74	-	-	-
19	-	46	50	54	57	61	65	68	72	76	-	-
20	-	45	49	53	56	60	63	67	70	74	78	81
etc.												

SOURCE: Laer and Spiecker 1951. Massenberechnungstafeln zur Ermittlung von Vorrat und Zuwachs von Waldbeständen.

TABLE 4.10.-6. Example of table with normal height form depending on diameter and series number for beech

Diameter cm	Series number											
	60	61	62	63	64	65	66	67	68	69	70	71
	Height form, m											
10	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9
12	6.8	6.9	7.0	7.1	7.2	7.3	7.4	7.6	7.7	7.8	7.9	8.0
14	7.5	7.6	7.7	7.9	8.0	8.1	8.2	8.4	8.5	8.6	8.7	8.9
16	8.0	8.1	8.2	8.4	8.5	8.6	8.8	8.9	9.0	9.0	9.3	9.4
18	8.5	8.6	8.7	8.9	9.0	9.2	9.3	9.4	9.6	9.7	9.9	10.1
20	8.9	9.1	9.2	9.4	9.5	9.6	9.8	9.9	10.1	10.2	10.4	10.5
22	9.3	9.5	9.6	9.8	9.9	10.1	10.2	10.4	10.6	10.7	10.9	11.0
24	9.7	9.9	10.1	10.2	10.4	10.6	10.7	10.9	11.0	11.2	11.4	11.5
26	10.1	10.3	10.5	10.6	10.8	11.0	11.1	11.3	11.5	11.6	11.8	12.0

SOURCE: Laer and Spiecker 1951. Massenberechnungstafeln zur Ermittlung von Vorrat und Zuwachs von Waldbeständen. J. D. Sauerländer's Verlag, Frankfurt a.M.

Hohenadl's standard or model height-dbh curve (Fig. 4.10.1.) is valid for all species and ages but its inconvenient is the necessity to determine two average heights which correspond to Hohenadl's average diameters $\overline{D} + s$ and $\overline{D} - s$ where *s* is the standard deviation. A detailed description of this method can be found in older standard mensuration textbooks.

Hohenadl (1939) also developed an equation for height (y) curve depending on d = dbh:

$$y = a_0 + a_1 d + a_2 d^2$$

Krenn proposed a technique for estimation of stand average tree using stand basal area. New researches on form factor (F) for wood having ≥7cm at upper diameter were continued by Mitscherlich (1942). Determination of stand volume based on V = f (dbh) function (tariff), h-d relationships and precision of height curve of stand were analyzed by Krenn (1944) and later (1965) by Prodan in "Holzmesslehre" where a special chapter refers to point sampling (relaskop).

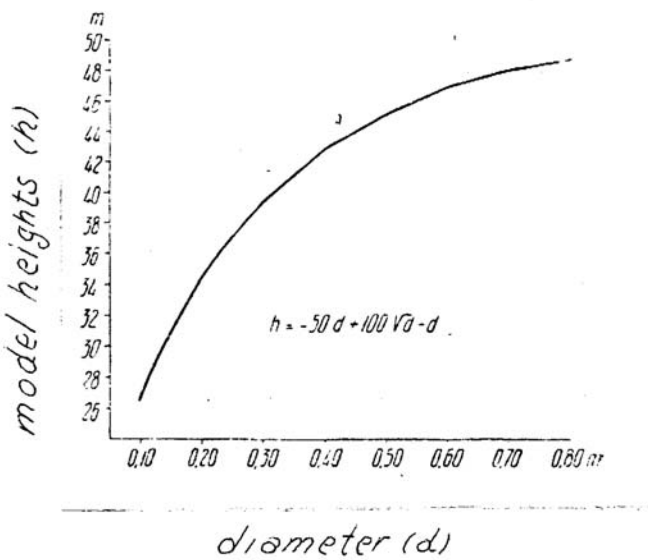


Fig. 4.10.-1. Hohenadl height model
SOURCE: Hohenadl 1939: Einführung in die Bestandesberechnung mit Hilfe von zwei Mittelstämmen. Fw. Cbl. 61

In his "Messung der Waldbestände" Prodan (1951) included two chapters for stand measurements, their inventories and growth determination. In the same year Wiedemann (1951) published a book on productivity as silvicultural basis of forestry where stand volume aspects are discussed; the second edition of this book appeared in 1955.

In 1953, Altherr simplified Hohenadl's procedure for stand volume determination and developed series of form quotient for individual trees or mean values by species.

Weck (1953) investigated utility and precision of some procedures applied in stand measurements and based on distance between trees.

The problem of errors in volume determination was analyzed by Peschel (1936), Krenn (1944), Dittmar (1956) and especially by Prodan in 1951 and 1965.

A comparative study on graphical Speidel's volume curve and Kopezky-Gerhardt massline was applied in a Scots pine stand where all trees were felled, and the KG-line (equation V=a+bx2) was preferred, in fact it was preferred in all Germany.

Kräuter (1958) proposed a system of unique height curves that does not take into account species influence or height curve form, and developed volume series especially for forest inventory works and determined the percentage of current volume increment of species groups according to the computed volume series.

Average value series of form quotients for individual trees and averages for stands have been constructed by Altherr (1953) and Dittmar (1958).

Volume tables and formulae for stand volume estimation and the description of the method based on dbh and height of trees in a stand are summarized by Ogaya in 1968.

Akça and Zindel (1987) determined wood quantity using digital aerophotogrammetry and regression models for spruce.

Fielder and Geissler (1988) presented unique data on the artificially established stand of yew (*Taxus baccata*) planted at Tharandt in about 1860-1865. The yew produced in 1988 114 m^3/ha at 120 years old which correspond to 534 m^3/ha for beech.

Volume estimation in selection forest using importance sampling and control functions was completed by Kleinn in 1993. In this period the Blume-Leiss range-tracer drum was constructed (at Göttingen Institute of Forest Management), which "is used in combination with the Blume-Leiss, Suunto or Haga hypsometer for optical determination of the boundaries of plots with a radius of 17.84 m and 12.62 m corresponding to a plot area of 0.1 and 0.05 ha - on slops it automatically adjusts for the slope effect on recorded height" (Laar and Akça 1997, p. 75). A more recent summary on the works concerning stand volume is completed by Prodan et al. (1997, pp. 308-361) in "Mensura forestal".

Cited authors:

Akça and Zindel 1986, Altherr 1953, Baur 1877, Borggreve 1888, Dittmar 1956, 1958 a, 1958 b, Draudt 1860/1862, Fielder and Geissler 1988, Gerhardt 1909, Grundner 1882, Grundner-Schwappach 1898, Heyer 1852, Hartig 1868, Hohenadl 1939, Kleinn 1993, Kopezki 1899, Kräuter 1958, Krenn 1942, 1944, Laar and Akça 1997, Laer 1936, 1938; Laer and Spiecker 1951, Lang 1938, Lorey 1877, Metzger 1894/1895, Mitscherlich Neumann 1933, 1942; Ogoya 1968, Paulsen 1795, Peschel 1936, Prodan 1951, 1965; Prodan et al. 1997, Prytz 1888, Riniker 1873, Schmid-Haas and Winzeler 1981, Speidel 1893, Spiecker 1948 a, 1948 b; Tischendorf 1925, Urich 1860, Weber J. 1902, Weck 1953, Wiedemann 1936, 1951/1955; Wielgosz 1935, Zetsche 1891, Ziegler 1928.

4. 11. Yield tables and equations

The yield table is a tabular presentation of stand volume per unit area according to age and other specific conditions. Usually, a yield table shows the future product of an even-aged pure stand and contains its principal characteristics. Yield tables can be normal showing the yield at different ages of fully stocked stands or empirically based on stands representing an average of the whole forest. Another type are yield tables of variable density of forest. A yield table represents a model which during the last decades could be expressed by functional relationships.

In variable density yield tables stand density is used as an independent variable. The basic methods for the construction of yield tables are the data from permanent or temporary sample plots that have to be analyzed using a criterion for site quality and that is usually the height (average or dominant) of a given standard age (10, 25, 50 or 100 years) or height at a given age, or mean increment of total yield at a standard age (50 or 100 years). Modern yield tables can be summarized in a set of equations to be used by computer supplying the tables. Today, in fact, a yield table is only a presentation of a mathematical model. As a rule, the main mathematical relations refer to $h_g = f(T)$ or $h_{dom} = f(T)$, $V = f(hg)$ and $V + \sum V_n = f(hg)$ where h_g = height of tree of basal area, T = time (years), V = volume, h_{dom} = dominant height.

The first yield tables have been constructed in Germany since the end of the 18th century and continuously developed till the present (1997). A sample of German yield tables is shown in table 4.11.-1.

The first yield table was constructed by J. C. von Paulsen in 1787: "Die erste Ertragstafeln von Paulsen weisen 1787 shon eine ziemlich moderne Form auf" using graphical methods (Paulsen 1795). These tables refer to beech and were reproduced by Th. Hartig in 1847 who attributed them to Paulsen and G. L. Hartig.

The outstanding late British forestry historian N. D. G. James mentioned in his last work (1996, p. 18) that "In 1855 H. Burckhardt who three years previously had published a set of yield tables …" that means in 1852.

After these early yield tables appeared in Germany the 1870s and 1880s series dominated by Norway spruce tables: Baur (1877), Pressler (1878), Hartig (1878), Kunze (1878) first mentioned as constructed for "normal stocked stands", Weise (1880: Scots pine) and Lorey 1884/1897 (fir).

In 1881, Baur analyzed the relationships between yield, growth and form in the case of beech.

The first yield tables of Schwappach (1890 spruce and 1893 beech) refer also to stands with normal density.

Table 4.11.-1. A sample of German yield tables for even-aged stands

Printing year	Author (s)	Species	Remarks
1795	J. C. v. Paulsen	Beech	Reproduced by Th. Hartig in 1847 and attributed to Paulsen and G. L. Hartig (not seen)
1877	F. Baur	Norway spruce	4 classes based on height and age
1878	M. R. Pressler	Norway spruce	5 classes based on site quality and stand productivity
1878	Hartig	Norway spruce	In Pressler (1878), two site quality classes
1878	M. F. Kunze	Norway spruce	4 classes based on age and height, normal stocked stands
1880	W. Weise	Scots pine	
1884,1897	Tuisko Lorey	Fir	
1899	Tuisko Lorey	Norway spruce	Normal density yield tables; Württemberg
1890	A. Schwappach	Norway spruce	Normal density yield tables
1893	A. Schwappach	Beech	Normal density
1902	Fritz Eichhorn	Fir	
1902	A. Schwappach	Norway spruce	Normal density stands in Preussen, 5 classes based on age and height
1907	H. Stoetzer	Norway spruce	Based on age and height, 7 quality classes.
1912,1923, 1929, 1943 (Praga)	A. Schwappach	Main German species	
1914	Anonymous	Norway spruce, Scots pine	Middle Franken region: part of Bavaria
1921	E. Gerhardt	Norway spruce	
1923,1930	E. Gerhardt	Oak, beech, fir, Norway spruce, Scots pine. In the 2nd ed. 1930 added Douglas fir and larch	3-5 classes
1925	L. Schilling	Scots pine, Norway spruce	Eastern Preussen
1931	Prussian Forest Research Institute	Beech	
1936	Prussian Forest Research Institute	Norway spruce	
1937	Prussian Forest Research Institute	Douglas-fir	

Table 4.11.-1. (cont.)

Printing year	Author (s)	Species	Remarks
1938	E. Wiedemann	Beech (1931), Norway spruce (1936), Douglas-fir (1937)	
1939	V. Christmann (cited by Assmann 1961)	oak (Q. petraea)+beech	A yield table for mixed stands
1945/1946	K. Krenn	Norway spruce	Southern Germany and Austria. 10 classes based on mean increment of total yield at the age of 100 years
1949/1950	G. Mitscherlich	Scots pine, Norway spruce, Douglas-fir, beech, oak, common alder and European birch	Local yield tables for northern Germany and Lausitz
1949	E. Wiedemann	The most important species	Different thinning intensity is considered
1949	H. Zimmerle	Norway spruce	Based on age and height, 5 classes. Tables for Baden-Württemberg
1951	K. Vanselow	Norway spruce	Tables for southern Bavaria, 3 classes
1954	C. M. Möller	Beech, oak, Norway spruce	
1957	E. Wiedemann, R. Schober		Different thinning intensity is considered
1962	Werner		Based on site productivity, 4 classes
1963	E. Assmann Franz	Norway spruce	Abs. height, 11 classes, based on mean increment of total yield at the age of 100 years, with three levels of productivity: U = upper, M = medium and O = low
1963	W. Erteld	Main species	2nd edn.
1964	R. Schober	Norway spruce	Thinning considered
1966	H. Wätzig	Norway spruce	4 site classes. Eastern Germany
1971	D. Bergel	Douglas-fir	Yield and assortment tables for northwestern Germany
1971	Franz	Norway spruce	Based on site quality (3 types) and three groups of productivity
1975	G. Lembcke	Scots pine	Eastern Germany (former DDR)

Table 4.11.-1. (cont.)

Printing year	Author (s)	Species	Remarks
1975	R. Schober	Main species	
1977	Bechter	Norway spruce	Tables for Baar-Wutachgebiet, Based on site quality, 18H100 productivity
1979	G. Wenk	Norway spruce	Thinning considered
1980	H. Watzig	Norway spruce	New yield tables for former DDR
1980	G. Wenk	Norway spruce	Medium high mountains in former DDR.
1981	Horndasch Franz		Site-yield tables, 6 vegetation zones with 19 site types and three groups of productivity
1984	W. Grosscurth	Black poplars Balsam poplars	
1985	O. Dittmar, E. Knapp, G. Lembcke	Beech	The new 1983 beech yield tables for former DDR
1986	D. Bergel	Douglas-fir	Site index at top height at 100 years, three productivity classes, north-western Germany
1991	T. Böckmann	*Tilia cordata*	Table for lower Saxony and northern Hesse
1994	M. Röss	Wild cherry (Prunus avium)	Table for north-western Germany
1997	K. W. Lockow	Silver birch (Betula pendula)	Table for stands in Mecklenburg-Pomerania, NE Germany

In 1902, Eichhorn constructed a yield table for fir (the next one after that completed by Lorey in 1884 and 1897 – Table 4.11.-2.) and on this table he defined his “law” in 1904 using hypotheses yield = $f(h_m)$, h_m = average height. The “law” of stand growth and its use for the construction of yield table was mentioned by Gerhardt in 1909.

Stoelzer (1907) developed a table for spruce based on age and height as entry and containing seven site quality classes.

Since 1902, different editions of Schwappach’s yield tables (1905, 1908, 1911 and especially 1912, 1923, 1929, 1943 and 1952 – the 10th edn.) for main German species have appeared. Examples of Schwappach’s yield tables for oak (1905), Scots pine (1908) and beech (1911) are presented in tables 4.11.-3., 4.11.-4. and 4.11.-5.

TABLE 4.11.-2. Fir yield table after Eichhorn, 1902

A	STANDING TREES						THINNINGS			MAI		CAI	
	N	H	G	D	V >7 cm	V T	N'	V' >7 cm	V' T	ST	TS	Wood >7cm and branches	
		m	m²	cm	m³			m³		m³	m³	m³	%
SITE CLASS I													
25	-	4.5	-	-	-	78	-	-	10	3.1	3.5	8.4	18.3
30	8.600	6.7	20.0	5.4	44	127	-	2	20	4.2	5.2	13.8	17.6
35	4.800	10.0	27.5	8.5	113	208	3.800	13	30	5.9	7.7	22.2	17.5
40	3.200	13.3	35.1	11.9	211	325	1.600	27	38	8.1	10.6	31.0	14.9
45	2.350	16.2	41.6	15.0	320	440	850	38	46	9.8	13.0	32.2	9.9
50	1.800	18.0	45.4	18.0	422	542	550	45	51	10.8	14.7	30.6	7.0
55	1.420	21.0	48.6	20.9	510	632	380	49	54	11.5	16.0	28.8	5.3
60	1.140	22.9	51.2	23.9	589	710	280	50	55	11.8	16.9	26.6	4.2
65	960	24.5	53.8	26.7	662	780	180	49	54	12.0	17.5	24.8	3.5
70	820	26.0	55.8	29.4	725	842	140	46	51	12.0	17.9	24.6	3.2
75	725	27.3	57.5	31.8	776	897	95	44	48	12.0	18.0	20.6	2.5
80	645	28.4	59.1	34.1	821	946	80	41	45	11.8	18.1	18.8	2.1
85	590	29.5	60.4	36.0	864	990	55	38	42	11.6	18.0	17.2	1.8
90	550	30.4	61.5	37.8	898	1030	40	36	39	11.4	17.9	15.8	1.6
95	515	31.5	62.5	39.5	931	1067	35	33	36	11.2	17.7	14.6	1.4
100	485	31.8	63.5	40.9	965	1100	30	30	33	11.0	17.5	13.2	1.2
105	460	32.4	64.4	42.4	992	1130	25	28	30	10.8	17.3	12.0	1.1
110	435	33.0	65.2	43.7	1024	1158	25	26	28	10.5	17.0	11.2	1.0
115	415	33.5	65.9	44.9	1048	1185	20	24	26	10.3	16.7	10.6	0.9
120	400	34.0	66.5	46.1	1071	1210	15	22	24	10.1	16.4	9.8	0.8
SITE CLASS II													
25	-	3.3	-	-	-	57	-	-	5	2.3	2.5	5.6	16.5
30	12600	5.1	16.6	4.1	18	93	-	-	13	3.1	3.7	0.8	17.2
35	7000	7.8	23.2	6.5	63	156	5600	1	20	4.5	5.5	16.6	17.8
40	4500	10.6	30.0	9.2	138	243	2500	9	28	6.1	7.7	23.0	14.7
45	3300	13.3	35.7	11.8	225	331	1200	23	35	7.4	9.6	24.6	10.1
50	2400	15.4	39.7	14.4	306	410	900	33	40	8.2	11.0	23.8	7.2
55	1900	17.3	42.6	16.9	375	480	500	36	42	8.7	12.0	22.4	5.5
60	1520	19.0	45.0	19.4	441	543	380	37	43	9.0	12.8	21.6	4.5
65	1260	20.5	47.1	21.8	504	601	260	37	42	9.2	13.4	20.0	3.7
70	1070	21.9	49.0	24.2	559	655	190	37	41	9.4	13.8	19.0	3.2
75	945	23.1	50.6	26.1	602	705	125	36	40	9.4	14.0	18.0	2.7
80	845	24.1	52.1	28.0	646	751	100	35	39	9.4	14.2	17.0	2.4

A = age, years, N = number of trees, H = mean height, G = basal area, D = average diameter, V = volume of standing trees, > 7cm = wood with more than 7 cm, T = wood > 7cm and branches, N' = number of extracted trees, V' = extracted trees, number of extracted trees having > 7cm diam., T' = wood > 7cm and branches.MAI = mean annual increment: of standing trees (ST), of all stand trees (TS), CAI = current annual volume increment, wood > 7 cm and branches.
SOURCE; Eichhorn 1902. Ertragstafel fur die Weisstanne, Berlin.

TABLE 4.11.-3. Oak yield table after Schwappach, 1905

A	STANDING TREES						THINNINGS				MAI		CAI	
	N	H	G	D	V >7 cm	V T	N'	G'	V' >7 cm	V' T	ST	TS	Wood >7cm and branches	
		m	m^2	cm	m^3				m^3		m^3	m^3	m^3	%
SITE CLASS I														
20	7.580	7.5	10.5	4.2	26	53	-	-	-	-	2.7	2.7	-	-
25	5.295	9.4	12.6	5.5	45	76	2285	4.4	8	26	3.0	4.1	9.8	12.5
30	3.538	11.2	74.4	7.2	68	100	1757	5.6	16	38	3.3	5.5	12.4	16.4
35	2.514	13.0	15.9	9.0	93	126	1024	5.9	22	45	3.6	6.7	14.2	14.2
40	1.748	14.7	17.3	11.2	121	152	766	5.5	26	48	3.8	7.7	14.8	11.8
45	1.272	16.3	18.6	13.6	149	179	476	4.7	28	45	4.0	8.5	14.4	9.5
50	971	17.8	19.8	16.0	177	207	301	4.1	30	43	4.1	9.0	14.2	7.9
55	770	19.1	20.9	18.5	205	235	201	3.6	31	41	4.3	9.5	13.8	6.7
60	629	20.3	21.9	21.0	230	261	141	3.2	32	38	4.4	9.8	12.8	5.5
65	524	21.4	22.9	23.5	254	287	105	2.8	32	36	4.4	10.0	12.4	4.8
70	445	22.4	23.8	26.0	278	312	79	2.5	31	34	4.5	10.1	11.8	4.1
75	385	23.3	24.7	28.5	300	336	60	2.2	30	32	4.5	10.2	11.2	3.6
80	338	24.1	25.5	31.0	322	359	47	2.0	28	30	4.5	10.2	10.6	3.2
85	301	24.8	26.2	33.4	342	381	37	1.8	26	28	4.5	10.2	10.0	2.8
90	271	25.4	27.0	35.7	361	402	30	1.7	24	26	4.5	10.1	9.4	2.5
95	247	26.0	27.7	37.9	380	422	24	1.6	22	24	4.4	10.1	8.8	2.2
100	227	26.6	28.4	40.0	397	441	20	1.5	21	23	4.4	10.0	8.4	2.0
105	211	27.1	29.0	42.0	414	459	16	1.4	20	22	4.4	9.9	8.0	1.9
110	197	27.6	29.6	43.9	431	476	14	1.3	19	21	4.3	9.8	7.6	1.7
115	185	28.1	30.1	45.6	447	492	12	1.2	18	20	4.3	9.7	7.2	1.5
120	175	28.6	30.5	47.2	462	507	10	1.1	17	19	4.2	9.6	6.8	1.4
125	166	29.0	30.9	48.8	475	521	9	1.1	16	18	4.2	9.4	6.4	1.3
130	158	29.4	31.2	50.3	488	534	8	1.0	16	18	4.1	9.3	6.2	1.2
135	151	29.8	31.5	51.7	500	547	7	1.0	16	18	4.1	0.2	6.2	1.2
140	145	30.2	31.8	53.0	512	560	6	1.0	16	18	4.0	9.1	6.2	1.1
145	140	30.6	32.1	54.2	524	572	5	0.9	16	18	3.9	9.0	6.0	1.1
150	135	31.0	32.4	55.4	536	584	5	0.9	16	18	3.9	8.0	6.0	1.1
155	130	31.4	32.6	56.5	547	595	5	0.9	16	17	3.8	8.8	5.6	1.0
160	126	31.8	32.8	57.6	557	605	4	0.9	16	17	3.8	8.7	5.4	0.9
170	118	32.4	33.2	59.8	576	624	4	0.9	16	17	3.7	8.5	5.2	0.0
180	111	33.0	33.3	61.9	590	639	3	0.9	16	17	3.6	8.3	4.8	0.8
190	105	33.6	33.3	63.7	602	651	3	0.9	15	16	3.4	8.1	4.4	0.7
200	100	34.1	33.2	65.0	610	659	2	0.9	15	16	3.3	7.9	3.8	0.6

Abbreviations ibidem Table 4.11. - except for G' = basal area of extracted trees.
SOURCE: Schwappach, 1905. Formzahlen und Massentafeln fur die Eiche, P.Parey, Berlin

TABLE 4.11.-4. Scots pine yield table after Scwappach, 1908

A	STANDING TREES						THINNINGS				MAI		CAI	
	N	H	G	D	V >7 cm	V T	N'	G'	V' >7 cm	V' T	ST	TS	Wood >7cm and branches	
		m	m^2	cm	m^3				m^3		m^3	m^3	m^3	%
SITE CLASS I														
30	2880	12.0	27.9	11.1	154	237	1500	3.2	11	19	7.9	8.9	9.6	5.8
40	1570	15.7	30.5	15.9	227	289	510	3.6	23	32	7.2	9.5	11.8	5.3
50	998	18.9	32.1	20.3	282	335	196	3.1	24	31	6.7	9.8	10.6	3.6
60	739	21.6	33.0	23.8	328	377	112	2.7	25	29	6.3	9.9	9.8	2.7
70	583	23.7	33.5	27.0	363	409	69	2.5	25	28	5.8	9.7	8.6	2.2
80	480	25.4	33.7	29.9	391	434	47	2.3	25	28	5.4	9.5	8.0	1.9
90	403	26.8	33.9	32.7	413	455	36	2.2	24	27	5.1	9.3	7.4	1.6
100	342	28.0	33.8	35.4	429	470	29	2.0	24	27	4.7	9.1	6.8	1.5
110	296	29.1	33.6	37.9	441	481	21	1.9	24	26	4.3	8.8	6.2	1.3
120	265	30.1	33.3	40.0	452	491	14	1.7	22	24	4.1	8.6	5.8	1.2
130	242	30.9	32.9	41.6	457	494	11	1.5	20	22	3.8	8.3	4.6	0.9
140	223	31.5	32.4	43.1	458	494	9	1.2	16	18	3.5	7.9	3.8	0.7
SITE CLASS II														
30	3940	10.2	26.2	9.4	104	194	1590	2.3	8	19	6.5	7.5	8.6	6.2
40	2100	13.2	28.7	13.3	175	238	640	3.5	16	28	6.0	8.1	9.8	5.2
50	1364	15.8	30.4	16.8	228	280	246	3.1	19	27	5.6	8.4	9.4	3.6
60	1005	18.1	31.4	20.0	266	314	162	2.6	20	25	5.2	8.4	8.2	2.7
70	763	20.0	32.1	23.2	296	343	109	2.3	20	24	4.9	8.3	7.6	2.3
80	601	21.6	32.4	26.2	322	367	73	2.2	21	24	4.6	8.2	7.2	2.0
90	491	22.9	32.5	29.0	344	385	50	2.1	21	24	4.3	8.0	6.4	1.7
100	413	24.1	32.4	31.6	358	398	36	2.0	21	24	4.0	7.8	6.0	1.5
110	352	25.1	31.9	34.0	365	403	29	2.0	20	23	3.7	7.6	5.0	1.3
120	303	25.9	31.1	36.2	367	403	23	1.9	19	22	3.3	7.3	4.4	1.1
130	266	26.7	30.2	38.0	367	402	17	1.7	17	20	3.1	1	4.0	0.9
140	240	27.3	29.1	39.3	361	395	12	1.4	15	18	2.8	6.8	2.8	0.7
SITE CLASS III														
30	5300	8.0	24.4	7.4	65	148	2390	2.2	5	12	4.9	5.3	6.4	6.2
40	3083	10.7	26.8	10.5	126	189	777	3.7	13	24	4.7	6.1	9.0	5.5
50	2003	13.0	28.5	13.4	175	228	480	3.0	16	22	4.6	6.6	8.4	3.9
60	1388	15.0	29.4	16.2	209	258	255	2.5	17	21	4.3	6.7	7.0	2.9
70	1053	16.7	30.1	19.0	238	285	150	2.2	18	19	4.1	6.7	6.2	2.3
80	823	18.1	30.4	21.8	258	303	105	2.1	18	19	3.8	6.6	5.4	1.8
90	653	19.3	30.4	24.4	272	317	79	2.0	18	20	3.5	6.4	4.8	1.6
100	528	20.3	30.1	26.9	283	323	58	2.0	18	20	3.2	6.2	4.8	1.4

Abbreviations ibidem Table 2.11.-2 In addition G'=basal area of extracted trees.
SOURCE: Schwappach 1908. Die Kiefer, Neudamm.

TABLE 4.11.-5. Beech yield tables after Schwappach, 1911

Alter Jahr	Verbleibender Bestand Stamm-zahl	Mittel-höhe	Mittel-durch-messer	Stamm-grund-fläche	Derbholz-volumen	Lfd. jährl. Zuwachs Derbholz		dGZ Derbholz
	Stück	m	cm	m^2	m^3	m^3	%	m^3
				Ertragsklasse I				
20	5917	7.1	7.5	26.0	39	7.8	-	2.0
30	3110	11.5	11.5	32.5	172	16.4	11.4	6.3
40	1886	16.6	15.5	35.5	304	17.4	6.6	9.1
50	1326	21.2	19.3	38.7	423	16.6	4.1	10.6
60	1007	24.7	23.0	41.9	529	15.6	3.0	11.5
70	787	27.4	26.9	44.7	615	14.6	2.4	11.9
80	631	29.7	30.7	46.7	681	13.6	2.0	12.2
90	520	31.6	34.2	47.9	725	12.2	1.6	12.2
100	435	33.3	37.6	48.3	754	11.8	1.5	12.2
110	366	34.8	40.9	48.0	765	10.4	1.3	12.0
120	308	35.9	44.3	47.4	767	9.6	1.2	11.9
				Ertragsklasse III				
20	5917	3.9	4.6	9.6	-	-	-	-
30	4927	6.2	7.5	21.6	27	4.4	27.5	0.9
40	3347	9.3	10.3	28.0	110	10.4	11.2	3.1
50	2422	13.1	12.8	31.4	203	12.2	6.6	4.8
60	1849	16.2	15.3	34.6	292	11.6	4.2	6.0
70	1453	18.9	18.1	37.2	365	10.6	3.0	6.7
80	1148	21.2	20.7	38.5	418	10.0	2.4	7.1
90	913	23.2	23.3	38.8	456	9.4	2.0	7.4
100	729	25.0	25.9	38.4	483	8.8	1.8	7.5
110	589	26.7	28.4	37.4	498	8.0	1.6	7.6
120	476	28.2	31.2	36.3	507	7.2	1.4	7.6
				Ertragsklasse V				
40	4880	4.5	6.8	17.6	17	-	-	0.4
50	3795	6.8	8.5	21.6	64	5.0	9.7	1.3
60	2965	9.3	10.3	24.6	117	7.0	6.5	2.0
70	2335	11.7	12.1	26.8	170	7.6	4.6	2.4
80	1900	13.8	13.7	27.9	208	7.0	3.4	2.6
90	1578	15.7	15.0	28.1	231	6.0	2.5	2.6
100	1325	17.2	16.3	27.5	245	5.2	2.1	2.5

Abbreviations ibidem Table 4.11.-2.
SOURCE: Schwappach 1911, Die Rotbuche Wirtschaftliche und Statische Untersuchungen der forstlichen Abteilung der Hauptstation des forstlichen Versuchswesen in Eberswalde, Verlag J. Neaumann, Neudamm.

These tables like Wiedemann's (1936/1942) yield tables are based on the data from about 1,000 sample plots obtained during 50-70 years of observations and are constructed for normal density stands, and low intensity thinnings, and having as entries age, height and five site classes (Table 4.11.-6.).

TABLE 4.11.-6. Wiedemann's spruce yield tables

Alter Jahr	Verbleibender Bestand Stamm-zahl	Mittel-höhe	Mittel-durch-messer	Stamm-grund-fläche	Derbholz-volumen	Lfd. jährl. Zuwachs Derbholz		dGZ Derbholz
	Stück	m	cm	m²	m³	m³	%	m³
				Ertragsklasse I				
20	5917	7.1	7.5	26.0	39	7.8	-	2.0
30	3110	11.5	11.5	32.5	172	16.4	11.4	6.3
40	1886	16.6	15.5	35.5	304	17.4	6.6	9.1
50	1326	21.2	19.3	38.7	423	16.6	4.1	10.6
60	1007	24.7	23.0	41.9	529	15.6	3.0	11.5
70	787	27.4	26.9	44.7	615	14.6	2.4	11.9
80	631	29.7	30.7	46.7	681	13.6	2.0	12.2
90	520	31.6	34.2	47.9	725	12.2	1.6	12.2
100	435	33.3	37.6	48.3	754	11.8	1.5	12.2
110	366	34.8	40.9	48.0	765	10.4	1.3	12.0
120	308	35.9	44.3	47.4	767	9.6	1.2	11.9
				Ertragsklasse III				
20	5917	3.9	4.6	9.6	-	-	-	-
30	4927	6.2	7.5	21.6	27	4.4	27.5	0.9
40	3347	9.3	10.3	28.0	110	10.4	11.2	3.1
50	2422	13.1	12.8	31.4	203	12.2	6.6	4.8
60	1849	16.2	15.3	34.6	292	11.6	4.2	6.0
70	1453	18.9	18.1	37.2	365	10.6	3.0	6.7
80	1148	21.2	20.7	38.5	418	10.0	2.4	7.1
90	913	23.2	23.3	38.8	456	9.4	2.0	7.4
100	729	25.0	25.9	38.4	483	8.8	1.8	7.5
110	589	26.7	28.4	37.4	498	8.0	1.6	7.6
120	476	28.2	31.2	36.3	507	7.2	1.4	7.6
				Ertragsklasse V				
40	4880	4.5	6.8	17.6	17	-	-	0.4
50	3795	6.8	8.5	21.6	64	5.0	9.7	1.3
60	2965	9.3	10.3	24.6	117	7.0	6.5	2.0
70	2335	11.7	12.1	26.8	170	7.6	4.6	2.4
80	1900	13.8	13.7	27.9	208	7.0	3.4	2.6
90	1578	15.7	15.0	28.1	231	6.0	2.5	2.6
100	1325	17.2	16.3	27.5	245	5.2	2.1	2.5
1	2	3	4	5	6	7	8	9

1 = age, 2 = number of trees, 3 = average height, 4 = average diameter, 5 = basal area, 6 = volume...7cm at top end, 1-6 stems which remain standing (after thinning), 7, 8 = annual increment, 8, 9 = mean increment

SOURCE: Wiedemann 1936/1942: Ertragstafeln der wichtigsten Holzarten bei verschiedener Durchforstung sowie einiger Mischbestandsformen mit graphischen Darstellungen.Hannover 1942: Der gleichaltrige Fichten-Buchen-Mischbestand.Mitt. Forstwirt U. Forstwiss l3.

A new set of tables was developed by Gerhardt (1923 and 1930, 2nd edn.) for pure and homogenous stands of oak, beech, fir spruce, Scots pine, Douglas-fir and larch.

The first German yield table for mixed stands (Scots pine + Norway spruce) was constructed by Schilling in 1925 for two types of these mixed forests in eastern Preussen (Prussia).

Prussian forest research institute developed (1938) a set of yield tables for this region.

Assmann (1961) mentioned Christmann's (1939) yield tables for *Quercus petraea* (Traubeneiche), oak and beech mixed forests.

In 1939, Mitscherlich constructed (probably the first in Germany) the assortment-yield tables, based on solids of rotation for spruce, pine, beech and oak growing in Prussia and northern Germany and common tables for central and western Germany. Mitscherlich constructed separate assortment-yield tables for oak in river meadow and for that on higher sites, and separate tables for eastern Prussian spruce and that in Hartz.

In 1942 Wiedemann completed yield tables for mixed spruce + beech stands.

Krenn's (1945/1946) yield tables have been considered as revolutionary. He used as criterion for stand classification 15 site classes based on mean increment of total yield at the age of 100 years. A detailed presentation of an extract of Krenn's tables is shown in tables 4.11.-7. (establishment of site classes) and 4.11.-8. (a yield table for spruce, site class 11).

Assmann (1949) analyzed the problem of growth determination on the basis of yield tables.

Wiedemann's (1949) yield tables constructed for the most important tree species contain tables (the second time after 1925) for mixed stands as oak + beech, spruce + beech with a low growth, spruce+beech with equal growth, pine + beech, pine + spruce, and yield tables for multiaged stands. Wiedeman's (1949) yield tables contain volume and growth only for wood ≥ 7cm. For same species as beech, spruce and pine the tables were constructed for three thinning intensities (medium, high and very high) for beech and pine or medium, high and graded (high at the beginning and medium after that) for spruce, medium and high for larch and only one type of intensity for oak, ash, birch.

Schober (1955) constructed yield tables for Sitka spruce (Table 4.11.-9.) comparing the yield of German and British resinous species using Hummel and Christie yield tables (1953, U.K.) and did not find notable differences.

TABLE 4.11.-7. Extract from Krenn's table necessary for establishment of spruce site classes in Krenn system of yield tables

Site class* m^3/y/ha	Age, years										
	20	30	40	50	60	70	80	90	100	110	120
	Average height, m										
4	-	1.8	4.3	6.6	8.9	11.0	13.0	15.0	16.8	18.6	20.2
5	0.2	3.1	5.8	8.3	10.7	13.0	15.2	17.1	19.0	20.7	22.3
6	1.1	4.2	7.1	9.9	12.5	14.9	17.1	19.1	21.0	22.7	24.2
7	1.9	5.3	8.4	11.4	14.1	16.6	18.9	21.0	22.9	24.5	26.0
8	2.7	6.3	9.6	12.8	15.6	18.2	20.6	22.8	24.7	26.3	27.7
9	3.4	7.2	10.8	14.1	17.1	19.8	22.2	24.4	26.3	28.0	29.3
10	4.1	8.1	11.9	15.3	18.5	21.3	23.8	26.0	27.9	29.6	30.9
11	4.8	9.0	12.9	16.5	19.8	22.7	25.3	27.5	29.5	31.1	32.4
12	5.4	9.9	13.9	17.7	21.1	24.1	26.7	29.0	31.0	32.5	33.8
13	6.0	10.7	14.9	18.8	22.3	25.4	28.1	30.4	32.4	33.9	35.1
14	6.6	11.5	15.9	19.9	23.5	26.7	29.4	31.8	33.8	35.3	36.5
15	7.2	12.2	16.8	20.9	24.6	27.9	30.7	33.1	35.1	36.6	37.8
16	7.8	12.9	17.7	21.9	25.7	29.1	32.0	34.4	36.4	37.9	39.0
17	8.3	13.6	18.5	22.9	26.8	30.2	33.2	35.6	37.6	39.1	40.2
18	8.9	14.3	19.3	23.8	27.8	31.3	34.3	36.8	38.9	40.3	41.3

* Site classes are based on average total growth at 100 years. Site classes (15) are spaced out from one m^3 to another m^3, the first class begins with 4 m^3/year/ha.
SOURCE: Krenn 1946 b. Ertagsttafeln fur Fichte (1945) für Süddeutschland und Österreich, Schriffenr. Bad. Forstl. Versuchsanst.

A new edition of Wiedeman-Schober yield tables (1957) contains tables for native and cultivated species: it is an excellent textbook (24 tables) for: American red oak (*Quercus borealis*), *Quercus petraea*, beech, *Alnus glutinosa*, birch, ash, *Robinia pseudacacia, Populus marilandica*, spruce, Sitka spruce, Douglas-fir, fir, Scots pine, larch, Japanese larch.

Assmann (1959) considered the height as the major criterion for the evaluation of site quality.

Assmann and Franz (1963/1965, 2nd edn. 1972) constructed for spruce regional yield tables for Bavaria (fig. 4.11.-1.) and adopted for site classes the American site index with 100 years as reference age instead of average height. These tables are the first based on complex mathematical models to be solved by computers. The computerized models are discussed by Franz in 1966.

Bergel's (1971) assortment and yield tables were developed for Douglas-fir plantations in north-western Germany.

Franz (1971) constructed yield tables for Norway spruce based on three site quality types and three groups of productivity and underlined the importance of relationship between site and capacity of production (Fig.4.11.-2.).

TABLE 4.11.-8. Extract from Krenn's yield table for spruce 11 site class

						Thinning intensity of stand							
						I=10 %				II=20 %			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
30	9.0	110	3.7	12.4	3.9	99	25.1	8.6	4314	88	22.3	10.3	2674
35	11.0	174	5.0	13.2	3.5	157	28.6	10.3	3430	139	25.4	11.9	2284
40	12.9	242	6.1	13.9	6.7	218	32.6	12.0	2879	194	28.9	13.5	2022
45	14.8	313	7.0	14.5	7.8	282	36.6	13.6	2499	260	32.3	15.1	1802
50	16.5	387	7.7	14.9	8.7	348	39.8	15.2	2196	310	35.4	16.6	1637
60	19.8	538	9.0	15.2	10.4	484	46.6	18.4	1753	430	41.4	19.6	1373
70	22.7	690	9.9	15.0	11.7	621	53.1	21.4	1477	552	47.2	22.6	1177
80	25.3	837	10.5	14.3	12.7					670	52.7	25.3	1049
90	27.5	975	10.8	13.2	13.5					780	57.9	27.8	953
100	29.5	1100	11.0	11.7	14.1					880	62.6	30.1	880
110	31.1	1208	11.0	9.8	14.5								
120	32.4	1297	10.8		14.8								

Thinning intensity of stand											
III=30 %				IV=40 %				V=50 %			
15	16	17	18	19	20	21	22	23	24	25	26
77	-	-	-	66	-	-	-	55	-	-	-
122	22.2	13.9	1465	104	-	-	-	87	-	-	-
169	25.3	15.4	1359	145	-	-	-	121	-	-	-
219	28.2	16.9	1258	188	-	-	-	156	-	-	-
271	31.0	18.4	1166	232	26.6	20.9	774	193	-	-	-
377	36.2	21.4	1008	323	31.1	23.8	698	269	-	-	-
483	41.3	24.2	898	414	35.4	26.6	637	345	-	-	-
586	46.1	26.9	812	502	39.5	29.3	586	418	32.9	32.0	410
682	50.6	29.5	741	585	43.4	31.8	546	487	36.2	34.5	387
770	54.8	31.8	690	660	40.9	54.0	517	550	39.1	36.7	370
846	58.4	33.8	651	725	50.1	35.9	495	604	41.7	38.7	355
908	61.5	35.5	621	778	52.7	37.6	474	648	43.9	40.4	342

1 = age, years; 2 = average height, m: 3 = total production (yield) m^3; 4 = average increment of the total production, m^3: 5 = current increment, m^3, 6 = height form, m; 7,11,15,19,23 = volume, m^3; 8,12,16,20,24 = basal area, m^2; 9,13,17,21,25 = average height, m;10.14,18,22,26 = number of trees.
SOURCE: Ibidem Table 4.11.-7.

Van Laar and Akça (1997) remarked that "Growth studies in Germany however have convincingly shown that the mean annual increment at the reference age of stands of a given age and site index may vary considerably (Assmann and Franz 1963).

For this reason, the concept of special yield level was introduced and incorporated into the Assmann-Franz Bavarian yield tables for Norway spruce. Several methods were proposed for estimating the special yield level of a given stand but no simple method is available to obtain a quick, accurate estimate” (p. 247).

TABLE 4.11.-9. Yield table for sitka spruce. Thinnings of medium intensity

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
								SITE CLASS I								
10	-	4.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	7.6	8.3	-	-	-	-	-	-	-	-	-	-	-	-	-
20	2.901	10.9	12.0	29.1	11.3	131	15.7	-	-	-	-	-	-	-	131	6.5
25	1.892	14.6	15.9	33.0	14.9	209	14.5	1.009	11.4	7.9	10.0	40	23.6	13.7	249	10.0
30	1.380	17.9	19.2	36.3	18.3	290	13.3	512	15.1	6.3	12.5	43	24.8	9.8	373	12.4
35	1.068	20.9	22.2	39.1	21.6	370	12.6	312	18.1	5.6	15.1	47	25.4	7.5	500	14.3
40	864	23.5	24.9	41.4	24.7	444	12.0	204	20.6	5.1	17.9	50	24.8	6.0	624	15.6
45	716	25.8	27.3	43.2	27.7	510	11.4	148	22.7	4.9	20.5	52	23.6	4.8	742	16.5
50	608	27.8	29.5	44.7	30.6	565	10.9	108	25.1	4.6	23.2	54	21.8	3.9	851	17.0
55	525	29.5	31.3	46.0	33.4	612	10.3	83	27.2	4.3	25.8	55	20.4	3.4	953	17.3
60	460	31.0	32.9	47.1	36.1	654	9.8	65	29.0	4.1	28.5	55	19.4	2.9	1.051	17.5
65	408	32.4	34.3	48.0	38.7	690	9.3	52	30.9	3.9	31.3	56	18.4	2.6	1.143	17.6
70	365	33.7	35.5	48.7	41.2	721	8.9	43	32.3	3.8	33.6	56	17.4	2.4	1.230	17.6
								SITE CLASS II								
10	-	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	6.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	3.619	9.3	10.2	26.2	9.6	95	16.2	-	-	-	-	-	-	-	95	4.7
25	2.315	12.4	13.5	29.8	12.8	153	15.3	1.304	9.4	7.0	8.3	28	17.2	13.8	181	7.2
30	1.673	15.3	16.4	32.8	15.8	216	14.1	642	12.2	5.9	10.8	32	19.2	10.0	276	9.2
35	1.284	17.9	19.0	35.3	18.7	278	13.2	389	15.2	5.2	13.0	35	19.4	7.7	373	10.7
40	1.028	20.2	21.4	37.3	21.5	338	12.6	256	17.6	4.8	15.4	38	19.6	6.2	471	11.8
45	846	22.3	23.6	38.9	24.2	393	12.1	182	19.5	4.6	18.0	41	19.2	5.1	567	12.6
50	713	24.1	25.5	40.2	26.8	441	11.6	133	21.6	4.4	20.5	44	18.4	4.3	659	13.2
55	613	25.7	27.2	41.3	29.3	481	11.1	100	23.5	4.2	23.0	45	17.0	3.6	744	13.5
60	535	27.1	28.7	42.2	31.7	515	10.6	78	25.3	4.0	25.5	46	16.0	3.1	824	13.7
65	472	28.4	30.0	42.9	34.0	544	10.2	63	26.8	3.8	27.9	47	15.2	2.8	900	13.8
70	420	29.6	31.2	43.5	36.3	570	9.8	52	27.2	3.7	30.3	48	14.8	2.6	974	13.9
								SITE CLASS III								
10	-	3.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	5.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	5110	7.4	8.1	23.2	7.6	60	16.6	-	-	-	-	-	-	-	60	3.0
25	3181	10.0	10.9	26.5	10.3	104	16.0	1.929	(7.1)	(6.1)	(6.2)	(11)	11.0	13.9	115	4.6
30	2234	12.4	13.3	29.2	12.9	150	15.2	947	9.5	5.1	8.3	20	13.2	10.3	181	6.0
65	602	24.4	25.8	38.6	28.6	421	11.3	82	22.9	3.8	24.2	39	13.2	3.1	683	10.5
70	536	25.5	26.9	39.3	30.6	446	10.9	66	24.2	3.6	26.5	40	13.0	2.9	748	10.7

1=Age, years; 2-8 Stems which remain standing (after thinning); 2= Number of trees; 3= Average height, m; 4= Dominant height, m; 5= Basal area, m^2; 6= Average diameter (dbh), cm; 7= wood volume with bark; 8 = bark percentage; 9-13- Thinnings; 9= Number of trees; 10= Average height, m; 11= Basal area; 12= Average diameter; 13= Wood volume with bark; 14-15= current annual increment; 14= m^3 15= %; 16= Total yield, m^3; 17= average annual increment, m^3

SOURCE: Schober 1955, Die Ertragsleitung der Nadelhölzer in Grossbritanien und Deutschland. Forstwissenschaftliches Centralblatt, Nr.1/2.

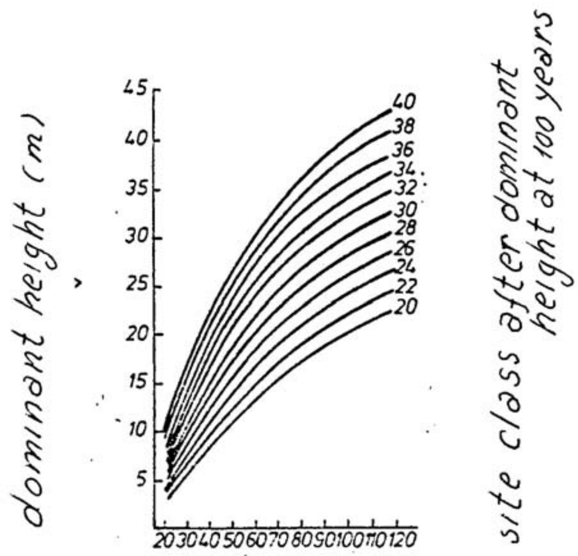


Fig. 4.11.-1. Spruce site classes established accord ing to age and dominant height. Site classes are numbered after dominant height at 100 years.

SOURCE: Assmann and Franz, 1965. Vorläufige Fichten - Ertragstafel für Bayern. Forstwiss. Cbl.84, 1/2.

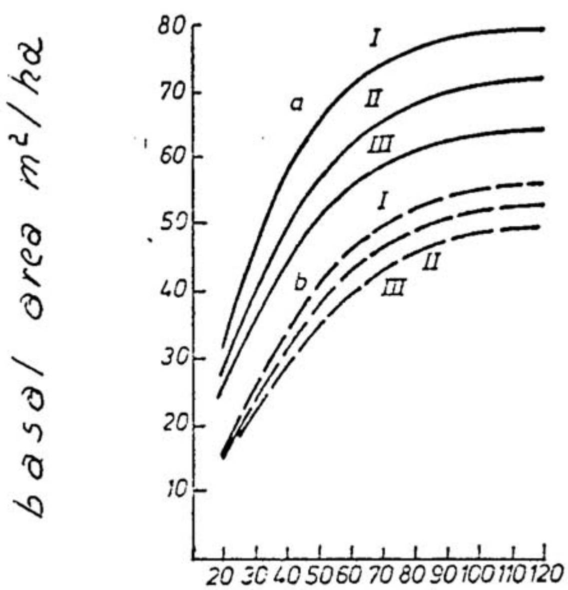


Fig. 4.11.-2. Basal area (G) per ha in spruce stands by site classes (a and b) and three productivity levels (I, II, III).

SOURCE: Franz 1971. Grundlagen und Verfahren standortsbezogener Leistung. Mit Fichten-Leistungstafeln fur einige Standortseinheiten in Mittelschwaben.

Kennel (1971) based on beech stand thinnings advocated that the observations should be taken into account for a long period of time.

Hradetzky (1972) presented an integrated computerized model of yield table system in modular form (equations are solved by computer). Zimmermann (1974, 1977) prepared a new method of yield tables construction based on growth function and applied it to spruce (1977). Wenk's (1979) spruce yield tables are strongly connected with thinning intensity.

Horndasch's (1981) yield tables are site-yield tables for six vegetation zones and 19 site types and three groups of productivity.

In 1989, Zimmermann analyzed the use of Magin's (1959) quotients in the construction of yield tables. Magin's method use the quotients of mean-tree volumes of the stand to be cut (thinned) and the whole stand in order to deduce the volumes of thinnings for yield table models. It is shown by Zimmermann that Magin's k value is identical to the ratio of the percentages of volume cut and stem number cut and it is possible to relate the volume development deduced by Tharandt yield table algorithm to the appropriate stem number reduction curve.

The development of Magin's quotient over age was calculated by three different regression functions, using data for the standing volume and top height of a Norway spruce indicator plots between the ages of 40 and 110 years.

Laar and Akca (1957) noted that "The German yield tables constructed by Schwappach and Wiedemann were based on Lorey's mean height, but those constructed more recently (Assmann and Franz 1965, Bergel 1985) are based on the quadratic mean diameter".

Among the more recent yield tables will be mentioned that referring to *Tilia cordata* in Lower Saxony and northern Hesse (Bokmann 1991), *Prunus avium* (Röös 1994) and a new table for *Betula pendula* in Mecklenburg – Pomerania (Lockow 1997).

Cited authors:

Anonymous 1914, Assmann 1949, 1959, 1961, 1963/1972, 1970; Assmann and Franz 1963, Baur 1877, 1881; Bachter 1977, Bergel 1971, 1985, 1986; Bokmann 1991, Dittmar et al. 1983, Eichhorn 1902, 1904, Franz 1966, 1971; Gehrhardt 1909. 1921, 1923/1930, Grosscurth 1984, Hartig Th. 1847, 1878; Harndasch 1981, Hradetzky 1972, Hummel and Christie 1953-UK, James N.D.G. 1996-UK, Kennel 1971, Krenn 1946, Kunze 1878, Laar und Akça 1957, Lembcke 1975, Lockow 1997, Lorey 1884/1897, 1899; Mitscherlich 1939, 1949/1950; Moller 1954, Paulsen 1795, Pressler 1878, Preussische Versuchsanstalt für Waldwirtschaft 1938, Prodan 1965, Röös 1994, Schilling 1925, Schober 1955, 1964, 1975, Schwappach 1890, 1893, 1902, 1912/1929; Stoetzer 1907, Vanselow 1951, Wätzig 1966, 1980; Weise 1880. Wenk 1979, 1980, Werner 1962, Wiedemann 1938, 1939, 1942, 1949, 1957; Wiedemann and Schober 1957, Zimmerle 1949, Zimmermann 1974, 1977, 1989.

4.12. Determination of stand growth using conventional methods

The most common methods for stand growth determination used in Germany refer to: (1) periodical inventory of sample plots (Growth = V_2 - V_1 + R, where V_1 = first inventory volume, V_2 = the second inventory volume, and R = volume of wood extracted by thinning or natural mortality); (2) the use of special volume tables (Krenn); (3) determination based on a single measurement of diameters and samples extracted with Pressler's borer at dbh; (4) determination of G in formula V = G•HF, HF supposed to be constant; (5) use of average tree; (6) use of growth percentage formulas; (7) volume tables and other techniques.

The first growth curve of logistic type was developed by Spaeth in 1797 and 1798 in a dissertation on determination of forest growth. Later stand growth was investigated by Paulsen (1845) who underlined the importance of species in computation of stand growth, G. Heyer (1852) and Baur (1860) who analyzed estimation of ages, volumes and growth in forest stands. Kunze (1878) determined the normal basal area in a spruce stand while Pressler (1878) and Blok (1888) developed researches on growth and yield. Schwappach (1888), proposed a percentage of growth estimation with formula

$$p_v = p_g + p_h + p_f = 2p_d + p_h + p_f$$

where d, g, h and f are subscripts for diameter, basal area, weight and form factor.

Kunze (1889) noticed the influence of silvicultural measures on growth and yield of spruce. Müller (1915) demonstrated the formula $p_v = p_h + p_g + p_f$ and indicated the time when current increment is equal with medium increment but an earlier demonstration was given by Heyer in 1883.

A more detailed analysis on forest increment was completed by Heck in a series of articles published in Forstwiss. Cbl. in 1922-1925 (partly commented by Kohler).

Among other contributions on stand growth studies it will be mentioned: Dietrich (1923), spruce and beech growth; Hudeczek (1932), tables for graphic estimation of growth percentage of stand volume; Wiedemann (1937), Norway spruce growth.

In 1939, Peschel used a function for growth estimation and underlined the necessity of the use of mathematical methods in growth and yield stand studies. Hohenadl's average trees were used in 1941 for the estimation of stand growth.

A summary of the works on stand yield with references to growth have been completed by Schober, in 1942, and, in 1944, Prodan investigated in his dissertation (Freiburg) growth and yield aspects in selection forest.

In 1941 (3rd edn. 1949), Vanselov published the first edition of his remarkable "Einführung in die Forstliche Zuwachs- und Ertragslehre" (Introduction into the knowledge of forest increment and yield) - a synthesis of the current knowledge in this field: a classic work on growth and yield.

In Spiecker's (1948) dissertation (Freiburg University) volume curves have been developed for the determination of stand growth and yield connected with biological aspects. These volume series with dbh entry may be applied only in mature stands.

Another important works on forest growth have been completed by Weck (1948/1955) who showed that the integral of growth function has the pattern of Gauss low. Weck considered that regional yield tables are not sufficient and the best way is to produce yield tables for groups of types at sites. Weck (1948) classified sites and observed that the development with age of overage tree of stand height is different from the overage height of stand which is smaller at least untill 80 years in a stand of spruce, in other words stand average height grows faster than the height of stand average tree or any other tree located in upper canopy. In another work (1950) Weck insisted on the importance of growth laws for forestry.

Another basic book was published by Wiedemann (1950, 2nd ed. 1955) on fundamentals of growth and forest yield.

In 1951, Laer and Spiecker completed tables for volume and growth determination of a stand based on height series depending on diameter and series by species on these height series (see Tables 4.10.-5. and 4.10.-6.). They constructed also a special table (Table 4.12.-1.) for the determination of increment percentage of volume increment depending on age, site class and species.

Aspects of growth and yield are also included in highly appreciated work of Wiedemann (1951, 2nd edn. 1955) on the basis of growth and silviculture.

In Prodan's (1951) "Messung der Waldbestände" (Measurement of forest stands) a special chapter (5) is designed to trees and stands growth. Prodan demonstrated that arithmetical average tree of the stand is in the same time the average tree from growth point of view. That means that arithmetical mean of diameter growth of all trees of the stand is equal with the growth of the diameter of average tree. This conclusion is valid also for the mean tree of stand basal area, for Hohenadl's trees and for the average tree of stand volume ($v = V/N$). Based on this conclusion it is possible to determine the diameter growth in even aged stands only on the basis of measurements of average stand tree. Procedure is applicable also in uneven-aged stands but in this case the stand should be separated in biohomogenous groups of trees called "elements of stands" (Stinghe and Toma 1958).

TABLE 4.12.-1. Increment percentage of volume increment depending on age and site class in the case of the stands over 70 years

Site class	Age at the end of the period								
	70	80	90	100	110	120	130	140	150
	Annual increment in % of volume at the end of the period								
Norway spruce									
I	0.64	0.42	0.30	0.24	0.19	0.15	-	-	-
II	0.75	0.50	0.35	0.26	0.20	0.16	-	-	-
III	0.80	0.60	0.46	0.35	0.27	0.22	-	-	-
IV	-	0.70	0.64	0.41	0.30	0.26	-	-	-
Fir									
I	0.16	0.53	0.50	0.40	0.32	0.25	0.19	-	-
II	0.67	0.53	0.50	0.40	0.32	0.25	0.19	-	-
III	-	0.50	0.48	0.40	0.32	0.25	0.19	-	-
Beech									
I	0.55	0.39	0.31	0.21	0.16	0.14	0.12	-	-
II	0.60	0.42	0.31	0.22	0.17	0.14	0.12	0.10	-
III	-	0.44	0.31	0.22	0.17	0.13	0.10	0.08	-
IV	-	-	0.33	0.22	0.17	0.13	0.13	0.10	-
Oak (*Quercus petraea*)									
I	0.45	0.34	0.24	0.19	0.15	0.13	0.12	0.10	0.08
II	0.43	0.32	0.23	0.18	0.15	0.13	0.12	0.10	0.08
III	0.43	0.32	0.23	0.18	0.15	0.13	0.12	0.10	0.08

SOURCE: Laer and Spiecker 1951. Massenberechnungstafeln zur Ermittlung von Vorrat und Zuwachs von Waldbeständen. J. D. Sauerländer's Verlag, Frankfurt a.M. Reproduced after Stinghe and Toma, 1958, Dendrometrie, p. 213.

In 1953, Loetsch advocated the use of mathematical statistics methods in the determination of yield and growth especially when growth cores are extracted with Pressler's borer.

Keylwerth analyzed qualitative (1954 a) and quantitative (1954 b) aspects of growth and the importance of statistics for wood study and forest economics (1954 c).

The method of tariff differences for volume and growth estimation was described by Loetsch (1954).

Investigation on form factors for the improvement of stand growth determination, on long range, were developed by Dittmar (1956) and the amount of growing stock is considered as an important factor which influenced stand growth (Erteld 1956).

Prodan summarized in 1956 the possibilities of growth determination and Mitscherlich published in the same year his remarkable "Ertragsgesetze" in which forest productivity laws are examined. Determination of increment on the basis of samples extracted with Pressler's borer was examined carefully by Richter et al. (1956).

Connection between stand basal area (G) of a closed canopy and growth was studied by Erteld (1957) in the case of Scots pine, spruce and beech.

Comparative studies of pure and mixed spruce and beech stands were performed by Wiedemann since 1942 and obtained comparative data examined in Figure 4.12.-1.

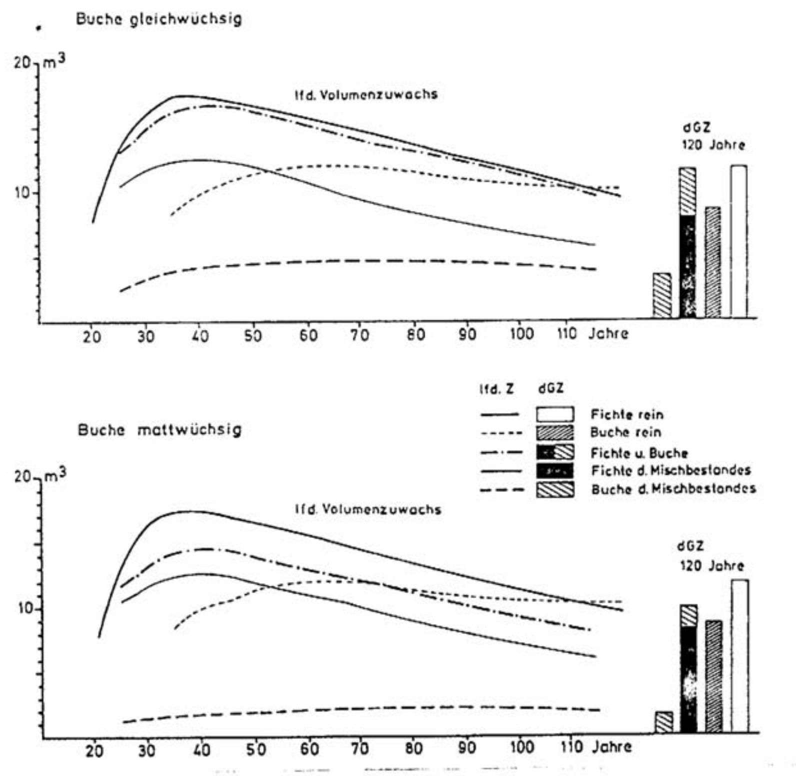


Fig. 4.12.-1. Growth in spruce and beech pure and mixed stands. Buche gleichwüchsig = Beech with high growth; Buche mattwüchsig = Beech with low growth; l.f.d. = mean annual increment dGZ = mean increment at age of 20 years; Volumenzuwachs = volume growth rein = pure; Mischbestand = mixed stand; Jahre = years

SOURCE: Wiedemann 1942. Der gleichaltrige Fichten-Buchen-Mischbestand. Mitt. Forstwirtsch. u. Forstwiss., 13. Reproduced after Schmidt - Vogt 1986, Die Fichte p. 185, Verlag Paul Parey, Hamburg and Berlin.

Kräuter (1958) determined the percentage of current volume increment by species groups based on unique volume series; he proposed a system of unique height curves whose form is not influenced by species and computed types of volumes series especially for the use of forest inventory works.

Theory and methods of current volume increment estimation based on differential calculus were published by Wolf in 1960.

The outstanding Assmann's (1961) work" Waldertragslehre" (The principles of forest yield study) contains numerous information on stand growth. The book was translated in to Polish (1968) and English (1970). Assmann underlined that growth curves have a sigmoidal form and have two common characteristics: (a) they are asymptotical and; (b) they have an inflexion point at age that depends on species and site quality. Assmann developed growth tables and regression equation to determine growth avoiding the measurement of radial growth. In opposition with general opinion Assmann affirms that the accentuated vertical repartition in selection forest resulted in reduction of productivity but this affirmation can be verified only by careful physiological researches. In our opinion this hypothesis of Assmann's cannot explain the one storey structure of multi-aged boreal forests and some stands (multiaged but with one storey) of Scots pine located on peat bogs at higher altitudes in Romania (Alexe 1964).

Weck (1962) completed a short monograph on growth and development of spruce.

In Prodan's (1965) treaty "Holzmesslehre" (Forest mensuration) a special chapter refers to growth determination.

Development curves of growth in some site types are not parallel as site index curves but are sometimes intersected (Assmann 1961, Alexe 1964) and functions for such curves which have a biological motivation are described in 1966 by Erteld and Hengst in "Waldertragslehre" (Forest yield) and are connected with a particular type of growth.

Importance of current increment for forest management was underlined by Hildebrandt (1967).

In 1970-1975 was printed Mitscherlich's encyclopedical work "Wald, Wachstum und Umwelt" (Forest, growth-development and environment) in which functions with biological motivation are used.

Loetsch et al. published their standard textbook on forest inventory in 1973 (Vol.I in 1964) which contains information on growth and volume determination in the case of the use of some techniques.

Wenk (1973/1978) proposed for development functions of growth a new solution based on the percentage of total stand volume current increment. Zimmermann (1974) used new models of percentage growth function whose purpose is to obtain an equilibrium between growth accumulation and extracted biomass from the stand. The relationship between growth, time and weather are examined critically by Wenk and Filder (1977).

Phenomena of growth decline have been extensively treated in the 1980s German literature and as examples will be cited Matzner and Ulrich (1985), "Studies on forest decline cause of the new forest decline in Germany";

Schöpfer and Hradetzky (1986), analysis of increment reduction in declining Norway spruce and silver fir stands (evaluation methods and results); Athari and Kramer (1989), problems of growth studies in beech stands with decline symptoms. A special congress on forest decline was organized at Friedrichschafen in October 1989 with a remarkable number of papers in which this problem was examined extensively but the complexity of the problems made not possible a formulation of conclusions accepted at least by a significant number of participants.

The indicators of yield performance used in pure stands are site classes - judged by volume, height, or mean annual increment and yield level - and the possibility to use these indicators in mixed stands (e.g. Norway spruce and beech, Scots pine and Norway spruce, and oak and beech is discussed in detail by Preuhsler in 1990).

A new book on forest yield was published by Wenk, Antanaitis and Smelko in 1990. In this book there are analyzed a few principles that may provide a good basis for criticising models for pure even-aged stands such as Eichhorn's rule, Langseter's hypothesis and a few recommendations for mixed, uneven-aged stands.

Kramer and Jimenez (1991) analyzed the development of heterogeneous resinous stands using the old method of stem analysis.

Kenk (1992) revealed his conclusions on growth and structural aspects from the data of long-term experimental-plots in mixed stands of south-western Germany.

Spiecker (1992) established which trees represent stand growth.

Pretzsch (1992) used data from stands of Scots pine, fir, spruce and beech to show the increasing discrepancy between expected and actual growth of forest stands in Germany (discrepancies between normal growth behaviour, as expected from yield tables and actual growth). According to Pretzsch forest growth research is "unable to replace the existing yield tables. It is necessary to speed up the process from data acquisition to develop of a usable growth model and future growth models must be flexible so that they can be easily expanded and adapted to changing conditions". In connection with this Vanclay (1994) affirmed: “There are also substantial areas of forest affected by acid rain, nitrogen deposition, and other forms of pollution.” These and other changes in the environment are likely to have a measurable effect on tree growth (i.g. Prezsch 1992).

Preuhsler and J. Mayer (1993) analysing growth of same predominant trees of different species in mixed stands of southern Bavaria, concluded that stem analysis is necessary to try retrospective conclusions about the development of the stand and interesting results are presented and discussed in connection with stem analysis of old oak, beech, hornbeam, birch, spruce, Scots pine and larch from 130 year old mixed stands near Munich.

In 1955 and 1966 Pretzsch, presented the following summary of growth trends of forests in Germany: "Inventories of leaf losses respectively needle losses and investigations of the growth trends in German forests show opposite results: on the one hand, the survey of leaf losses indicates a decreasing vitality since the 1980s. On the other hand, since the 1950s the growth of the main species is even increasing in many forests stands with high leaf losses rising and lies at present considerable above the level rated by the yield tables. Environmental conditions like air pollution, frost and draught causing a decrease of growth are superposed by effects of rising carbon dioxide concentration and nitrogen input, both increasing the growth, so that growth decline below the level of yield tables is merely observed in the high elevations of the German Middle Mountain with heavy inflex of air pollution" and " Repeated forest inventories in Bavaria diagnosed an increase of 20 % of the standing volume and a species specific superiority of the annual volume increment in relation to the yield table of 50-100 %. The national-wide network of long term experimental plots show similar growth trends in other regions of Germany" (p. 275).

Spiecker (1995) analyzed long-term observations on trees growth dynamics in a changing environment.

Height growth investigations of Norway spruce in the eastern part of Germany during the last century have been presented in a short abstract by Wenk and Vogel in1996 in "Growth trends in European Forests".

A general review on growth and yield is included in Prodan's et al. (1997) forest mensuration written in Spanish (pp. 431-465).

Cited authors:

Alexe 1964, Assmann 1961,1968, 1970; Athari and Kramer 1989, Baur 1860, Block 1888, Dieterich 1923, Dittmar 1956. Erteld 1956; 1957; Erteld and Hengst 1966, Heck 1922-1925, Heyer G. 1852, Hildebrandt 1967, Hudeczek 1932, Kenk 1992, Kevlwerth 1954a, 1954b; Kramer and Jimemez 1991, Kräuter 1958, Krenn 1941, Kunze 1878/1884/1888, 1889, 1895/1902/1907; Laer and Spiecker 1951, Loetsch 1953, 1954; Loetsch et. al. 1973, Matzner and Ulrich 1985, Mitscherlich 1956, 1970/1978, Müller U. 1899/1915/1923; Pard, 1959; Paulsen 1845, Peschel 1939, Piessler 1878, Pretzsch 1992, 1995, 1996, Preuhsler 1990, Preuhsler and Mayer 1993, Prinz et al. 1985, Prodan 1944, 1949, 1951, 1956, 1965; Prodan et al. 1997, Richter et al. 1956, Scmidt-Vogt 1986, Schober 1942, Schöpfer and Hradetzky 1986, Schwappach 1888, Schöpfer 1914, Spaeth 1797,1798, Spiecker H. 1992, 1995, Spiecker Mr. 1948, Stinghe and Toma 1958 (Romania), Vanclay 1994 (Denmark); Vanselow 1941/1949, Weck 1948/1955, 1950, 1960; Wenk 1973, Wenk and Fiedler 1977, Wenk and Vogel 1996, Wenk et al. 1990, Wiedermann 1937, 1950/1955; Wolf 1960, Zimmerman 1974.

4.13. Growth and yield modelling

In Germany computerized modelling became a new field of forest mensuration in the early 1960s, partly under American influence where computers and simulation were born earlier.

Among the first German works it should be remembered Assmann and Franz's (1963, 1972, 2nd edn.) the Bavarian preliminary spruce yield tables using the American site index system and based on development functions solved by computer. The structure of new modern yield tables based on computerized mathematical models are discussed by Franz (1966 and 1972), who advocated the use of the American models for yield prognoses.

In 1970, Assmann defined two basic relations $h_m = f(A)$ and yield = f(A) which are valid to stands of a given species, site class and silvicultural treatment. This relations suggest yield = $f(h_m)$ which is Eichhorn`s (1904) rule. In the mentioned relations A = age, h_m = mean height.

Simulation and modelling were developed in Germany in a steady way by: Hradetzky (1972), a model for an integrated system of volume table in modular form; Franz (1973), growth simulation and analysis of necessary energy for growth; Preussner (1974), construction, experimentation and verification of mathematical models applied to stand growth development and diameter distribution; Zimmermann (1974), a proposal for a new method for yield tables whose construction was based on growth function and in 1977 an analysis of spruce yield tables based on new growth model.

"Of considerable theoretical and practical significance is the modelling approach initiated by Sloboda (1971, 1988). This category of growth models is based on differential equations with the rate of growth (dy/dA) being estimated from Y and age, with Y representing the size variable (diameter, height). These models were applied to predict growth but also in predicting the diameter distribution of stands. They can be modified to account for influential external variables such as competition (Nagel 1985)" – comment by Laar and Akça (1997, p. 229).

Butter et al. (1978) constructed and verified spruce stand models with variable density and Tuyll (1982) elaborated a model for the reconstruction of spruce and Douglas-fir growth.

Kenk and Hradetzky developed in 1984 a stand growth simulation model to evaluate the effects of four thinning intensities in Baden-Württemberg Douglas fir stands and presented on the basis of this model: yield, site index and related tables. In the same year a mathematical model for growth and thinning simulation in pure even-aged stand was completed by Römisch (1984) in a dissertation work.

Peerenboom and Petri (1986) analysing yield data for the management of Norway spruce in relation to site and growing space concluded that it is feasible to refine the traditional yield tables and to use differentiated growth models appropriate to site and treatment. They outlined the procedure for constructing these growth models, simulating the desired silvicultural options by varying the initial stand density, and type, intensity and timing of thinnings, and developing simple aids for practical silviculture and management decision-making.

Dong et al. (1989) developed a model for research on forest decline developing two regression equations. Equation with age, site, index, needle loss, a dummy variable representing area, and quadratic and compound variables as independent variables was considered to be more useful.

The programm Stanly 2.0 Nieder was published by Nagel in 1989.

In 1991, Bossel et al. and Bossel (1991) published two papers on simulation and forest stand dynamics using real structure process models. Bossel moving from description to explanation underlined that "Descriptive (statistical) models of forest growth cannot cope with changing environmental and management conditions. Since explanatory models attempt to capture the essential eco-physiological processes of forest growth, they are better-suited for the computation of forest dynamics under changing conditions, even when long term empirical observations are not possible or feasible" (p.129). He analyzed the "requirements of forest simulation models, and essential processes of forest growth, which must be represented in structurally valid models. Steps in obtaining valid by compact tree models for complex forest simulations are outlined and recent software developments (object-oriented programming are assessed with respect to their potential for forest simulation model" (p.129). Bossel mentioned that not all model components must be physiologically-based but eco-physiological and other biological elements should be included (when and where possible) in the key components of models. On the other hand, Vanclay (1994) appreciated that "It is unlikely that there will be a single super-model satisfying all these diverse demand simultaneously, even though it is possible to provide expert systems offering the user problem-specific access to many different models within a single software system. The need is for compact models which provide a valid structural representation with a few state variables, and which provide reasonable predictions over a wide range of conditions" (p. 250/251). Bossel considered since 1991 that in essence "Forest modelling is in a period of transition because of the rapid change in environment”.

In 1994, Bossel developed TREEDYN 3 Forest Simulation Model, a mathematical model that refers to program documentation and simulation results, (University of Göttingen).

Research on modelling pure and mixed beech and spruce stands in Bavaria developed by Pretsch (1991, 1992, 1993) used the single-stem growth simulator SILVA 1. The basic characteristics of SILVA 1 are several functions which controlled the development of height and crown as well as the changes of the basis of the crown, the diameter growth and the mortality of single stem in dependence of their respective conditions.

The simulation problem of growth and yield with an emphasis on mixed stands have been investigated by Preuhsler (1992) and Wenk (1992). Wenk's model, so-called model of stand development, has been developed at the Institute of Growth and Forestry Computer Science (Technical University, Dresden) and can be used for even-aged or two storied pure and mixed stands and the decisive factors for the model are under initial values of stand volume, tree number and stand height at any age, functions of relative volume increment, functions of relative tree number utilisation, and allometrical exponent.

Pretzsch (1996) concluded that growth models for mixed stands represent a challenge for forest growth research. His SILVA model shows the dimensional development of all the individual trees in the stand as a function of their lateral crown restriction on their shading in 5-year intervals.

Verification and validation in forest growth modelling denote usually qualitative and quantitative tests of the considered model. Oreskes et al. (1994) affirmed that verity implies truth, but it is impossible to prove a model "true" except the special case of a closed system. Analysing the problems of verification, validation, and confirmation of numerical models in the Earth sciences Oreskes et al. considered this as impossible: "This is because natural systems are never closed and because model results are always non-unique. Models can be confirmed by the demonstration of agreement between observation and prediction, but confirmation is inherently partial. Complete confirmation in logically precluded by the fallacy of affirming the consequent and by incomplete access to natural phenomena. Models can only be evaluated in relative terms, and their predictive value is always open to question. The primary value of models is heuristic" (Science, 1994, vol. 263, p. 641).

In 1995, Hampel presented a first prototype of an expert system "dendrometry", to be used for single trees and stands applicable as a teaching system and an instruction system which contains text information, calculation examples, supporting graphics and it is based on the structured science tree mensuration in system theoretical presentation.

Kahn (1995) developed a thinning model which can be implemented into distance dependent single tree growth simulator. Röhle (1995) developed a yield model for spruce on high elevations in southern Bavaria, and Moosmayer et al.

(1996) constructed new growth models for beech and source based on detailed analyses of site and environmental factors and current measurement techniques.

Cited authors:

Assmann 1963/1972, 1970, Bossel 1991, 1994, Bossel et al. 1978, Dong et al. 1989, Franz 1966, 1972, 1973; Hempel 1995, Hradetzky 1992, Kahn 1995, Kenk 1984, Moosmayer 1996, Nagel 1989, Oreskes et al. 1994, Peerenboom and Petri 1986, Pretzsch 1991, 1992a, 1992b, 1992c, 1993; Preuhsler 1992, Preussner 1974, Röhle 1995, Römisch 1984, Sloboda 1971, Tuyll 1982, Wenk 1992, Zimmermann 1974, 1977.

4.14. Weight and biomass studies

Early data on weight of wood and bark were published by Baur (1879). In 1898 Schwappach developed investigations on weight and compressive strength of the wood of important trees (spruce, silver fir, white pine and red beech).

Burger (1929/1953) established a relation between the quantity of leaves and growth whereas Hildenbrandt (1953) analyzed variability of wood density in spruce stands, growth and yield of "pure wood". Data on wood (matter) production of vegetal stratum can be found in an article published by Lieth in 1962.

The term "Biomasse" (biomass) was used probably in Germany for the first time by B. von Droste zu Hülshoff - a dissertation work (University of Munich) in 1969 in his analysis of structure and biomass of a spruce stand.

Van Laar (1973) established a relationship between needle-biomass and growth of *Pinus radiata.*

Schulze et al. studied spatial distribution of photosynthetic capacity and performance in a mountain red spruce forest in northern Germany, biomass distribution and daily uptake in different layers (1977 a) and the significance of evergreen habit (1977 b).

Spank (1982) developed sampling studies for the estimation of crown and needle biomass of Scots pine. The crown and branchlet biomass per tree have been regressed on dbh and tree height using a logarithmic transformation of the dependent and predictor variables (Laar 1977, p. 213).

A detailed investigation on biomass was performed in 1986 by Pellinen on beech stand growing on calcareous soil.

Heinssdorf and Krauss (1990) constructed tables for estimating dry matter and nutrient storage of Scots pine stands.

Cited authors:

Baur 1879, Burger 1929/1953, Droste zu Hülshoff 1969, Heinssdorf and Krauss 1990, Laar 1973, Hildebrand 1953, Lieth 1962, Schulze 1977a, 1977b; Schwappach 1898, Spank 1982, Pellinen 1986.

4.15. Tree-ring studies

In 1753, C. G. Schober discovered that the number of rings agreed with the number of branch whorls in a pine tree and he should be considered as the first German pioneer in the field of tree-ring studies.

After more than a century D. F. Unger discussed the basic aspects of the construction of multiannual ring strata in the woody plants. The discontinuity of annual tree rings in the stem of dominated trees was observed in 1869 by R. Hartig who connected later (1895) the double annual tree-ring (Doppelringe) with spring frosts - frost being considered as the cause of this phenomon.

Nördlinger (1871) considered the tree rings as the basis of the tree skeleton (Grundlage des Baumkörpers). Jost (1891) wrote about diameter growth and formation of tree-ring and Wieler (1898) showed the annual periodicity of diameter growth of trees (branches included), but the problem of the cessation o secondary growth will be examined later after five decades by Schober (1951). Walter Gothan (1904) accepted the existence of a connection between formation of annual rings in the fossil stems of Araucariaceae and their geological dating.

In 1917, Antevs published a review (about 350 titles) on the importance of annual tree-rings as climatic indicators. He underlined the fact that multiple rings may result from a number of causes such as: damage to growing tip, damage of storms, defoliations, insect damage, girdling, decapitation, especially favourable following unfavourable climatic conditions (e.g. warm after frost) – rings determined by this group of factors have been called "injury rings".

Annual rings variation of paleozoic trees was discussed in connection with climatic conditions of this period by Gotham Walker (1911).

Späth (1912) confirmed the periodical character of the annual tree-ring growth and its connection with spring shoots (Johannistrieb) in woody summer green plants.

André Hans referred in 1920 to technological and causal explication of tree-ring formation in stems. Some information on tree-rings are given in the excellent book completed by Büsgen and Münch, "The structure and life of forest trees", translated in to English by T. Thomson in 1929.

Weather and wood growth have been discussed in 1934 by Aurén.

In 1938, Krauss and Gärtner presented a cutting machine for the preparation of increment core sections confirming the rising interest in tree ring studies.

Bruno Huber was the first to initiate tree-ring dating studies in Germany, in Europe respectively, in the similar frame of the dendrochronological concepts developed in the U.S.A. by Douglass and his co-workers since 1919.

Huber (1941, 1942, 1943), Huber et al. (1941) introduced dating method which used a semi-logarithmic scale as a rule. Since 1941 was commonly used in central, southern and western Europe but it "does not eliminate the age trend of the ring series which is not very marked in the oak. As a measure for the similarity of two tree-ring curves the value of agreement ('Gleichläufigkeitswert') is accepted. It is defined as the percentage of parallel intervals in two different curves not taking into account the absolute tree-ring width" (Eckstein. 1972, p. 2).

From a historical point of view B. Huber remains the first man who advocated in 1941 the construction of a central European tree-ring chronology ("Aufbau einer mitteleuropäischen Jahrringschronologie").

In 1948, Huber affirmed that tree-rings can help climatology and dating of events, Jazewitsch discussed the possibility of an individual tree-ring diagnosis from dendrochronological point of view and Wallenhofer presented in this dissertation thesis the tree-ring width, variation in the oak Spessart tree-ring chronology.

Next year, for the same species and forest Huber et al. (1949) presented a tree-ring chronology.

Tree-ring chronological and climatological researches on *Pinus cembra* at elevations above 900 m have been developed by Artman (1949) and for larch (Berchtesguederer Landes) by Brehme (1951).

During the 1950-1952 period Huber and Jazewitsch published a short synthesis on practical dendrochronologycal works.

Comparative researches on tree-ring series have been developed by Müller-Stoll (1951) who underlined the influence of slope, species, site and climate on different tree-ring series.

A sample of the early German tree-ring chronologies is presented in the Table 4.15.-1.

One of the first clear dendrochronology was performed by Wita von Jazewitsch for beech from Spessart forest in 1953 whereas one of the early and longest (over 1100 years) in central Europe was constructed by Becker and Giertz-Siebenlist (1970) for fir (*Abies alba*). For the longest but discontinuous chronology Schmidt (1973) used radiocarbon and concluded that the growing conditions in the southern part of central Europe differ from those in northern Germany and suitable oak tree-ring chronologies should be set up for this region.

TABLE 4.15.-1. A sample of early German tree-ring chronologies

Year	Author(s)	Species	Chronology period	Location
1953	W. v. Jazewitsch	*Fagus sylvatica*	AD 1948-1320	Spessart forest, southwestern Germany
1963	O. Fürst	*Picea abies*	AD 1961-1583	South, south western Germany
1965	E. Hollstein	*Quercus robur* *Q. petraea*	AD 339-717 BC AD 1963-383	South, SW Germany
1967	E. Hollstein	*Quercus* spp.	Latin, Roman and Merovingian periods	Rhine, Moselle and Maas areas
1969	B. Huber, V. Giertz-Siebenlist	*Quercus* spp.	AD 1960-832	South and SW Germany
1970	B. Becker, V. Giertz-Siebenlist	*Abies alba*	AD 1965-820	South, SW Germany
1970	D. Eckstein, J. Bauch W. Liese	*Quercus* spp.	AD 1970-1266	Northern Germany
1971	D. Eckstein, W. Liese	*Quercus* spp.	AD 1100-500	North of Hamburg (Haithabu)
1972 a, b	B. Becker	*Quercus* spp.	AD 200-6700 BC discontinuous chronology	South, SW Germany
1972	A. Delorme	*Quercus* spp.	AD 1970-1004	Weserbergland, Lower Saxonia

In 1956, Hubert Bruno and Wita von Jazewitsch presented in a short article published in Tree-Ring Bulletin (U.S.A.) tree ring studies of the forestry-botany institutes of Tharandt and Munich where about 250,000 annual ring widths have been measured since 1938 and so-called Leitz "cross adjustable mount" (Kreuzverschiebungsstativ) was used for the measurements (the microscope was movable and not the studied object such as tree section or increment core).

Their first chronologies refer to:

Taxus baccata	1784 - 1939
Abies alba	1701 - 1950
Picea abies	1642 - 1943
*Larix decidua**	1340 - 1947
Pinus cembra	1573 - 1947
Pinus sylvestris	1961 - 1939
*Quercus petraea**	1224 - 1950
Fagus sylvatica	1661 - 1948

* Dating by radiocarbon has been started (From Tree-Ring Bull vol. 21 p. 29, 1956).

The above-mentioned authors considered *Larix decidua* and *Fagus sylvatica* as the most sensitive species for dendrochronological studies and affirmed that "**By comparing German with Scandinavian spruce and pine there was found a percentage of disagreement of 46.2 and 47.0. Since per cent agreement shows a purely change distribution, it appears that crossdating between central Europe and Scandinavia and even more between Europe and America is impossible**" (our underlining). The hypothesis of Ebba H. De Geer (1956) that the variations in width and varves depend on cosmic factors and therefore agree over the whole earth does not stand up under critical examination. "Each country must set up its own chronologies" (Huber and Jazewitsch, 1956, Tree-Ring Bull., vol. 21, p. 29). After 16 years Eckstein (1972) based on the works of Becker (1972) and Schmidt (1973) in which radiocarbon analysis (C^{14} dating) was used, wrote: "…after whose conclusion a C^{14} comparison between America and Europe will be possible" (Eckstein, Tree-Ring Bull. 1972. vol. 32, p. 13).

Dendrochronological researches have been developed on broad-leaved species in northern Germany, near Hamburg, by Weitland in 1960.

A short summary of European literature on dendrochronology in Europe (Germany included) was completed by Huber et al. in 1961. A more detailed synthesis on tree ring research in Europe was published by Eckstein in 1972, synthesis in which are cited some German works. Eckstein mentioned the following countries which possessed in 1972 dendrochronological laboratories: United Kingdom (Oxford, Belfast), France (Caen), Belgium (Louvain), Germany (Cologne, Trier, Hamburg, Göttingen, Stuttgart, Munich, Berlin), Norway (Oslo), Sweden (Lund, Stockholm), Italy (Rome), Finland (Helsinki), former U.S.S.R. (Kaunas, Moscow), former Czechoslovakia (Zbraslav), Poland (Warsaw).

In 1972, Eckstein affirmed that "The establishment of chronologies alone has lessened in importance, of major interest today is the solution of archaeological history on the basis of existing chronologies" (Tree-Ring Bull., vol. 32, p. 13), but his opinion was not valid a long time especially in other parts of the World such as the United States.

The German scientist covered almost all subjects of dendrochronology.

Methodological aspects have been discussed and developed by: Huber (1952, 1954); Jazewitsch (1952); Abetz (1960); Fürst (1963) - he "tried to interpret the tree-ring width of fir, spruce, beech and oak of various proveniences and different periods of time concerning their climatological evidence. The mean sensitivity served as a parameter"; Eckstein and Bauch (1969) - correct identification of tree-ring early sequences, synchronization (of tree ring series) has been rationalized by the use of computers and the use of electrical portable generators for Pressler type borers;, Jähring (1972) - basic principles of dendrochronology and its limits.

DENDROCLIMATOLOGY. According to Jazewitsch (1961) there is in Germany a positive correlation between tree-ring growth and temperature during May, June and July in the case of a larch forest located on the alpine timber line. For correlation with precipitation she used a pine wood near Würzburg (very warm and dry climate for the central European conditions) and the result was a positive correlation with the rainfall during the April - July period. Elling (1966) proved that "the growth of alder (*Alnus glutinosa*) was affected by temperature in a southern German site before the growing season and rainfall during it". On northern German sites half of the tree-ring variations of oak trees were explained due to the influence of climatic fluctuations with the predominance of temperature influence (Eckstein and Schmidt (1974). After Brandson (1976) tree-rings are the key for the determination of past climate. Some dendroclimate studies on conifers from Germany and Great Britain have been completed in 1979 by Schweingruber et al. The influence of temperature and precipitation on vesel area and ring width of oak and beech was investigated by Eckstein and Frisse in 1982.

DENDROARCHAEOLOGY. Lerchenfeld (1954) analyzed the dating possibility of buried oak wood. Eckstein and Liese (1971) investigated medieval urban-excavations of Haithbau (150 km north of Hamburg) which belonged to the largest trading center in northern Europe during the time of the Vikings and constructed a relative chronology using oak pieces. Jahrring studied in 1971 wood samples from a Slavonic settlement near Neubrandenburg in eastern Germany.

ARCHITECTURAL HISTORY. Jahring (1972) published the first results on dendrochronological examination of a 16th century castle. Delorme (1972) constructed Weserberg-land oak chronology - a German frame-work architecture in Lower Saxonia - data based on oak building material. The first work in the field should be Jazewitsch (1954/1955) attempt to date oak beams. Dendrochronological researches in historical buildings have been carried out also by Huber (1962). Using dendrochronological methods Liese und Bauch (1965) dated (AD 1378) the "Hanse-Kogge" ship, in the harbour of Bremen, ship that was built at the time of Hanseatic navigation.

Hollstein investigated for dating materials from a Roman house (1966) and from Trier and Speyer Cathedrals (1968).

The use of dendrochronological methods in art history was practised (probably firstly in Germany) by Lottermoser and Meyer (1958) in the area of forgery of the Italian string instruments constructed by the masters of 17th and 18th centuries. The tree-ring analysis of suspected forgery violin centuries was compared with tree-ring curves of the violins of the same master and that are genuine without any doubt. Holstein (1970) dated (AD 1222-1330) and established the authenticity of "Luxuria" a medieval carving work suspected to be a forgery. The techniques of dating sculptures carved out of wood and especially the frames of paintings was summarized by Bauch et al. in 1974.

Occasionally, dendrochronology can be used in detective and legal problems (Liese and Eckstein 1971).

Dendrochronological investigations in the field of dendrogeomorphology (the term coined in Finland by Alestalo in 1971) have been completed in Germany by Becker (1972a, 1972b) who analyzed subfossil trunks of oak trees for the purpose of establishing the paleogeographical changes of the river system (the Danube, Main and Rhine). Becker developed 15 floating chronologies (series up to 650 rings) based on radiocarbon dating and covering a period from 6700 BC to AD 200.

DENDROECOLOGY. Pollanshütz (1971) considered that dendroecology became a special discipline of environmental control. With the analysis of tree-rings the beginning of the damage can be determined and the decrease of growth can be calculated. Dendroclimatological researches have been connected with tree decline phenomena, such as missing rings in the lower part of the bole of spruce (Athari 1980) and the decline of fir (Eckstein et al. 1983), beech (Eckstein et al. 1984), and spruce (Bauch et al. 1985). Eckstein and Krause (1989) used Norway spruce trees to monitor environmental changes around Hamburg.

Among more recent works in German dendrochronology will be mentioned Mattheck and Breloer's (1992) paper about the root cross-section as a record of load history (tension, bending and combined tension and banding) that could be used for failure analyses in forensic of windbroken or windthrown trees (cited after Forestry Abstract 1993, vol. 54, 110.10, summary 7387).

In 1995, Riek et al. analyzed the relation between water budget and annual ring growth of old Scots pine in Berlin Forests using spectral analytical interpretation.

Connections between climate and increment have been investigated by Makkonen-Spiecker (1996) in the case of *Picea abies, Abies alba, Fagus sylvatica, Quercus petraea* and *Q. robur* in the Black Forest, the Vosges and Lothringer in order to develop climate/increment models on the basis of X-ray densitometric measurements, cell structure and isotope analyses.

INSTRUMENTS. Johann (1977) described two types of the "System

Digitalpositiometer", a new device for measurements of tree rings, borer samples and stem cross sections. The device is manufactured by the Austrian firm Kutschenreuter. In 1992 Bräker introduced an instrument for measurement of rings widths similar with Eklund device but with the advantage that adjustment of increment core is not necessary. In the same year Lega (1992) introduced the dendrograph "SMU 3" with a confirmed accuracy of 0.01 mm. Roth and Wilpert (1992) developed the computer package "ARISA" (Automated Ring Sequence Analysis) based on digital image processing, enabling the user to measure simultaneously a large number of radials on stem cross sections. A measuring device using polar co-ordinates with an accuracy of 1/1000 mm and 1/100 described by Taube and Sloboda (1992) is a multi-purpose instrument but proper first of all for the measurement of tree-ring widths on stem discs or on photographs.

Cited authors:

Abetz 1960, Alestalo 1971 (Finland), André 1920, Antevs 1917, Artman 1949, Athari 1980, Auren 1934, Bauch et al. 1974, Bausch et al. 1985, Becker 1972 a, 1972 b; Becker and Giertz-Siebenlist 1970, Brandson 1976, Brehme 1951, Büsgen and Münch 1929, De Geer 1956, Delorme 1972, Eckstein 1972, Eckstein and Bauch 1969, Eckstein and Krause 1989, Eckstein and Liese 1971, Eckstein and Schmidt 1974, Eckstein et al. 1983, Eckstein et al. 1970, Eckstein et al. 1972, Eckstein et al. 1983, 1984, Elling 1966, Fürst 1963, Gothan 1904, 1911; Hartig R. 1869, 1895; Hollstein 1965, 1966, 1967, 1968, 1970; Huber 1941, 1942, 1943, 1948, 1952, 1954, 1962; Huber and Giertz-Siebenlist 1969, Huber and Holdheide 1942; Huber and Jazewitsch 1950/1952, 1956; Huber et al. 1961, Huber et al. 1941, Huber et al. 1949; Jahring 1971, 1972a, 1972b; Jazewitsch 1948, 1952, 1953, 1954/1955, 1961; Johann 1977, Jost 1891, Krauss and Gartner 1938, Lega 1992, Lerchenfeld 1954, Liese and Bauch 1965, Liese and Eckstein 1971, Lottermoser and Meyer 1958, Makkonen - Spiecker 1996, Mattheck and Breloer 1992, Müller-Stoll 1951, Nördliger 1871, Pollanschütz 1971, Riek et al. 1995, Roth and Wilpert 1992, Schmidt 1973, Schober C. G. 1753, Schober Reinhard 1951, Schweingruber et al. 1979, Späth 1912, Unger 1847, Weitland 1960, Wellenhofer 1948, Wieler 1898.

4.16. Application of mathematical statistics in timber mensuration

In *sensu lato* "biometrics" implies, especially since the foundation of English journal "Biometrika" in 1901, a combination of all those mathematical methods giving a quantitative explanation of "life's processes" and "means the combination of all statistical methods of regarding and describing the processes of life". Forest biometrics embraces, in addition, the evaluation of the main fundamentals of the natural laws and the methods of mathematical statistics that are important to forestry (Prodan 1961, p. 5, 2).

During the 18^{th} and 19^{th} centuries biometrics was used "in the present day sense, even though the simplifying methods of mathematical statistics which had not yet been developed - could not have been consciously applied" (Prodan 1961, p. 7).

Among old workers in forest mensuration or in the fields connected with it (such as forest management) should be mentioned: Oettelt (1765) - who presented practical arguments for use of mathematics in forestry; Hennert (1791/1795) and Hartig G. L. (1795), the use of mathematics in forest management; Paulsen (1795); Spaeth (1797); Cotta (1804).

In 1804, Schlözer published his "Theorie der Statistik"; König (1813), showed how to apply mathematics in forestry, especially in forest mensuration; Hundeshagen (1826); Bavarian volume tables (1846); Karl Heyer (1846), recommended the use of statistical methods in forestry; Langenbacher (1875) published a remarkable textbook on "Forestmathematik" and Zetsche (1891) used circular plots as sample units in forest inventory.

Herman Hollerith, who worked in the U.S.A. in 1880-1882 on a population census, invented punched cards method but the first Hollerith machines were introduced in Germany by the year 1911 and used on a large scale by "Statistiches Reichsamt" and later in forest surveys.

Hohenadl (1923/1924) expanded the use of statistics in forest mensuration.

In 1925, Tscuprow developed the basis of correlation theory with large implications in forestry whereas Rietz (1930) published a handbook on mathematical statistics. Statistics was applied also by Weck in 1932 in volume determination.

In 1935, Stan Kusal used biometrical methods for study of stand structure. Forest research was also influenced by textbooks on the application of statistics in biology (Ringleb 1937) and research in general (Behrens 1933).

In 1938, Krutzsch and Loetsch published the first book of forestry based on mathematical statistics.

Mathematical statistics for foresters (instead of forest mathematics) was introduced by Krenn (1908-1949) as a subject for study. Krenn was the founder of Freiburg seminary which become the Society for Work in Forest Biometrics in 1953 (Prodan 1961, p. 9)

Prodan (1944) discussed statistical and mathematical aspects of stem form and decreased distribution of trees in uneven-aged stands. In a dissertation (University of Freiburg), Halla (1947) developed statistical researches in spruce stands.

A "Forstmathematik" (an old and long time preferred term in German literature) in forest research and education was published by Hopmann in 1951. The problems of mathematical statistics have been analyzed by Prodan (1952), Richter et al. (1953) (applications in forest inventory), Vanselow (1953), Keylwerth (1954) and in Luckey-Treusch's contributions "Nomographie"

(1954), Erna Weber's (1957) elements and principles of statistics in sciences of nature and medicine, Mudra's (1958) statistical methods for research in agriculture and Beckmann's (1959) linear programming influenced favourably the application of statistics in forestry.

In 1961, Prodan published an excellent textbook on forest biometrics: "Forstliche Biometrie" (Forest Biometrics – translated into English in 1968 by Sabine Gardiner) in which numerous examples of application on statistics in forest mensuration are given.

The one of the most important statistics is "s" (standard deviation) which can be estimated (s_{est}) (by the formula $s_{est} \approx (x_{max}-x_{min})/4.5$ using a reduced number of determination (x_{max}=maximum value, x_{min}=minimum value). The general relation is $s_{est} \approx (x_{max}-x_{min})/2\alpha$ because in the case of normal distribution almost all values are located in the interval $\bar{x} \pm 3s = 6s, \bar{x} = mean.$. Prodan (1961) recommended the following values of α.. depending on the number of observations (n):

n	5	10	20	30	40	50
2α	2.2	3.0	3.7	4.1	4.3	4.5

Loetsch and Haller (1964) underlined the fact that x ± ts depend on the type of distribution so if t = 2 (Student statistics) then the following probability of observations is located in this interval:

- any type of distribution 0.75 (75 %)
- generally any unimodal distribution with two descending tails 0.89 (89 %)
- normal distribution 0.95 (95 %)

These considerations have been remembered in this text due to their practical importance especially in forest inventories where should be determined the MRE (minimum reliable estimate) which is

$$\bar{x} - tS_{\bar{x}}\% \quad \text{and} \quad \pm tS_{\bar{x}}$$

representing the accepted error (Alexe and Milescu 1983).

New statistical works were completed after 1960, some of them referring to forest mensuration: Liebold (1962), a new procedure for the determination of the constant of Backmann's function; Statistical programmes of the German Calculation Centre, parts A and B (1969) which represents a collection of statistical standard programmes in FORTRAN IV; Rowat and Franz (1974), detailed non-linear asymptotic regression studies on tree and stand growth with particular reference to forest yield research in Bavaria; Sloboda (1976), Kolmagorow - Suzuki and stochastic differential equations; Sacks (1978), Practical Statistics - 5th edn.; Hradetzky (1980), spline function and its utilization in forest research.

Cited authors.

Anonymous 1846 (Bavarian volume tables), Beckmann M. 1959, Behrens 1933, Cotta 1804, Deutsches Rechenzentrum 1969, Halla 1947, Hartig G. L. 1795, Hennert 1791/1795, Heyer K. 1846, Hohenadl 1923/1924, Hopmann 1951, Hradetzky 1980, Hundeshagen 1826, Keylwerth 1954, König 1813, Krutzsch and Loetsch 1938, Kusal 1935, Langenbacher 1875, Liebold 1962, Loetsch and Haller 1964, Luckey - Treusch 1954, Mudra 1958, Oettlet 1765, Paulsen 1795, Prodan 1944, 1952, 1961, Rawat and Franz 1974, Richter et al. 1953, Rietz 1930, Ringleb 1937, Sachs 1978, Schlözer 1804, Sloboda 1976, Spaeth (Späth) 1797, Tschuprow 1925, Vanselow 1953, Weck 1932, Weber 1957, Zetsche 1891.

4.17. Forest inventory and remote sensing

4. 17. 1. Forest inventory

In Germany "During the early period the collection of area-related tree information only aimed at the assessment of the total growing stock. This information was fully satisfactory, because during the 18th and the beginning of the 19th century the demand for fuel was far greater than for saw-timber. The whole forest estate was divided into "Forstorte" which served as units of assessment and the total growing stock per hectare in each unit was visually estimated. The visual estimate was checked by the yield from felled sample areas. The learning of visually estimating the growing stock per unit area was then part of a good training in forestry. The method was extremely simple and cheap. It was in use for instance in the state forest of Saxony until the forties of this century (20th), where it had been developed to a high degree of unequaled perfection"… The first sampling methods in forestry date back to the end of the 18th century. During the 19th century the occasional use made of sampling methods the common way for obtaining estimates for single stands. As an example,K. Zetzsche (1891) describes a statistically perfectly sound sampling method by circular plots" (Loetsch and Haller 1964, p. 7).

In Germany, for a long period of time like in other Central European country, (see 3, France) there were used compilations of data from individual states or districts. The first such investigation was completed in 1878 and planned to be repeated every ten years.

According to Pelz (1993), in West-Germany the last such compilation was made in 1961 whereas in the former Democratic Republic large scale inventories were designed and implemented in the 1960s. Pelz underlined that “The compilation of data from stand or management inventories is not without problems, since many examples show it was found in several cases that objective sampling inventories had results that were 20-30 % above the results from adding up these lower level inventories. Combining data from diverse sources is problematic, as errors will go unchecked and often unnoticed” (p. 11-12).

In 1978, in the Federal Republic of Germany, the Federal Ministry for Nutrition, Agriculture, and Forestry commissioned a specialized committee to elaborate a national forest inventory for the country based on sample plots (Koehl 1996, p. 358).

This national forest inventory started in 1985. “The system used is modelled after the tract systems of the Nordic Countries, a tract being a square with 150 x 150 m, the tracts were distributed systematically with a grid of 4x4 km in some states or regions the number was doubled with a grid of 2.83 km or quadrupled with a grid of 2 x 2 km. In the corner of the tracts relascope points and regeneration plots are located. Line sampling is used for area calculations and road inventory. The tracts are marked permanently to allow remeasurements” (Pelz 1993, p. 13).

Koehl (1996) noted the following characteristics which deserve to be mentioned for a better understanding of German first national inventory: “Square clusters with 600 m long sides centred on the intersection points of the grid are surveyed. The sides of the tracts serve as assessment lines for the determination of stand boundaries, stand characteristics and an inventory of roads and path. At each corner of the tract sample stems (dbh >10cm) are assessed through angle point sampling using a factor of 4, and young growth is surveyed over a concentric plot (r = 1.2 or 4m)… where the centre of an angle point sampling plot lies close to the limit of a forest area or stand, the mirror image of the centre is located and sample trees distributed around it are selected. For each sample stem the location is recorded from the azimuth and horizontal distance, and the species, age, the stand, and damage are documented. As well as dbh and overall height, diameter at 7 m is measured with either calipers or a relascope” (p. 358).

Since the beginning of the forest mensuration a high attention was paid to plot problem. In 1950, Wiedeman published the results of 75 years work on research plots in northern Germany and laid down the basis for silviculture on a quantitative basis. Accustomed with the plots used in silviculture it was normal that the idea to use them in forest inventory prevailed. Since Zetsche`s time (1891) it seams that circular plots were preferred.

Researches on circular plots and point (plotless) sampling in forest inventory were developed by Richter and Grossman (1951, 1959). The problem of sample plots was discussed by different authors such as Akça and Sangen-Emden (1986) - optimization of representative stand surveys); Keller (1987) - recommendation to take in account the site characteristics when plots are located; Kirchhoff and Hess (1987) - possibilities of permanent marking of the position of sample plots); Schabenger (1991) - a measure for the efficiency of cluster sampling.

The aspects of sample representativity and statistical techniques applied in forest inventory were analyzed by many authors but only a few of them will be mentioned: Prodan (1953), (1955), (1958), (1965); Richter et al. (1953); Moser (1958); Haller (1968); Zöhrer et al. (1982); Ulbricht and Richter (1984); Ulbricht (1987); Pommerening and Lewandowski (1997) - a new approach to the simulation of sampling methods in inventoried, mixed, uneven-aged forest stands; the method permits the estimation of sampling errors in relation to sample size and method used.

In the first volume (1964) of one of the most valuable German textbooks on forest inventory Loetsch and Heller presented exercises with the following basic systems of selection: 1) unrestricted random lay-out of sampling units; 2) restricted random lay out of sampling units; 3) restricted random lay-out of sampling units with blocks of equal sizes (stratified random sampling); 4) restricted random lay-out with optimum allocation of sampling units (stratified random sampling); 5) random and restricted random sampling by strips of unequal length; 6) the sampling by plots on lines; 7) the lay-out of sampling units in clusters as a multi-stage or sub-sampling; 8) two stage sampling; 9) three stage sampling; 10) systematic lay-out of sampling units; 11) sampling of populations with qualitative characteristics; 12) multi-phase sampling; 13) sequential sampling.

German literature on forest inventory is represented by a large number of papers containing comments and proposals in this field. Only a small number of these works will be mentioned in this text: Ulbricht and Grossman (1978) - National forest inventory in DDR, problems and purposes; Zöhrer (1978) - National forest inventory: goals, concepts, changes; Hildebrandt (1981) - proposal for a permanent European forest inventory system; The West German National Forest Inventory (1986) - a collection of 8 papers on the legal basis, basic inventory procedures, history of forest surveys in Germany, limits, organization and execution of the current inventory, and determination of volume and assortment volume from the inventory data; Pelz and Cunia (1985) - national forest inventories in Europe, with references to Germany; Schwenke (1985) - the West German Federal Forest Inventory: a political necessity with underline of the role of such an inventory in the setting of forest policy goals; experience with national inventories in Switzerland, Austria and Sweden; Tzschupke (1986) - national forest inventories in some countries neighboring the German Federal Republic: Sweden, Austria, France and Switzerland - comparisons with sampling procedure; Kennel (1987) - experience in carrying out the 1970/71, Bavarian forest inventory - details on the planning and execution; Kohl (1987 - Switzerland) - National forest inventories in Europe with references to Germany; Smaltschinski (1990) - point sampling at stand boundaries; Kleinn (1991) - the definition of forest in large-scale forest inventories, comparison of the various definitions of forest used for national forest inventories in 15 European countries and FAO; conclusion: it is very difficult to present the results of different inventories in a strictly comparable form; Köhl and Pelz (1991) - forest inventories in Europe with special reference to statistical methods; Tzschupke (1991) - management inventory of forest condition on an enterprise basis or on a stand basis ? Reply: at present time the most appropriate procedure is a combination of inventories at the stand level with sample inventories at the enterprise level" For. Abs. 1835/1993; Pelz (1992) - National forest inventory: past development and future prospects; Dahm, Akça and Saborowski (1997) - a three phase sample design for the German Federal Forest Inventory.

The first use of inventory data for assessing growth was attributed by Erteld and Hengst (1966) to R. Weber (1881). In 1949, Kreutzinger defined the increment on large areas. Grossmann (1959) presented the results of forest inventory (1951) of standing trees and their growth in selection forest Keula. In 1977, Stage established the connection between forest inventory data and the construction of growth models.

As a result of forest decline phenomena during the 1980s and 1990s appeared the necessity of a new type of forest inventories: forest inventory and monitoring of endangered forests. Infra-red color aerial photographs were used for determination of forest damage since the mid 1960s. The ECE worked out guidelines for Forest Damage Surveys and in 1988 most European countries followed these guidelines in assessing forest decline. In Germany (FRG) sampling design was 4 x 4, 8 x 12 km, 24 trees/plots (Koehl 1996). An important problem of these inventories and monitoring works was that of the choice of reference tree. Koehl (1996) underlined that "In most cases nobody knows how the perfect healthy tree looks like. In some countries (e. g. Switzerland, Federal

Republic of Germany) field crews are provided with color photographs to help them in diagnosing and classifying forest damage" (p. 361).

In 1987, Köhl summarized the current status of methods for the inventory and monitoring of endangered forests. This review of methods refers to "remote sensing and aerial photography, by ground inventory and by combined inventory methods…it is concluded (data from 9 countries) that the present situation does not ensure comparability between inventories in different countries and in different years and that a procedure should be developed for an international (EC) forest-damage inventory" (Abs. 5682/1990).

We reproduced here the ECE guidelines for forest damage survey taking into account its importance from technical but in the same time historical importance:

Defoliation			Discoloration		
class	needle/leaf loss	degree of defoliation	class	foliage discolored	degree of discoloration
0	up to 10%	none	0	up to 10%	none
1	11-25%	slight	1	10-25%	slight
2	26-60%	dead tree	2	26-60%	moderate
3	>60%	severe	3	>60%	severe
4	11-25%	moderate			

Kublin (1987) developed statistical models for the evaluation of forest damage inventories: assessment of methodologies. "With average needle loss as dependent variable, the classic linear regression model combined with a visual check of the data and results is a suitable and effective method for study of correlations…with the local damage class distribution as response variable, the correlations from the 1985 forest damage inventory in W. Germany were studied using the LOGIT and cumulative LOGIT models, which generally confirmed the relationships established using the linear model" (For. Ab. S465/1987).

An inventory of forest decline and game damage in Sulzschneider forest, Füssen forest district, was described by Franz, Pretzsch and Smaltschinski (1991).

A short but consistent paper was completed by Kochl (Switzerland 1996) on National inventories and inventories of endangered forest in Europe with references on Germany.

A list of selected German texts (books and textbooks) on forest mensuration is presented in table 4.17.1.

Table 4.17 - 1 Selected German texts on forest inventory

Year	Authors (s)	Title	Editor, place
1938	F. Loetsch, H. Krutzsch-	Holzvorrats inventur und Leinstungsprüfung der naturgemässen Wald -- wirtschaft (The inventory of forest and its natural productivity), 164 pp.	Neudamm
1964	Loetsch, F., Haller, K. E., Zöhrer, F.	Forest inventory Vol. I, 436 pp.	B.L.V. Verlagsgesellschaft, München-Basel-Wien
1973	Loetsch, F., Zöhrer, F. , Haller, K. E.	Forest inventory Vol. II xiv+479 pp.	B.L.V. Verlagsgesellschaft, München-Basel-Wien
1980	Zöher, F.	Forstinventur. Ein Leitfaden für Studium und Praxis (Forest inventory. A textbook for study and practice), 207 pp.	Verlag Paul Parey, Hamburg, Berlin.
1986	Vries, Pieter G. de	Sampling theory for forest inventory: a teach-yourself course, 399 pp.	Springer-Verlag
1987	Kramer, H., Akça, A.	Leitfaden für Dendrometrie und Bestandesinventur (Textbook for dendrometry and inventory of stands) 2nd edn., 251 pp.	J.D. Sauerläder's Verlag Frankfurt a. M.
1993	Köhl, M.	Forest inventory. In: Pancel, L. (ed.) Tropical Forestry Handbook. pp. 243-332.	Springer Verlag, Heidelberg
n.d. (1992-93?)	Anonymous	Bundeswaldinventur 1986-1990 (Federal forest inventory 1986-1990), 118 pp.	Bundesministerium für Ern..Landwirt u. Forsten
1995	Dahm, S.	Bundeswaldinventur-Ausvertungs-modelle und Vorschläge zur Effektivitätssteigerung (Federal Forest Inventory-models for evaluation and proposals for increasing efficiency)	BFA für Forst und Holzwirtschaft Hamburg

All these texts are valuable but the most extensive - textbook with monographical structure - remains "Forest inventory" written by Loetsch, Haler and Zohrer in two volumes (1964 and 1973). For many years this text was considered a classical textbook compared with the American Spurr's "Forest inventory" published in 1952 by Roland Press, New York. From a technical point of view Loetsch's book contains basic techniques in forest inventory which in many cases remain valid until today but from many points of view it is under the level of this discipline at the end of 20 century when the importance of remote sensing and GIS in forest mensuration became notable. The first volume of Loetsch-Haller book refers to statistics of forest inventory and information from aerial photographs at 1964 level while the second volume (1973, with Zöhrer as the second co-author) refers to inventory data collected by terrestrial measurements and observations, data processing in forest inventory, the sample plot, plot less sampling, regeneration survey, list sampling with unequal probabilities, planning, performance and field checking of forest inventories.

Loetsch and Haller defined the term forest inventory as follows: “forest inventory is the tabulated, reliable and satisfactory tree, information, related to the required unit, respectively units of assessment in hierarchic order: an essential feature of a forest inventory is the assessment of the size of the area of each unit of assessment and in many instances the delineation of the locality of the units of assessment on a forest map. The object of the inventory prescribes the kind of tree information that must be obtained and the required precision of the area-related tree information for each level of assessment. The forest inventory has in common with the inventory in industry and commerce that the collected information is vital for the planning of a balanced economic development” (Vol. I, p. 3 and 4).

Dahm (1995) and Dahm, Akça and Saborowski (1997) proposed a three phase sample design for the German Federal Forest Inventory. This procedure is based on terrestrial surveys in single sample plots overcame shortcomings with cluster sampling for the forest inventory in Germany. The main inventory characteristics are forest area and standing volume. The first phase is based on Landsat-5 TM data and 1x1 km grid the inventory area being divided in three subclasses: certain forest, certain non-forest, overlap. In the second phase, a systematic sub sample is taken from the first-phase sample points in each of the three sub-classes. For the third phase, each of the three sub classes from the first phase is stratified into growth zones and age classes. In every stratum again a sub sample of the second phase sample points was chosen. Each sample point selected for the third time was the centre of a terrestrial sample plot. The expected standing error of the forest area was estimated at 0.7 %. With 6108 sample plots covering the FRG area the same sampling error was achieved as with the survey of proximally 6000 clusters including 15000 sample plots (For. Abs. 9445/1996 and 1824/1998).

German were speaking about multi resource inventories since the late 1970s. In 1978, Pelz presented an automatic data processing system for multi resource inventories (MRI) and next year he discussed about integrating timber and wildlife habitat inventories (Pelz and Thom 1979).

The necessary development of forest function mapping as the result of the greatly increased importance of the functions of recreation was underlined during the 1970s.

In 1996, Ebervin presented an account of the inventory of forest biotopes carried out on all Federal property in Germany including military exercise areas “which are often important habitants or refuges for rare and endangered species“.

Century report for Germany included in the Study on European Forestry Information and Communication System was completed by Kleim et al. (1997) and the MRI questionnaire was finalized by Schmitz (1997).

Quantitative characterization of the shape of forest areas based on three groups indices (perimeter related measurements, neighborhood indices and the fractal dimension) was developed by Traub and Kleinn (1997).

In Germany the institution in charge with MRI is Bundesministerium für Ernahrung, Landwirtschaft. MRI national objectives are timber and environment.

4. 17. 2. Remote sensing in forestry and GIS

Terrestrial photogrammetric mapping known as Messtisch - Photogrammetrie was developed in the 1850s almost simultaneously by the French Laussedat and the German Meydenbauer. This method was replaced by stereoscopic measuring device which was constructed in Jena by Pulfrich who was considered as the father of stereophotogrammetry and under his direction Zeiss optical instruments at Jena built the first Stereokomparator (1901), a Feld-Phototheodolit (1904) and the Zeiss Stereoautograph. In this period, before the turn of the century, black and white panchromatic films exposed to visible wavelengths of light were used in balloon photography for forestry purposes (Anonymous 1887).

In 1911, Hugershoff, strongly interested in photogrammetry, was appointed professor of Geodesy at Tharand where he developed the basic researches for the application of aerial photography in forestry and vegetation mapping. It should be noted that the Tharandt school started the first studies on the relationship between crown diameter and dbh, based on air photos.

The early aerial photography was applied in forestry and vegetation mapping by Hugershoff (1920, 1923); Zierau (1920), Hilf (1923), Ewald (1923), Rebel (1924), Krutzsch (1925), Weissker (1927), and between 1918 and 1926 a remarkable number of forests had been photographed in Germany (Hildebrandt 1933 p. 198 and 199).

In 1925, Krutzsch published the first detailed study on the aerial photographs in the service of forest management.

In 1928, Zieger presented the results of the determination of stand volume from aerial photographs with the help of the Hugershoff-Heyde Autocartograph. He plotted crown diameter over stem diameter for 2015 Scots pines and concluded that a straight line relationship existed between the two variables up to a stem diameter of about 12 inches, but in the case of largest trees (12-14 inches dbh) the diameter of the crown was constant for the various stem diameters (averaging about 13 feet).

Among the papers published in the 1930s it will be mentioned Müller G. (1931) - stereophotogrammetrical measurement of the stand; Jacobs M. R. (1932) - the aerial photograph in the service of forest management with the proposals for their development especially in undeveloped countries (a dissertation, Bufra, Dresden) - Jacobs insisted on height and stand profiles for volume determination; Hugershoff R. (1933) - a general perspective on the use of photogrammetry in determination of wood volume; Neumann C. (1933, 1934) - crown counts on the aerial photographs and the use of stand profiles instated of average height for stand volume determination. A summary of the developments of survey and forestry in Germany was published by G. S. Andrews in Canada.

“Under the unfavorable circumstances of 1939-1949 period the progress in aerial photography for forest purposes was slow. Nevertheless a few facts are still noteworthy “ out of which Hildehrandt (1933, p. 200) noted: “In a task force of the German forces, German and Austrian foresters, geographers and photogrammetrists developed simple methods for a quick assessment of the timber resources in the occupied lands of Eastern Europe and produced “large quantities“ of controlled photo mosaics for military and administrative purposes “.

In spite of the marginal improvements in aerial photography the progress in sensor technology was considered by Hildebrandt (1933) as “epoch-making“: Kodak and Agfa produced black-and-white infrared films, Agfa was working on a color infrared film and “ on the basis of thermal-IR-radiation Weihe developed KIEL for the German Air Force, a remote sensing system for vision at night which was actually functioning. It fell into Allied hands in 1945 and was subsequently used to produce the first thermal infrared remote sensing systems of the USA. The third new sensor system was devised in Britain in 1940. It was called RADAR (radio detection and ranging) and was used for early detection of enemy ships and planes and the first imaging airborne PPI (plan position indicator) to provide the pilot with a real-time continuous “map“ of the ground below the airplane. Radar is based on the reflection of radio waves from solid material: a phenomenon which Hertz in Karlsruhe had described as early as 1889. A prototype detector for radio waves reflected in this way has already been constructed and patented by another German, Hülsmeyer, in 1904. In the 1950s radar was further developed by the North American companies into imaging systems such as SLAR and SAR. In the first postwar decades photographic airborne remote sensing became accepted almost everywhere. Dutch foresters who worked in the tropics as well as the Czechoslovakian photogrammetrists and foresters resumed the use of aerial photogrammetry immediately after the war, whereas Allied regulations prevented their colleagues in West Germany and Austria from doing so until 1950, and in East Germany even until 1955.(after Hildebrandt 1993 p. 200 and 201).

In 1952, Forstarchiv dedicated a special number on forest photogrammetry (23).

Glaser (1953) used photography for determination of wood in stere. Krause (1955) discussed plant-sociological interpretation of aerial photographs. Hildebrandt (1956) showed the present position of air photo-interpretation for management and mensuration. A booklet on the introduction in forest photogrammetry was signed by v. Laer in 1956. Hildebrandt analyzed the choice of photo scale and film for aerial photography of forests (1957a), and examined the determination of working-plan data with the help of aerial photography (1957).

Stereomapping was used in mountainous forest areas, especially in Bavaria. Regular use of orthophotomaps was begun in 1968. Very important for detection and monitoring of forest diseases was the introduction of color infrared photography (CIR) from the mid 1960s.

It is interesting and deserve to mention that in 1984 Barnes was working on forest ecosystem classification and mapping in Baden-Wurttemberg.

Akça (1984) estimated growth using crown measurements from aerial photographs. He established regression equations for estimating 5 yr d.b.h. increment from aerial crown width and area, and for estimating 5 yr basal area (b.a.) increment from crown area. Regression equations were based on relations between crown estimates from photographs (length, width, area and volume and measurements made on the ground (crown width, dbh in 1983 and dbh and b.a. increment between 1978 and 1983)).

Dendrometric evaluation of aerial photographs of Scots pine stands for inventory purposes was completed by Spellmann (1986), who compared ground based and aerial photographic stand data for identical plots and derived regressions for the evaluation of stem number, stand height, basal area, stoking and stand form factor.

Akça and Zindel (1987) estimated stand volume through digitized aerial photograph data and regression models using the example of Norway spruce.

Possibilities of using aerial photographs for inventories of timber growing outside the forest were experimented by Ott (1987) mainly in the form of poplar. Aerial inventories proved to be superior in terms of accuracy and can be as cheep as or even cheaper than ground inventories (For. Abs. 2755/1990).

The accuracy of different stock inventory methods based on data obtained from aerial photographe was estimated by Spellmann (1987).

Katsch (1991) tried to establish what opportunities aerial photographs offer in the case of rationalization of forest inventories at the enterprise level. The case study refers to a forest area of about 7500 ha in SW Lower Saxony. The combination of ground survey with aerial photography (the combined method) gave a standard error only 1-2% greater than the ground survey with only one quarter of the number of sample plots (For. Abs. 1834/1993).

In 1993, Kenneweg presented new approaches of forest inventory and monitoring techniques integrating aerial photography. He presented examples for integrated evaluation of aerial photography in practice and research; following areas (subjects) are mentioned: 1) forest planning and forest mapping: the demand for digital maps and geo-information systems introduced practices to derive digital cartographic data directly from analogous tool "aerial photography" without the need for any drawn maps; 2) volume, increment and observation of permanent plots for ecological purposes; 3) tree damage and forest decline: a complete structural change of the interpretation of CIR (color infrared) aerial photography; 4) the use of aerial photography in the evaluation of satellite remote sensing: the comparison between aerial photography and satellite data sets as sources of information became very important for users of remote sensing data; 5) inventory of large areas: CIR-film was used and sampling techniques were applied.

Color IR aerial photographs (scale 1:5000) taken in the leafless period (after snowmelt) were used by Münch (1995) for documentation of forest structure in mixed forest located in Baden-Württemberg. These photographs provided data for the construction of a digital model of the terrain, tree height measurement, mapping of dead wood and mapping of under storey conifers (For. Abs. 1220/1996).

Beisch and Eilermann (1996) tested small-scale (1:35000) IR-photographs in volume and increment estimation. They applied two-phase sampling as a combination of terrestrial and aerial photographic sampling. The results based on regression models showed that the estimation of timber and increment volume was more cost-effective than in the case of terrestrial sampling used alone. (For. Abs. 4466/1996).

As early as 1971 Hildebrandt and Heller (1976) underlined the implication of remote sensors for forestry research and practice. IUFRO work (1971) contains 13 papers on "Application of Remote Sensors in Forestry" (189 pp), signed by A. Akça, R. N. Colwell, R. C. Heller, G. Hildebrandt, J. A. Howard, H. Kenneweng, P. G. Langley. D. T. Lauer, C. E. Olson, J. v. Roessel, L. Sayn-Wittgenstein, D. A. Stellingwerf, F. P. Weber. This report represented the state of the art at 1971 level. "The authors of the report are of the opinion that conventional aerial photography will continue to be widely used in the future…However, we have consider new techniques of aerial photography and other remote sensing systems along with conventional methods. These new techniques have opened up new fields of forestry application in mapping, inventory, protection, engineering, soils, wildlife and range management" (Gerd Hildebrandt p. 5). The following subjects have been taken into account: collection and processing of multi spectral imagery (C.E. Olson Jr.); multiband photography for forestry purposes (D.T. Lauer); color and false color photography; its growing use in forestry (R.C. Heller); color and false photography, its growing use in forestry- a European view (H. Kenneweg); applications of airborne thermal remote sensing in forestry (F.P. Weber); aspects of the use of aerial remote sensors in tropical forestry (D.A. Stellingwerf); large scale aerial photography and radar altimetry- the state of art (L. Sayn-Wittgenstein); factors governing the inventory of natural resources from satellite orthophtography (R.N. Colwell); the benefits of multi-stage variable probability sampling using space and air craft imagery (P.G. Langley); the reflective foliaceous of tree species (J.A. Howard); identification of land use classes and forest types by means of micro densitometry and discriminant analyses (A. Akça); orthophotography- a new effective technique also in forestry (G. Hildebrandt); automated mapping of forest resources from digitized aerial photography (J. van Roussel). In 1976, Hildebrandt noted the importance of the spectral reflectance of vegetation for photo-interpretation. Determination of spectral signatures of different species and forest damages was completed by Koch et al. (1984), Elling and Knoppic (1986), and Kadro (1986a, 1986b).

According to Hildebrandt (1993) "In spite of former studies, especially in the USSR, the USA and Sweden, virtually nothing was known about variations and variability of the spectral reflectance of particular objects and the resulting spectral signatures. Systematic on-the-spot spectroradiometric measurements were begun in Germany and the Netherlands in the mid 1970s. Reichert was the first to discuss and test spectral signature analysis with an eleven-chanel scanner and different flight heights as radiometer" (p. 209).

"The first applied aerial survey to inventory forest disease in Central Europe was completed in 1969 by Kenneweg and Hildebrandt over 20000 hectares of forest land in the Ruhr area...The first complete inventory and health assessment of trees in an urban area was made in 1972 by Kadro in Freiburg" (Hildebrandt 1993, p. 207).

The development of an inventory model for monitoring forest damage based on German experience was published in U.K. by Groves and Hedges in 1987.

Preliminary assessment of airborne imaging spectrometer and airborne thematic maper TM data acquired for forest decline areas in the Federal Republic of Germany was performed by Herrmann et al. in 1988.

Hoque et al. (1988) analyzed the relationship between discoloration and historical changes in leaves of trees affected by forest decline, concluding that the results may be helpful in assessing forest decline from remote sensing data.

In 1993, Bayer and Runkel compared different remote sensing techniques for the evaluation of forest decline: CIR photos and Landsat-5 TM based evaluations of forest decline using Geographic Information System (GIS). The study area was Harz Mountains located in Northern Germany. In a way, this study is a critical evaluation of both analyzed techniques. The authors noted that “In practice of forest decline inventories satellite data and CIR photos are often used in combination. The CIR photos shall deliver the ground truth for test areas and for verification purposes” (p. 296).

Health status assessment of urban tree vegetation in Munich using color-infrared photographs was carried out in 1993 by Martin Klaus. Tree species with low percentage of clearly visible damage proved to be: *Acer pseudoplantus*, *Populus nigra* var. *italica* and *Aesculus hippocastanum* whereas the species with high percentage of clearly visible damage were *Quercus robur* and *Fagus sylvatica*.

Remote sensors for airborne and space borne imagery were presented in 1976 by P. C. Heller.

In 1985, Spellmann tested a digital photogrammetric method for automatic stand mapping and area computation with aerial photographs of scale 1:25000 obtained area accuracy being 2.7 %, sufficient for forest purposes.

Rhody (1986) analyzed the possibility of remote sensing in large scale inventories and proposed two models of a national forest inventory based on satellite and aerial photos. The first proposal is a 2-phase model using small-format aerial photographs and ground samples, the second is a 3-phase inventory model based on large format satellite photos, aerial photographs and ground surveys.

In 1987, Hildebrandt concluded that “satellite remote sensing is already an important tool for inventory and monitoring in extensively managed areas”.

The use of MOMS (Modular Optelectronic Multispectral Stereo Scanner) data for monitoring tropical rain forests in developing countries was proposed by Helbing (1990), from German Aerospace Establishement (DLR), in Wessting, Germany. He outlined a project to map the rain forest in East Kalimantan using satellite and MOMS images.

In 1993, Hildebrandt completed a remarkable short synthesis (16 pp.) on “Central European contribution to remote sensing and photogrammetry in

Forestry" in which the German contribution in this field is underlined. In his study, Hildebrandt established the following periods in the development of remote sensing in Central Europe: 1) the Beginnings (1839-1909); 2) the establishment of aerial photogrammetry and airborne remote sensing in forestry (1919-1939); 3) World War II and after (1939-1949); 4) the period of consolidation (1949-1969); 5) the "New Age" in remote sensing and analytical photogrammetry since 1969.

In a collection of four papers (Holuba, Kettemann, Kreutter, Oefverberg) published in 1995 a particular reference is made to the development of FOGIS (Forest Geographical Information System) and to the application of GPS (Global Positioning Systems).

Another collection of 13 papers was published in 1996 under the title Fernerkundung (Remote sensing) in with there are presented various aspects of remote sensing application to forestry based especially on German experience.

Other four papers are presented on the development of FOGIS and its application in forest management in Baden-Württemberg. The use of FOGIS refer to site mapping, forest biotope mapping, designing forest road systems and the mapping of forest functions (Teuffel et al. 1996).

A group of selected texts (books, textbooks) on remote sensing published by German authors is presented in table 4. 17- 2.

In our opinion it should be underlined the historical importance of books published before 1970 including Hildebrandt's 1887-1968 bibliography which was enlarged in his 1996 text.

TABLE 4. 17.-2. Selected German texts on remote sensing

Year	Author (s)	Title	Editor, place
1932	Gruber, O. von	[Photogrammetry, collected lectures and essays] Translated from the German by G.T. Mc Caw and F.A. Cazalet. 454 pp.	American Photographic Publ. Co. Boston
1938	Krutsch H., Loetsch, F.	Holzvorrats inventur und Leistungsprüfung in der naturgemässen Waldwirtschaft (Forest inventory of Standing trees and research on natural productivity of forest units), 164 pp.	Neudamm
1952	Zeller, M.	Textbook of Photogrammetry Trans. by E.A. Miskin and R. Powell. 281 pp.	H.K. Lewis and Co., Ltd. London
1956	Laer, W. von	Einführung in die forstliche Photogrammetrie (Introduction in forest photogrammetry) Forstliche Lehrbuch. 5.	Neudamm
1959	Bauman, Hugo	Forstliche Luftbild-Interpretation. (Forestry aerial photo-interpretation 109 pp + 16 plates.	Forstdirektion Südwürttem-berg-Hchenzo-llern. Tubingen-Bebenhousen.
1969	Hildebrandt, G.	Bibliographie des Schrifttums auf dem Gebiet des forstlichen Luftbild Auswertung 1887-1968 (Very important bibliography on forest photogrammetry 1887-1968), 315 pp.	Freiburg-i-Br. Institute for Forest Management
1971	Different authors (13)	Application of Remote Sensors in Forestry. 189 pp. German authors: A. Akça, R.C. Heller, G. Hildebrandt, H. Kenneweg, L. Sayn-Wittgenstein, D.A. Stellingwerf, F.P. Weber	IUFRO S. 25 Printed in Germany
1984	Huss, J. (Hersg.)	Luftbildmessung und Fernerkundung in der Forstwirtschaft (Aerophoto-grammetry and remote sensing in management)	Karlsruhe Wirtschaft.

TABLE 4. 17.-2. (cont.)

Year	Author (s)	Title	Editor, place
1986	Kändler, G.	Die Ermittlung von Bestandsparameterm als Eingangsgrössen für Interzeptions--modelle mit Hilfe aerophotogra--mmetrischer Verfahren (Determining Stand parameters as entry values for interception models with the aid of aero-photogrammetric methods) 129 pp.	Baden Wüttemberg
1990	Hobbs, R.J. Mooney, H.A. (eds).	Remote sensing of biosphere functioning. 312 pp.	Springer-Verlag
1996	Hildebrandt, G.	Fenerkundung und Luftbildmessung (Remote sensing and aerophotogra--mmetry) 676 pp.	Wichmann Heidelberg
1996	Reuther, M.; Hausler, T.; Akgoz, E.; Hoffmann, K.; Stätter, R.	Waldzustandserfassung im Fichtel-gebirge und Erzgebirge mit Hilfe der Fernerkundung (Recording forest condition in the Fichtelgebirge and Enzgebirge mauntains with the aid at remote sensing) 236 pp.	München University

Cited authors:

Akça 1984, Akça and Sangen-Emden, Akça and Zindel 1987, Andrews 1934, Anonymous 1887, Anonymous n. d. (1991 ?), Bauman 1959, Bayer and Runkel 1993, Beisch and Eilermann 1996, Bundesinventur 1986, Dahm 1995, Dahm et al. 1997, Eberwein1996, Elling and Knoppik 1986, Erteld and Hengst 1966, Forstarchiv 1952, Franz et al. 1991, Glaser 1953, Grossmann 1959, Groves and Hedges 1987, Gruber 1932, Haller 1968, Helbing 1990, Heller 1976, Herrmann 1988, Hildebrandt 1956, 1957, 1957a, 1969, 1976, 1981, 1987, 1993, 1996; Hildebrandt and Heller 1971, Hobbs and Mooney 1990, Holuba 1995, Hoque et al. 1988, Hugershoff 1933, Huss 1984, IUFRO 1971, Jacobs 1932, Kadro 1986 a, 1986 b, Kätsch 1991, Keller 1987, Kennel 1987, Kenneweg 1993, Kirchhoff and Hess 1987, Kleinn 1991, Kleinn et. al. 1997, Koch et al. 1984, Kochl 1996, Köhl 1987 a, 1993; Köhl and Pelz 1991, Kramer and Akça 1987, Krause 1955, Kreutzinger 1949, Krutzsch 1925, Krutzch-Loetsch 1938, Kublin 1987.Laer 1956, Loetsch et al. 1964, 1973; Martin 1993, Moser 1958, Müller 1931, Münch 1995, Neumann 1933, 1934; Ott 1987, Pelz 1978, 1993; Pelz and Cunia 1985, Pelz and Thom 1979, Pommerening and Lewandowski 1997, Prodan 1953, 1955, 1958, 1965; Remote sensing 1996; Reuther et al. 1996, Rhody 1986, Richter and Grossmann 1951, 1959; Richter et al. 1953, Schabenger 1991, Schmitz 1997, Schwenke 1985, Smaltschinski 1990, Spellmann 1985, 1986, 1987; Stage 1977, Teuffel 1996, Traub 1997, Tzschupke 1986, 1991; Ulbricht 1987, Ulbricht and Grossmann 1978; Ulbricht and Richter 1984, Volk 1987, Vries 1986, Weber 1881, Wiedemann 1950, Zeller 1952, Zieger 1928, Zöhrer 1978, 1980; Zöhrer et al. 1982.

4.18. Chronology of the selected works on forest mensuration

1753: Schober's discovery that the number of rings agreed with the number of branch whorls in a pine tree. (C. G. Schober should be considered as the first German pioneer in the field of tree rings studies).

1765: The first German textbook containing practical arguments for the use of mathematics in forestry, aspects of timber mensuration, basic formulae for log volume determination (K. C. Öttelt (Oettelt)).

1765: Stand average height at a given age is proposed as criterion for classification of site quality evaluation (K. C. Oettelt) adopted later by F. Baur (1877) who used before 1877 total yield in cubic measure as indicator of site in the so-called Baur's method of bands used in yield tables construction.

1765-1835 (1864): Application of the theory of the solids of revolution for log and stem volume determination (K. C. Oettelt 1765, Krünitz 1781, W. Hossfeld 1812, G. König 1835, 1864; H. L. Smalian 1837, F. Riecke 1840).

1787: The first yield table constructed by graphical method. This table (for beech) was reproduced by Th. Hartig in 1847, who attributed it to J. C. von Paulsen (1795) and G. L. Hartig.

1790s - 1846 (1873, 1893): Form factors, types and determination (J. C. von Paulsen 1795, 1800; W. Hossfeld 1812, Gottlob König 1813, 1835, 1864; J. L. Klauprecht 1846, H. Riniker 1873, E. Speidel 1889, 1893).

1797, 1798: The first growth curve of logistics type presented in a dissertation on determination of forest growth - the first (?) treaty about the growth of forest - (J. L. Späth).

18th and 19th centuries the whole forest estate was divided into “Forstorte” which served as unit of assessment and total growing stock per ha in each unit was visually estimated and cheched by the yield from felled sample areas.

1804: The first recommendation for volume tables construction (H. v. Cotta).

1804: A. L. Schlözer's "Theorie der Statistik".

1813: Applications of mathematics in forest mensuration (G. König).

1822: First growth function (W. Hossfeld).

1828-1849: The oldest and best known formulae for log volume: B. Huber 1828 (known in fact since the 16th and 17th centuries), H. L. Smalian 1837, W. Hossfeld 1849, Issac Newton - F. Rieke 1849.

1837: "Beitrag zur Holzmesskunst": contribution to the art of timber mensurement which may be considered as the first prestandard German book on forest mensuration (H. L. Smalian).

1842/1846: The development of the form factor theory and recommendation for the use of the mathematical statistics in forestry (J. L. Klauprecht).

1845-1860: Early works on stand growth (J. C. von Paulsen 1845, G. Heyer 1852, F. Baur 1860).

1846: "Bayerische Massentafeln": Bavarian volume tables based on data from 40220 trees and graphical methods, expressed in old Bavarian foot and inch measure (Bavarian Government).

1846: Early study on the influence of thinning on competition and development of stands (E. von Berg).

1852: Different relationships between tree variables as diameter, height, volume and formheight in a stand presented for the first time (Gustav Heyer).

1852-1902: Early yield tables (H. Burckardt 1852) F. Baur 1877, M. R. Pressler 1878, T. Hartig 1878, M. F. Kunze 1878, Weise 1880, Tuisko Lorey 1884, 1897, 1899; Adam Schwappach 1893, 1902).

1855: Pressler's method of director point or height procedure for determination of standing tree volume (M. R. Pressler).

1860s: Determination of stand volume and assortments based on sample tree techniques (A. Draudt 1860, C. Urich 1860, T. Hartig 1847, 1868).

1860: The first edition of the Franz Baur's "Holzmesskunde" (Forest mensuration) - the first comprehensive forest mensuration textbook.

1865: Calipers constructed to supply directly the data on volume depending on the class length of logs - introduced in Württemberg in 1865 by Waldraff (Udo Müller 1899).

1865: M.R. Pressler's formula for the determination of growth percentage.

1866: M. R. Pressler's increment borer.

1870: An early detailed work on diameter and height mensuration (E. Heyer).

1872, 1896: Translation of Bavarian volume tables into metric system by A. von Granghofer.

1873,1896: Total volume of a stand with a closed canopy used as an indicator of site quality (Karl Philipp von Baden).

1875: F. L. Langenbacher's "Forstmathematik".

1878: Probably the first determination of the normal basal area in a spruce stand (M. F. Kunze).

1878: The first compilation of data from individual states or districts to obtain the assessment of growing stock at national level. The last compilation was made in West Germany in 1961 and in DDR in the 1960s.

1880: The technique to perform stem analysis (Tuisko Lorey).

1880: W. Weise's caliper which indicated directly the section area instead of diameter.

1881: The first use of inventory data for assessing growth (R. Weber).

1883: The relationship between current and mean increment (K. Heyer).

1884: Gustav Kraft's classification of the trees according to their position in the canopy.

1887: Balloon photography for forestry purposes (Anonymous 1887).

1888: Determination of the contribution of diameter classes to stand growth (F. Grundner).

1889: Early investigations on weight and compressive strength of the wood of important trees (Adam Schwappach).

1890: Franz Baur's volume tables based on 55874 trees of Norway spruce.

1891, 1898, 1899: Introduction of form quotient concept and relationships between form factor and form quotient (M. F. Kunze 1891, 1907; K. Schuberg 1898; A. Schiffel 1899 in Austria).

1891: The first use of a statistically perfectly sound sampling methods by circular plots (K. Zetsche).

1891: The middle point of the stem height is the most critical for the second measurement of diameter and is capable of expressing any variation in form due to any factor or combination of factors such as site, age or silvicultural conditions (K. Schuberg).

1893: Mechanical theory of the stem form determined in principal by wind influence on stem growth (K. Metzger).

1893: Translation in time of height-diameter curves in even-aged and ±even-aged stands (E. Speidel).

1895: Connection between double annual tree-ring (Doppelringe) and spring frost (R. Hartig).

1896: Measurement of the diameter at different heights: K. Wimmenauer's Baummesser, and later optical devices as Zeiss Teletop (W. Schneider 1938), W. Bitterlich relascop and telerelascop (after 1948).

1898: F. Grundner -A. Schwappach's volume tables for trees and form factors for stands. The 10th edition was published in 1952.

1899: Udo Müller's well-known standard text book on forest mensuration.

1899, 1927: Text books with a detailed description of calipers and hypsometers (U. Müller 1899/1915/1923; Wilhelm Tischendorf 1927).

1899, 1901: The first function adopted in Germany for tree volume determination, applicable in volume table construction and called "Kopezki-Gerhardtsche Masseline" (Kopezki 1899, Gerhardt 1901).

1902: Proposal for volume determination based on photography (Jacob Weber).

1904: E. Eichhorn's rule ("law"), original formulation: "for a given average stand height corresponds the same volume per unit area (hectare) independent of site class or age".

1905: Haehnle's assortment tables for spruce even-aged stands thinned regularly in Württemberg.

1909: Introduction of the term **coefficient of distance** = average distance between trees/average diameter of the stand - as an indicator of competition (Paul Statz).

Since 1911: R. Hugershoff developed the basic researches of aerial photography in forestry and vegetation mapping. He started first studies on the relationship between crown diameter and dbh based on air photos.

1912: The discovery of the periodical character of the annual tree-ring growth (H. Späth).

1912/1913/1929, 1943: Adam Schwappach's yield tables for the main German species.

1916: P. Jaccard's hypothesis of pipe model considering the stem as a pipe and connection of this theory with tree form and growth.

1917: A review (about 350 titles) on the importance of annual tree-ring as climatic indicator (E. Antevs).

1918-1926: A remarkable number of forests had been photographed in Germany using air photography (G. Hildebrandt 1993).

1919: Monomolecular growth function (E. A. Mitscherlich).

1920 - 1939: W. Hohenald's studies on tree form (1924 – a theory about mechanical construction of stem, 1936 - the Introduction of the term "natural form quotient $k_H = d_i/d_{0.1h}$) where d_i = diameter at height "i", $d_{0.1h}$ = diameter at 0.1 height.

1925: The first German yield table for mixed stands: Scots pine + Norway spruce (L. Schilling).

1925: The first detailed study on the aerial photographs in the service of forest management (H. Krutzsch).

1928: E. Zieger presented the results of the determination of stand volume from aerial photographs with the help of the Hugershoff-Heyde autocartograph.

1930: The use of photography for growth determination (R. B. Hilf and H. Schmeel).

Since 1931: Repartition of trees in a stand by diameter categories using distribution and probability functions (K. Mauve 1931. G. Mitscherlich 1939, K. Krenn 1942, M. Prodan 1944, 1949, 1951, 1953, 1961, 1968; H. Zimmerle 1947, R. Schober 1949, 1953; H. Weiss 1956, F. Zohrer 1969; F. Loetsch, F. Zohrer and K. F. Haller 1973, K. von Gadov 1984, 1999).

1933, 1934: Crown counts on the aerial photographs and the use of stand profiles instead of average height for stand volume determination (C. Neumann).

1935: The use of biometrical methods for determination of stand structure (Stan Kusal).

1935: Biometrics of tree groups (T. Wielgosz).

1936, 1944: Height-diameter relationship in a stand, height curves (W. Hohenadl 1936, K. Krenn 1944).

1936-1965: Different function for volume table construction (Berkhout 1915 -cited by W. Müller 1915, W. Hohenadl 1936, Krenn 1944, G. Müller and E. Zahn 1958, G. Wenk 1962, Honer 1965 -cited by Prodan et al. 1997 p. 98).

1936: Official German rules for wood division into sections, measure and assortments, so-called HOMA = "Bestimmungen über die Ausformung Messung und Sortenbildung des Holzes in dan deutschen Forsten" or "Reichshoma".

1936: A new procedure for stand volume determination based on mathematical and statistical principles (W. Peschel).

1937: H. Zimmerle's form quotient $k_z = d_{5m}$/dbh.

1938: The first book of forestry on the basis of mathematical statistics in the German language (H. Krutzsch and F. Loetsch).

1938: Series of formheight - "Formhöhen" (W. von Laer 1938, A. Lang 1938).

Since 1938: Stand assortment tables and assortment - yield tables (A. Lang 1938, G. Mitscherlich 1939, K. Vogel 1939, R. Schober 1946, K. Krenn 1952, Baden 1952, H. Harder 1955, E. Altherr 1953, 1954; L. Schilling 1960, R. Schober and E. Wiedemann 1969, R. Schober 1979/1980, W. Schöpfer and E. Dauber 1989).

1939: W. Hohenadl's two average diameters in a stand and their importance.

During 1939-1945 period Kodak and Agfa produced black-and-white infrared films and Agfa was working on a color infrared film (G. Hildebrandt 1993).

1940: A. Topcuoglu's research on annual growth distribution along the stem.

1941, 1942, 1951, 1968: L. von Bertalanffy's growth model.

1941, 1942, 1943, 1948: The first German scientist to initiate tree-ring dating studies in Germany respectively in Europe in the same way as Douglass did it in the U.S.A. (Bruno Huber).

1941, 1948, 1949: A remarkable book on forest increment and yield (Karl Vanselow).

1942: Mathematical statistics for foresters (instead of forest mathematics) as a subject of study was introduced by K. Krenn the founder of Freiburg Seminary.

1942: G. Mitscherlich's researches on form factor of wood with diameter more than 7 cm at top end and the general equation of stem form: $f_{1.3} = f(d_{1.3}, d_5,$ age, site productivity, height$)$.

1942: A yield table for mixed spruce + beech stands (E. Wiedemann).

1943: G. Backmann's growth model.

1944: Existence of a strong statistical relation between $f_{0.1}$ (true form factor) and $k_{0.5}$ form quotient $k_{0.5} = d_{0.5}/d_{0.1}$ (K. Krenn and M. Prodan 1944, M. Prodan 1944).

1944, 1947: Growth and yield in selection forest (M. Prodan)

1945/1946: Krenn's yield tables containing 10 classes based on mean increment of total yield of the age at 100 years.

1948: K. Krenn's volume tables or tariffs which give volume of the average tree of stand, have been constructed on the basis of yield tables and offer the possibility of current increment determination of stands if they are constructed for different thinning intensities.

1948: Volume curves for determination of stand growth and yield in connection with biological aspects (M. Spiecker).

1948, 1951: Volume series based on form height series (W. von Laer and M. Spiecker).

1948: Forest mensuration text book (J. Weck).

1948, 1955: "Forstliche Zuwachs- und Ertragskunde" (Science of forest growth and yield). Site classification according to their productive capacity can be solved by the direct investigation of their characteristics. The best way in Weck's oppinion is to produce yield tables for groups or types of sites (J. Weck).

1948-1953: Early German tree ring chronologies (Bruno Huber 1948, W. Wellenhofer 1948, A. Artman 1949, K. Brehme 1951, B. Huber and Wita von Jazewitsch 1950-1952, 1953.

1949: Introduction of recording calipers: "Registrierkluppe" (W. Hohenadl).

1949: M. Prodan's site classes in selection forests (Plenterwälder).

1949: E. Wiedemann's yield tables for most important species.

Since 1950: Methodological aspects of tree ring studies (B. Huber 1952, 1954: W. v. Jazewitsch 1952, P. Abetz 1960, O. Fürst 1963, D. Eckstein and J. Bauch 1969, M. Jahring 1972).

1950/1955: E. Wiedemann's book on fundamentals of growth and forest yield).

1951: Use of photography for determination of solid content in stacked wood (Hensler, Gläser und Zieger quoted by Prodan 1965).

1951: Hopmann's "Forstmathematik".

1951: W. Laer and M. Spiecker's volume tables for principal species that give volume series depending on dbh and tariff number determinated depending on dbh of stand average tree and its height. These tables may be used for determination of stand growth.

1951, 1953: Determination of wood contraction which affects the measurement of logs and woody material (F. Kollman 1951, H. Mayer and H. Wegelin 1953).

1951: Prodan's studies on stem form divided into five portions equal in length and measurement of diameters at the middle of this sections.

1951: M. Prodan's remarkable textbook on measurement of forest stands: "Messung der Waldbestände".

1951: M. Prodan's volume tables for fir and beech in selection forest (Plenterwald).

1951: Textbook on volume determination: "Massen-Berechnungstafeln" (Wilhelm von Laer and Martin Spiecker).

1951, 1959: Researches on circular plots and pointless sampling (A. Richter and H. Grossmann).

1952: G. Mitscherlich table for site evaluation.

1952: Moss species as indicators of site productivity (K. Vanselow and K. Rubner).

1953: E. Alther's true form quotient series for stem form of different species.

Since 1953/1954: Methodological aspects of the structure of mixed stands (E. Assmann 1953/1954, Helmut Schmidt-Vogt 1986, H. Spellman 1992).

1953: M. Prodan's work on diameter distribution using beta function and determination of 25 types of asymmetric distribution for even-aged stands representing almost all cases existing in Germany.

1955, 1956: Determination of tree stem volumetrical structure based on series of form quotients (G. Speidel 1955, K. Hauser 1956, K. Hauser and E. Bolsinger 1956).

1956: G. Mitscherlich's "Ertragsgesetze", a book on forest productivity laws.

1957: E. Wiedemann and R. Schober's yield tables for main species.

1958: Tables with quotient form series, form factors (for trees and stands), and decrease stem factors (O. Dittmar).

1958: A system of unique height curves which do not take in account species influence of height curve form (G. Kräuter).

Since 1958: Dendrochronological methods in art history (W. Lottermoser and F. J. Meyer 1958, E. Holstein 1970, J. Bauch, D. Eckstein and G. Brauner 1974).

1959, 1964: Errors in girth measurement (R. Kennel 1959, 1964).

1959: The use of least squares method in the development of tree volume tables (R. Schmidt and B. Schneider).

1960: The use of decrease factors in assortment determination (E. Altherr).

1960: Proposal for construction of volume tables or tariffs for different site types (G. Müller).

1960s: Use of dendrographs for diameter growth determination (L. Klemmer 1961, 1969: K. Abetz 1966, G. Hildebrand 1966; G. Mitscherlich, W. Moll, E. Künstle and P. Maurer 1966; M. Geissler 1970).

1960s, 1970s: Dendrochronology and architectural history (B. Huber 1962, W. Liese and J. Burch 1965, A. Delorme 1972).

1961: E. Assmann's remarkable "Waldertragslehre" (The principles of forest yield study), Polish version 1968, English version 1970.

1961, 1972: Summaries of dendrochronological studies (B. Huber, W. Merz and O. Fürst 1961; D. Eckstein 1972).

1961-1976: Dendroclimatological works (W. von Jazewitsch 1961, W. Elling 1966, D. Eckstein and B. Schmidt 1974, Terry Brandson 1976).

1961: M. Prodan's growth model.

1961, English version 1968: M. Prodan's outstanding "Fortliche Biometrie" (Forest biometrics).

1962: A short review of literature in German language on forest site productivity published after 1945 (H. U. Mossmayer).

1962, 1963: Distance between two trees considered as a good indicator of competition (H. Hausburg 1962, K.F. Stöhr 1963).

1963, 1965: Statistical relationships between the real form quotient ($k_{0.5}$) and false form factor (E. Altherr 1963, M. Prodan 1965).

1963, 1972: First yield tables based on complex mathematical models to be solved by computer; 1000 years as reference age for height was adopted for site classes (E. Assmann and F. Franz).

1964, 1973: The comprehensive textbook on forest mensuration highly appreciated and published in English (Vol. I 1964 by F. Loetsch and K. E. Heller and Vol. II 1973 by F. Loetsch, F. Zöhrer and K. E. Heller).

1965: M. Prodan's "Holzmesslehre" (Forest mensuration).

1965: An extensive analyse of all errors affecting the measurements of stand characteristics (M. Prodan).

1966, 1972: F. Franz's recommendation for the use of American models for yield prognoses.

1968: Regular use of orthophotomaps begun in 1968 (Hildebrandt 1933).

Mid 1960s: Introduction of color infrared photography (CIR) very important for detection and monitoring of forest diseases (G. Hildebrandt 1993).

1969: Hildebrandt's bibliography on forest photogrammetry 1887-1968.

1969: The first applied survey to inventory forest disease in Central Europe, in the Ruhr area (H. Kenneweg and G. Hildebrandt).

1969: The use of term biomass ("Biomasse") in the case of a spruce stand (B. von Droste zu Hülshoff).

1970-1975: G. Mitscherlich's encyclopedic work "Wald, Wachstum und Umwelt" (Forest growth-development and environment) in which are used functions with biological motivation.

1970, 1978: G. Mitscherlich's book on form and growth of trees and stands.

1970s: The use of photogrammes becomes o common procedure for determination of tree and stand heights (A. Akça 1971, 1973: G. Hildebrandt and P. Reichert 1971).

1970s: Kyritz's recording caliper in which data have been introduced in punched tapes ready to be processed by the computer (W. Binder 1972).

1971: Tables and graphs that indicate the optimum number of trees per hectare (J. Pollanschütz).

1971, 1989: Dendroecology as a special discipline of environmental control (J. Pollanscütz 1971, D. Eckstein and Krause 1989).

1971: Studies on growth process using first order differential equations for growth of height (B. Sloboda).

1972: Dendrogeomorphological works (B. Becher).

1972: An integrated computerized model of yield table system in modular form, equations solved by computer (J. Hradetzky).

1972: The first complete inventory and health assessment of trees in urban area (in Freiburg, A. Kadro).

1974: Construction, experimentation and verification of mathematical models applied to stand growth development and diameter distribution (K. Preussner).

1974: A proposal of a new method for yield tables construction based on growth function. An analyse of spruce yield tables based on a new growth model (R. Zimmermann).

1976: Functions of stem form used for the determination of assortments (P. Roiko-Jokela, P. Schmidt-Haas).

1976: Kolmogorow-Suzuky and stochastic differential equations as a means of description of a forest stand evolution (B. Sloboda).

1976: G. Hildebrandt noted the importance of the spectral reflectance of vegetation for photo interpretation.

Mid 1970s: Reichert was the first to discuss and test spectral signature analysis with an eleven-chanel scanner and different flight heights as radiometer (Hildebrandt 1993).

1976: Remote sensors for airborne imagery were presented by R. C. Heller.

1977: A. R. Stage established the connection between forest inventory data and construction of growth models.

Since the late 1970s Germans were speaking about multi resource inventories.

1978: Automatic data processing system for multiple resource inventories-MRI (D. R. Pelz).

1978: Models for spruce stands with variable density (D. Butter, M. Dutka and U. Zitterbart).

Since 1980: Forest inventories and monitoring of endangered forests.

1980: Spline function and its utilization in forest research (J. Hradetzky).

1980s: Phenomena of growth decline (W. Schöpfer and J. Hradetzky 1986, Friedrichshafen Congress 1989).

1983-1985: Dendroclimatology and tree decline phenomena (D. Eckstein, R. W. Aniol and J. Bauch 1983; D. Eckstein, K. Richter, R. W. Aniol and F. Quiche; J. Bausch, P. Rademacher, W. Berneike, J. Knoth and W. Michaelis 1985).

1981: Site-yield tables for six vegetation zones and 19 site types and three groups of productivity (Franz Horndasch).

1981: Air pollution and forest decline (E. D. Shulze, O. L. Lange, R. Oren).

1982: Methods of stem analysis with a computer program for evaluating results (J. Nagel and S. Athari).

1984: A stand growth simulation model to evaluate the effects of four thinning intensities in Baden-Württemberg Douglas-fir stands (G. Kenk and J. Hradetsky).

1984: Forest ecosystem classification and mapping in Baden Wurttemberg (B. V. Barnes).

1984: Estimation of growth using crown measurements from aerial photographs (A. Akça).

1984-1986: Determination of spectral signature of different species and forest damages (B. Koch et al.-1984, W. Elling and D. Knoppic-1986, A. Kadro 1986a, 1986b).

1985: Started the first national forest inventory based on sample plots in Federal Republic of Germany.

1986: Analysis of the possibility to use the remote sensing in large scale inventories and proposals of two models for a national forest inventory (B. Rhody).

1986: An ultra sonic set (manufacturer ELP in Germany) was used by M. Köhl and T. Mecke to measure distances in forest.

1986-1992: Structure and forest dynamics (J. A. J. Metz and O. Diekmann 1986, H. Koop 1989, S. Möller 1992).

1986: The possibilities to refine the traditional yield tables and to use differentiated growth models appropriate to site and treatment (H. G. Peerenboom and H. Petri).

1986-1991: An excellent monograph on Norway spruce that contains an extensive (207 pp) text on the growth studies and yield tables - comparative analyses (H. Schmidt-Vogt).

1987: Statistical models for the evaluation of forest damage inventories (E. Kublin).

1989: A model for research on forest decline (P. H. Dong, A. von Laar and H. Kramer).

1990: Tables for dry matter and nutrient storage of Scots pine stands (D. Heinssdorf and H. N. Krauss).

1990s: Single-stem growth simulator SILVA-1: modelling pure and mixed stands (Hans Pretzsch 1991, 1993, 1996).

1991: Modelling forest dynamics (Hartmut Bossel).

1992: VESO; a stand development model on the basis of diameter distribution simulator and assortment simulator (D. Gerold).

1992, 1995: Discrepancies between normal growth behaviour (as expected from yield tables and actual growth). Need for new growth models that can be easily expanded and adopted to change conditions. Growth trends of forest in Germany (Hans Pretzsch).

1992: Simulating of growth and yield with emphasis on mixed stands (Teja Preuhsler 1992 (ed.1), G. Wenk 1992).

1993: Volume estimation in selection forests using importance sampling and control functions (C. Klen).

1993: New approaches of forest inventory and monitoring techniques integrating aerial photography (H. Kenneweg).

1994: Verification and validation in forest growth modelling (N. Oreskes, K. Shrader - Frechette and Belitz).

1994: RMI, girth tapes for automatic recording of girth at 3-4 intervals for interpreting short-term fluctuations in the radial growth (M. Vogel).

1995: A thinning model which can be implemented into distance dependent single tree growth simulators by implementing a fuzzy logic controller (Markus Kahn).

Since 1995: Increased number of papers on the development of FORGIS (Forest Geographical Information System) and the application of GPS (Global Positioning Systems).

1995, 1997: Proposal of three phase sample design for the German Federal Forest Inventory (S. Dahm, A. Akça and J. Saborowski).

1995-1997: The problem of changing site productivity (Heinrich Spieker 1995, Hans Untheim 1995, 1996; H. Röhle 1997).

1996: A growth model based on detailed analyses of site and environmental factors and modern measurement techniques (H. U. Moosmayer, W. Schöpfer, G. Mühlhäusser, E. Kublin, H. U. Burger).

1996: Electronic calipers and mobile data-recording instruments have been tested with good results (D. Ruppert and H. H. Kurzdorfer).

1996: An account of the inventory of forest biotopes carried out on all Federal property (M. Ebervein).

1997: M. Bachmann's competition indices for modelling individual tree growth. Different competition models.

1997: Forest mensuration textbook (Anthonie Van Laar and A. Akça).

1997: Analysis and modelling of spatial stand structures - STRUGEN model (H. Pretzsch).

1997: A new standard forest mensuration textbook: "Mensura Forestal" (Michail Prodan, Roland Peters, Fernando Cox and Pedro Real - in Spanish).

End of 1990s: In Germany MRI national objectives are timber and environment.

1999: Forest structure and diversity: new German variables for describing the spectral diversity of tree positions, tree dimensions and tree species within a given forest.

4.19. Author's selection of the most important events

(1) 1765: Stand average height at a given age as criterion for site quality evaluation (K. C. Oettelt).

(2) 1765-1830s: Application of the theory of the solids of revolution for log and stem volume determination (Oettelt, Krünitz, Hossfeld, König, Smalian, Riecke).

(3) 1787: First yield table constructed by graphical method (J. C. von Paulsen).

(4) 1790-1846 (1873, 1893): Form factors (v. Paulsen, Hossfeld, König Klauprecht, Riniker, F. Speidel).

(5) 1797: First growth curve of logistic type for the determination of forest growth (J. L. Späth).

(6) 1828-1849: The best known formulae for log volume (Huber, Smalian, Hossfeld, Newton - Rieke).

(7) 1845-1860: Early works on stand growth (v. Paulsen, G. Heyer, F. Baur).

(8) 1846: Bavarian volume tables.

(9) 1860: Determination of stand volume and assortments based on sample trees (Draudt, Urich, Hartig).

(10) 1860: The first comprehensive forest mensuration text book (F. Baur, first edition).

(11) 1866: M. R. Pressler's increment borer.

(12) 1880: Stem analysis technique (Lorey).

(13) 1891,1898: Introduction of form quotient concept and relationships between form factor and form quotient (Kunze, Schuberg).

(14) 1898: F. Grundner - A. Schwappach's volume tables.

(15) 1899, 1927: Standard textbook on forest mensuration with a detailed description of calipers and hypsometers (U. Müller, Tischendorf).

(16) 1899, 1901: The first function for tree volume used for local tariffs and called "Kopezki - Gerhardtliche Masseline".

(17) 1902: Volume determination based on photography (J. Weber).

(18) 1904: Eichhorn's rule.

(19) Since 1911: The basic researches of aerial photography in forestry and vegetation mapping developed by R. Hugershoff. First studies on the relationship between crown diameter and dbh, based on air photos.

(20) 1920-1939: W. Hohenadl's studies on tree form.

(21) 1925: First German yield table for mixed stands (L. Schilling).

(22) 1928: Measurement of stand volume from aerial photographs (E. Ziegler).

(23) Since 1931 The use of distribution and probability functions in studies on repartition of trees in a stand diameter categories (first application Mauve 1931).

(24) 1936: HOMA = Official German rules for wood division into sections, measure and assortments.

(25) 1938: The first book of forestry on the basis of mathematical statistics in the German language (Krutzsch and Loetsch).

(26) During 1939 - 1945 period Kodak and Agfa produced black -and- white infrared films and Agfa was working on a color infrared film.

(27) 1941, 1951, 1968: L. von Bertalanffy's growth model

(28) 1941, 1948, 1949: K. Vanselow's textbook on forest increment.

(29) 1940s: The first German scientist who initiated, tree-ring dating studies in Germany and Europe in the same way as Douglass did in the U.S.A. (Bruno Huber).

(30) 1944, 1947, 1949: Site classes, growth and yield in selection forest (M. Prodan).

(31) 1945/1946: Krenn's yield tables based on mean increment of total yield at the age of 100 years.

(32) 1948: K. Krenn's volume tables.

(33) 1948: J. Weck's Forest mensuration text book.

(34) 1948, 1951: Volume series based on form height series (von Laer and Spieker).

(35) 1950/1955: E. Wiedemann's book on fundamentals of growth and forest yield.

(36) 1956: G. Mitscherlich's book on forest productivity laws.

(37) 1957: E. Wiedemann and R. Schober's yield tables.

(38) 1961: E. Assmann's book on the principles of forest yield study ("Waldertragslehre").

(39) 1961: M. Prodan's "Forest Biometrics" (Forstliche Biometrie).

(40) 1963, 1972: First yield tables based on complex mathematical models to be solved by computer.

(41) 1964, 1973: Classical textbook "Forest inventory" (F. Loetsch, K. F. Heller, F. Zöhrer).

(42) 1965: M. Prodan's "Forest Mensuration" ("Holzmesslehre").

(43) Mid. 1960s: Introduction of color infrared photography (CIR) very important for detection and forest monitoring.

(44) 1970-1975: G. Mitscherlich's encyclopedical work "Wald, Wachstum und Umvelt" (Forest, growth-development and environment).

(45) 1984: Estimation of growth using crown measurements from aerial photographs (A. Akça).

(46) 1984-1986: Determination of spectral signatures of different species and forest damages (B. Koch et al.-1984, Elling and Knoppic-1984, A. Kadro 1986).

(47) 1985: Started the first national forest inventory based on sample plots in the Federal Republic of Germany.

(48) 1980s: Phenomena of growth decline (see Friedrichschafen Congress 1989, and a model for research on forest decline (Dong, von Laar and Kramer 1989).

(49) 1986: The possibilities of refine the traditional yield tables and to use differentiated growth models appropriate to site and treatment (Peerenboom and Petri).

(50) 1992: Simulating of growth and yield with emphasis on mixed stands (Preuhsler (ed.), Wenk).

(51) 1996: Hildebrandt's remarkable book on remote sensing and aerophotogrammetry.

(52) 1996: A growth model based on detailed analyses of site and environmental factors and modern measurement techniques (Moosmayer, Schöpfer, Mühlhäusser, Kublin and Burger).

(53) 1996: Electronic and mobile data-recording instruments have been tested with good results (Ruppertand Kurzdorfer).

(54) 1997: Analyses and modelling of spatial stand structures: STRUGEN model (Pretsch).

4.20. Selected contributors

Contributor	Printing year(s)	Field
C. G. SCHOBER	1753	6
K. C. OETTELT	1765	1, 2
J. L. SPÄTH	1770s, 1790s	01, 1
KRUNITZ	1781	1
J. C. v. PAULSEN	1780s, 1790s, 1800s	1, 4
H. v. COTTA	1810s, 1820s	1
W. HOSSFELD	1810s, 1820s, 1840s	1
G. KÖNIG	1810s, 1830s, 1860s	1
F. X. HUBER	1820s	1
H. L. SMALIAN	1830s, 1840s	01, 1
F. RIECKE	1840s	1
J. L. KLAUPRECHT	1840s	1
E. v. BERG	1840s	4
K. HEYER	1840s, 1880s	1
T. HARTIG	1840s, 1860s, 1870s	1, 4
H. BURCKHARDT	1850s	1
G. HEYER	1850s	4
SCHNEIDER	1850s	1
M. R. PRESSLER	1850s, 1860s, 1870s, 1880s, 1900s	01, 1, 4
K. BREHMANN	1850s, 1860s	01
F. BAUR	1860s, 1870s, 1890s	01, 1, 4
A. DRAUDT	1860s	4
R. HARTIG	1860s, 1880s, 1890s	01, 4, 6
C. URICH	1860s	4
E. HEYER	1870s	1
A. v. GRANGHOFER	1870s, 1890s	1
K. PHILIPP v. BADEN	1870s, 1890s	4
H. RINIKER	1870s	1
E. L. LANGENBACHER	1870s	01
M. F. KUNZE	1870s, 1880s, 1890s, 1990s, 1910s	01, 1, 4
T. LOREY	1880s, 1890s, 1900s	01, 1, 4
H. STOETZER	1880s, 1890s	01, 1
W. WEISE	1880s, 1900s	1, 4
G. KRAFT	1880s	1, 3

Contributor	Printing year(s)	Field
K. METZGER	1880s	1, 3
H. BEHM	1880s, 1900s	1
F. GRUNDNER	1880s, 1890s, 1900s	1, 4
K. SCHUBERG	1880s, 1890s	01, 1
A. SCHWAPPACH	1880s, 1890s, 1900s, 1910s, 1920s	01, 1, 4, 5
E. SPEIDEL	1880s, 1890s	1, 4
K. WIMMENAUER	1890s, 1900s, 1910s	01, 1, 3, 4
R. KOPE	1890s	1
U. MÜLLER	1890s, 1910s, 1920s	01, 1
E. GERHARDT	1900s, 1920s	1, 3, 4
E. EICHHORN	1900s	4
E. ANTEVS	1910s	6
R. v. GUTTENBERG	1910s, 1920s	01
W. HOHENADL	1920s, 1930s	1, 3, 4
H. KRUTZSCH	1925	7
E. ZIEGER	1928	7
O.v. GRUBER	1932	7
R. HUGERSHOFF	1933	7
E. WIEDEMANN	1920s, 1930s, 1940s, 1950s, 1960s	01, 1, 3, 4
M. ZELLER	1952	7
L. SCHILLING	1920s	4
W. TISCHENDORF	1920s	01, 4
E. ZIEGLER	1920s	4
H. ZIMMERLE	1930s, 1940s	01, 1, 2, 3, 4
J. WECK	1930s, 1940s, 1950s, 1960s	01, 1, 2, 3, 4
E. ASSMANN	1930s, 1940s, 1950s, 1960s, 1970s	01, 2, 3, 4
W. PESCHEL	1930s	1, 4
K. VANSELOW	1930s, 1940s, 1950s	1, 2, 3, 4
H. KRUTSCH	1930s	01
W. van LAER	1930s, 1940s, 1950s, 1960s	4
A. LANG	1930s, 1940s, 1973 ?	4
F. LOETSCH	1930s, 1950s, 1960s, 1970s	01, 1, 4, 7
G. MITSCHERLICH	1930s, 1940s, 1950s, 1960s, 1970s	01, 1, 2, 3, 4

Contributor	Printing year(s)	Field
L. v. BERTALANFFY	1940s, 1950s, 1960s	1, 4
B. HUBER	1940s, 1950s, 1960s	6
K. KRENN	1940s, 1950s	01, 1, 3, 4
G. BACKMANN	1940s	1
R. SCHOBER	1940s, 1950s, 1960s, 1970s	01, 1, 3, 4, 6
M. PRODAN	1940s, 1950s, 1960s, 1970s, 1980s, 1990s	01, 1, 2, 3, 4, 5, 7
W. v. JAZEWITSCH	1940s, 1950s, 1960s	6
M. SPIECKER	1940s, 1950s	4
A. RICHTER	1950s	7
E. ALTHER	1950s, 1960s, 1970s, 1980s	1, 4
H. GROSSMANN	1950s, 1980s	7
G. HILDEBRAND	1950s, 1960s, 1970s, 1980s, 1990s	1, 4, 5, 7
D. ECKSTEIN	1950s, 1960s, 1970s, 1980s	6
W. ERTELD	1950s, 1960s	3, 4
R. MAGIN	1950s	1, 3, 4
G. MÜLLER	1950s, 1960s	1
H. U. MOOSMAYER	1950s, 1960s, 1970s, 1990s	2, 4
O. DITTMAR	1950s, 1980s	1, 4
E. ZIMMERMANN	1950s, 1960s, 1970s, 1980s	4
H. KRAMER	1950s, 1960s, 1970s, 1980s, 1990s	01, 1, 2, 3, 4
K.E. HALLER	1950s, 1960s	7
P. ABETZ	1960s	1, 4, 6
H. PETRI	1960s, 1970s	3, 4
J. POLLANSCHUTZ	1960s, 1970s	1, 3, 6
W. SCHÖPFER	1960s, 1980s	1, 4
F. FRANZ	1960s, 1970s, 1990s	2, 4
E. HOLLSTEIN	1960s, 1970s	6
F. ZÖHRER	1960s, 1970s, 1980s	1, 3, 7
D. BERGEL	1960s, 1970s, 1980s	1, 2, 4
A. AKÇA	1970s, 1980s, 1990s	01, 1, 7
B. SLOBODA	1970s	1, 3, 4
J. HRADETZKY	1970s, 1980s	1, 4
A. van LAAR	1970s, 1980s, 1990s	01, 2, 4
D.R. PELZ	1970s 1980s 1990s	7
K. GADOV	1980s	3

Contributor	Printing year(s)	Field
H. SCHMIDT-VOGT	1980s, 1990s	01, 3, 4
H. SPELLMAN	1980s	7
R. ULBRICHT	1980s	7
M. KÖHL	1980s, 1990s	7
T. PREUHSLER	1990s	1, 3, 4
H. PRETZSCH	1990s	1, 3, 4

Selected contributors: 18th century 5 %
19th century 35 %
20th century 60 %

Fields: 01 = textbooks, 1 = tree and primary products, 2 = site evaluation, 3 = stand structure, 4 = stand growth and yield, 5 = biomass studies, 6 = tree ring studies, 7=forest inventory and remote sensing, s = statistics

4.21. Comments

The British forestry historian N. D. G. James wrote in his last paper (1996): "By 1770, the Germans were going a reputation as foresters. The reasons are not difficult to recognize, Germany was in the fore front of a more technical approach to forestry. An increasing number of books on forestry matters were being published in Germany which provided valuable sources of information as well as a means of disseminating new ideas. The importance of education was realized and a number of forestry schools were formed, several of which subsequently merged with universities" (p.17).

To write o short history of German forest mensuration is not an easy task to the fact that historian's subjectivity cannot be avoided in such a manner to obtain uncriticizable conclusions. The most disputable problem is the selection of works and events considered as representative for a period which lasted almost two and a half centuries (1753-1999) More than 2000 published works containing information on forest mensuration and out of tem 857 were selected and mentioned in this text. from the cited papers 23 % were printed after 1980 and 12 % after 1990.

The most frequent subjects are: log and tree measurement, stand growth and yield, textbooks and local or regional studies, forest inventory and the use of remote sensing, Stand structure, and tree ring studies.

The periodic values of all cumulated works (all fields) have two maximums: (a) 1881-1900 and (b) 1941-1960 (1980). The maximum (a) coincides with the "culmination" for the application of the theory of solids revolution, form factors and empirical studies on tree volume resulted in volume tables. The second maximum (b) is in concordance with the application on a large scale of mathematical statistics methods in forest mensuration.

After 1960 or 1980 (depending on the field) many fields seem to present a decreasing trend except: 1) growth and yield modelling whose powerful increasing trend begun in 1961-1980 and coincided with the use of simulation technique and computerized models which become the leading field in post 1961 period, and 2) forest inventory and use of German remote sensing and GIS techniques.

In our opinion the following four periods could be delimited in the history of German forest mensuration:

The first period (1765-1840) can be called "Forstmathematik" period and is characterized by the use of stereometry (part of the geometry which has as object the mensurement of solids) especially the application of the theory of the solids of revolution for log and stem volume determination. This is the period of form factors introduction, of classical formulae for log volume, of the first growth function and first yield tables based on graphical methods. The most important representants of this period are the personalities such as Oettelt, Krunitz, Paulsen, Hossfeld, Cotta, König, Huber, Smalian, Riecke, Berg and K. Heyer.

The second period will be named as "predominant empirical" but during its decades (1840-1920) some theoretical aspects based on mathematical and statistics as form quotient theory and relations between form factors and form quotients have not been neglected. The dominant works of this period refer to tree form, volume tables, yield tables, different devices for measurements, determination of stand volume and assortments by tree sample techniques, the first function of tree volume, the development of stem analysis and early works on stand growth. The most representative personalities of this period are F. Baur, Pressler, Lorey, F. Grundner, Schappach, Kopezki, Gerhardt, Eichhorn, Draudt, Urich, Hartig, Kunze, Schuberg and U. Müller.

The development of mathematical statistics had a powerful impact on the further development of forest mensuration and the third period (1920-1960 (1970) was dominated by the works based on statistical methods, especially the use of regression equations. Another characteristic of this period was the consideration paid to biological factors in tree-stand study on growth. The most investigated fields in this period were stand structure, local and regional studies, tree form studies, yield tables and equations, stand volume and growth determination by conventional methods. Important works were completed during this period by Hohenadl, Bertalanffy, Vanselow, Bruno Huber (first German tree ring-dating), Prodan, Krenn, Weck, van Laer, Spiecker, Mitscherlich, Wiedemann, Assmann, Franz, Schober et al. The syntheses developed in this period that deserve to be mentioned are Assmann's "Waldertragslehre" (1961), Prodan's "Forstliche Biometrie" (1961) and "Holzmesslehre" (1965) an Mitscherlich's "Wald, Wachstum und Umwelt" and Loetsch et al. “Forest inventory”.

The beginning of the last period - the period of growth and yield modelling was marked in 1963, by Assmann and Franz's first yield table based on complex mathematical model to be solved by computers. During this period the growth decline phenomenon has been studied, a lot of models have been constructed and growth and yield in mixed stands were simulated, models based on detailed analyses of site and environmental factors have been developed and new measurement techniques (electronic calipers and mobile data recording instruments) and modelled spatial stand structures were introduced. National Forest Inventory and the use of remote sensing techniques were adopted. Among the contributors to the development of this period it will be mentioned Assmann and Franz, Dong, van Laar, Akça, Hildebrandt, Pollanschutz, Sloboda, Schmidt-Vogt, Kramer, Peerenboom and Petry, Wenk, Preuhsler, Moosmayer, Pretsch, Haller, Zöhrer, Pelz, v. Gadow, Köhl, Preuhsler, Pretzsch et al.

The development of modelling in Germany was influenced in some ways by the works completed in this field in the U.S.A.

German literature on forest mensuration (and other fields of forestry) had a strong impact on the development of this discipline in other countries among which it should be mentioned almost all European countries and non European such as India, Philippines, Latin American countries, the U.S.A. and Canada. Some German foresters have become well- known since the end of the 19th century and were leaders in foreign forest institutions. For the sake of history a few examples will be presented here.

In 1904, A. Schwappach's "Forestry" was translated into English and published in London.

Dietrich Brandis (born and trained in Germany was appointed in 1864 as the first general inspector of forests in India and was instrumental in establishing the Imperial Forest College of Dehra Dun in 1878. Brandis was succeded in his function in India by W. Schlich in 1883 who at his turn was succeeded by other German forester, Berthold Ribbentrop, in 1888. W. Schlich returned to the United Kingdom in the 1885 upon a British government invitation and organized the Forestry Branch of the Royal Indian Engineering College at Cooper's which was transferred to Oxford University in 1905. Schlich published a "Manual of Forestry" (1889-1896) in five volumes (for details see the U.K.). Chapter William Schlich was appointed in 1909 a "Knight Commander of the Indian Empire" (N. D. G. James, 1996).

Another representative German forester was Bernhard E. Fernow (a pupil of Gustav Heyer) who became chief of the Forestry Division of the United States, Department of Agriculture in 1866-1899, and organized the New York State College of Forestry at Cornell University and was its first director until 1903. In 1907 Fernow became dean of the Faculty of Forestry at the University of Toronto. His most important works were "Economics of Forestry" (1902) and "A Brief History of Forestry in Europe, the United States and other countries (1907, 2nd edn. 1913).

Another German forester was Carl A. Schenk (he studied at the universities of Tübingen and Giessen) who managed the forests of G. W. Vanderbilt's Biltmore estate in North Carolina, established Biltmore Forest School in 1898, retired from Biltmore in 1909 and returned to Germany in 1913 (Cleeper 1971). C. A. Schenck published in 1905 a work that was in fact the first American "Forest Mensuration" textbook, at Sewanee, Tennessee, just one year before the first edition of Grave's "Forest Mensuration" (1906, 2nd printing 1910) usually considered the first American textbook in spite of the fact that Graves cited in his book Schenck's work. We compared the contents of these books and observed similitudes in many compartments. Grave's book is an excellent and extensive old standard forest mensuration text of early of 20th century whereas Schenk's text is a synthesis for the people who wanted to teach forestry at that time.

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5. POLAND

General information

Land area 304,450 sq. km (117,553 sq. mi.), forest and other wooded land 86,720 sq. km (33,484 sq. mi.), total forest 8,672,000 ha (33,484 sq. mi.) or 28 % of land area; volume m^3/ha, biomass 108 tons/ha. (FAO 1995-124 Forest resources assessment 1990).

Round wood production: industrial round wood 15.3 mil. m^3, fuel and charcoal 3.0 mil. m^3, total round wood 18.3 mil. m^3 (World Resources 1996-1997, table 9.3, p. 220).

Forest vegetation: Temperate mixed forests

- Conifers 84 %
- Broad-leaved 16 %
- Main species: Scots pine (*Pinus sylvestris*) ca. 73%, Norway spruce (*Picea abies*) ca. 8%, European beech (*Fagus sylvatica*), oak (*Quercus robur*), hornbeam (*Carpinus betulus*) alder (*Alnus* spp.), tremble aspen (*Populus tremula*).

Forestry education and research organizations involved in the area of forest mensuration and forest management (data of establishment given in brackets):

- Warsaw Agricultural University, Faculty of Forestry, Warsaw, (1816).
- The Forest Research Institute, Warsaw, (1930).
- Krakow Agricultural University, Faculty of Forestry, Krakow, (1945).
- Agricultural University of Poznan, Faculty of Forestry, Poznan, (1951 ?).

Publications (Primary Journals and Serials):

- Las Polski, Warszawa.
- Sumarski list.
- Sylvan.
- Acta Agraria et Silvestria.
- Folia Forestalia Polonica.
- Panstowe Wydawnictwo Rolnicze i Leśne.
- Roczniki Nauk Leśniczych.

5.1. Textbooks and general problems of forest mensuration

In 1926, Wielgosz discussed the accuracy of forest measurements. Later, in 1932, Jedlinski and Grochowski presented methodological principles of forest research and experiments in Poland.

”Dendrometria” – a forest mensuration textbook – was completed in 1949 and another one was printed in 1957 by Grochowski in Lodz and Warszawa. Grochowski’s “Dendrometria” has the similar structure and contains five sections: (1) measurement of felled trees; (2) measurement of standing trees; (3) stand inventory; (4) determination of the age of trees and stands and; (5) increments of trees and stand. It should be noted that forest inventory of larger forest areas and the problem of allocation of felling areas is outside the scope of this book. A revised edition of Grochowski’s book was printed in Warszawa in 1973.

The methods and problems of forest mensuration were analyzed in 1958 by Borowski while in the same year a new “Dendrometria” was printed in Poznan by Wielgosz and Zabielski.

In 1959, Gieruszinski published “Promiar drzew I drzewostanow” (Measurement of trees and stands), a text in which he proposed his form quotient

$$k_{GIC} = \frac{(d_{0.5})^2}{d}$$

where d=dbh and $d_{0.5}$ is the diameter at 0.5 height, a form factor $f_{0.1} = 0.58k^2{}_{0.5} + 0.25$, and the formula for a section of volume

$$V = l\left(0.23_{g_{0.1}} + 0.58_{g_{0.5}} + 0.19\, g\right)$$

where $g_{0.1}$, $g_{0.5}$ and g_s are sections of the stem (log) at 0.1, 0.5 and the top.

The development of the forest mensuration in Poland between 1918 and 1968 was summarized by Borowski (1968).

At the same time (1968) Borowski presented biometrics including growth characteristics of lowland and mountain spruce stands which represents population studies of Norway Spruce in Poland. In 1970, Borowski published his “Pomiar drzew I drzewostanóv” (Measurement of trees and stands).

Bruchwald and Rymer-Dudzinska (1978/1980) published the “Mensurational characteristics of Scots pine stands in Poland”, a series of six papers: (1) Tables of stem form factors with and without bark; (2) appraisal of regression equation determining the relation between height and dbh within a stand; (3) a unified system of equations of height curves in relation to dbh; (4) over bark stem volume tables; (5) under bark stem volume tables; (6) merchantable volume tables for standing stems.

A more recent forest mensuration textbook is “Dendrometria”, written by Bruchwald (1986).

Cited authors:

Borowski 1958, 1968 a, 1968 b, 1970; Bruchwald 1986, Gieruszyhski 1949, 1959, Grochowski 1957, 1973; Jedlinski and Grochowski 1932, Wielgosz and Zabielski 1958.

5.2. Tree

5.2.1. Measurements of trees and logs

In 1931, Grochowski proposed a new method for the measurement of tree and stand height and Taraszkiewicz described a "new method" for determination of volume increment. Volumetric formulae for felled trees were developed by Czuraj (1948) and by Gieruszynski (1948b) who determined in 1953 the accuracy of Huber's formula used on a large scale in Poland. A dendrometer (hypsometer) is described by Matusz in 1955: Klepac (1958) established the relationship between the diameter over bark and the bark thickness for the most important Polish species.

Borowski determined the intensity of volume increment in Scots pines grown in Poland. In 1961, Grochowski and Rymerówna presented the results of investigations on the contribution of the bark to the volume of stems in pine stands.

Kawalec and Krupinski (1988) developed "the coincident for the diameter measurements of a standing tree". The concept of diameter measurement of coincident measurement of a parallactic angle was discussed by the authors and the design, construction and operation described a new Polish dendrometer based on this principle and named it codimeter which enables rapid measurements of distance, stem diameter and height from any distance and at large inclination of the height using a staff of set length mounted on the tree. The mentioned values can be taken directly from the scales of the instrument without other determination for further conversion.

5.2.2. Tree form

Grochowski (1932, 1937) underlined the importance of the determination of stem form of trees in forest experiments and forest mensuration. A more detailed work on stem form of forest trees was completed in 1948 a by Gieruszinski. Another detailed study on form factor and taper was performed in Scots pine stands of Rogowa (forest) area by Cichowski (1950, 1954).

Radwański (1955) constructed volume and taper tables for Scots pine, and the same type of tables were constructed for spruce by the same author in 1956 and 1957.

Grochowski presented in 1961 the results of investigation on the breast-high form factor ($f_{1,3}$) of stem in pine stands and for the true form factor in 1962.

Rymer–Dudzińska determined in 1962 the dependence of breast-high form factor ($f_{1,3}$) of stems on bark thickness in pine stands. In 1964, Grochowsky investigated form quotients in pine stands (q).

In 1978/80 Bruchwald and Rymer–Dudzińska constructed form factors tables for stems with and without bark for Scots pine. In 1996 these authors proposed a new empirical formula for defining dbh taper curve shape in spruce thick wood. The equation is based on dbh alone and can be used for estimating stand thick wood volume using methods which measure dbh.

5.2.3. Volume tables and equations

Among the earlier Polish volume tables the one published by Dyrr in 1932 will be quoted. Volume tables constructed by Grundner and Schwappach were proposed by Grochowski (1953 a) and the obtained errors in the case of their use, as von Laer's tables, were determined for Scots pine stands (as an example of error determination). In 1956 Gieruszynski studied the accuracy of Grundner–Schwappach's volume tables in case of spruce.

Emrovic (1957) advocated the use of French Algan–Schaeffer tariffs in Poland and constructed nomograms (alignment charts) for Schaeffer "lent" (slow) tariffs and Algan–Schaeffer's "rapides" (rapid) tariffs presented in the Figures 5.2.3.–1. and 5.2.3.–2.

Bruchwald and Rymes Dudzińska (1978/1980) constructed for Scots pine volume tables showing over bark and under bark stem volume and merchantable volumes tables for standing stems.

In 1988 (a, b) Bruchwald and Rymer–Dudzińska established empirical formulae (equations) for determining the stem volume of standing Scots pine (a) and spruce (b) trees. In the case of Scots pine they investigated 6,300 trees having 29-95 years old and found three strong relation between breast height form factor ($f_{1,3}$) and different diameter quotients were used to develop three equations for determining volume of standing trees form diameter and height data, but for spruce (b) only two equations were established. A similar work was completed by Michalak (1988) who based on empirical formulas constructed volume tables for Scots pine standing trees and assortments of thick round wood to be determined from measurement of height and dbh.

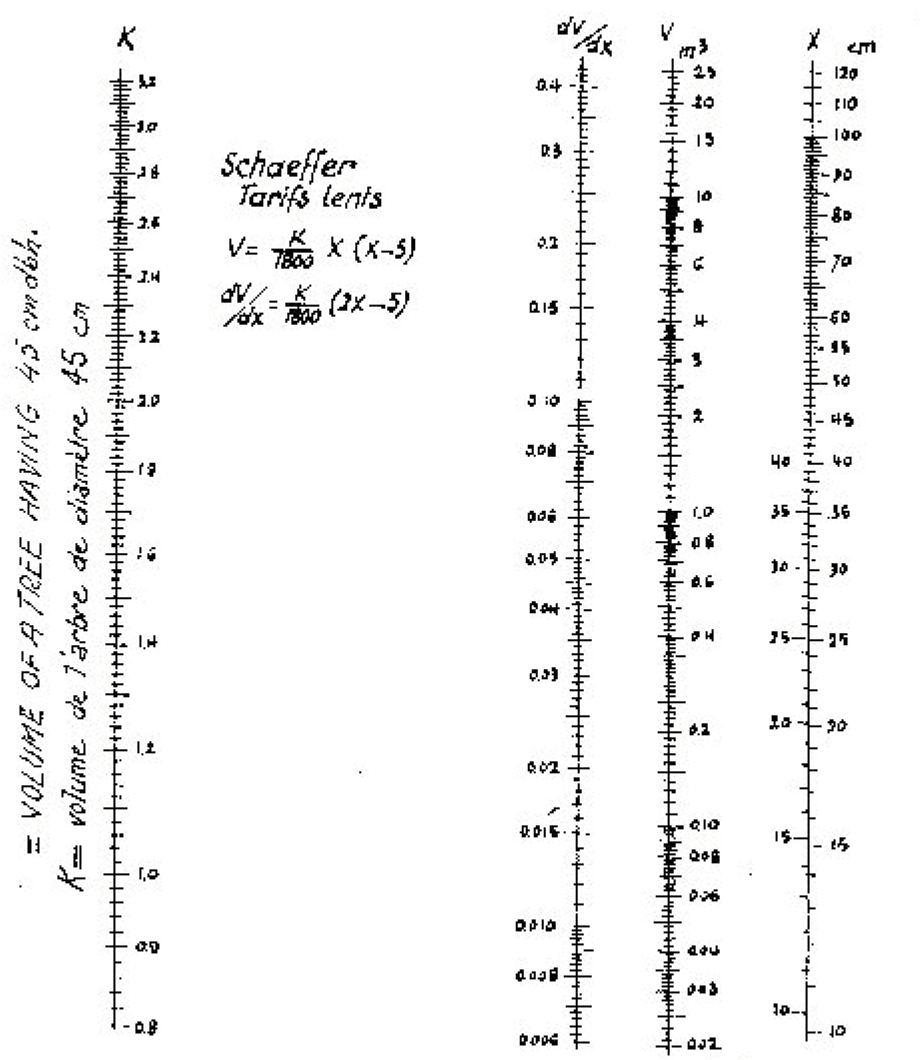

Fig. 5.2.3.–1. Nomogram "Emrovic" for Schaeffers's tariff lent. For estimation of dV/dx when x<40 cm use the left part of x axis.

SOURCE: Original : Emrovic, B. 1957 "Nomogrami za Algan – Schaeffer ove Tarife" , Sumarski List nr. 7/8 p. 293–302. Reproduced after Pardé 1961, "Dendrometrie ", p. 290, fig. 129.

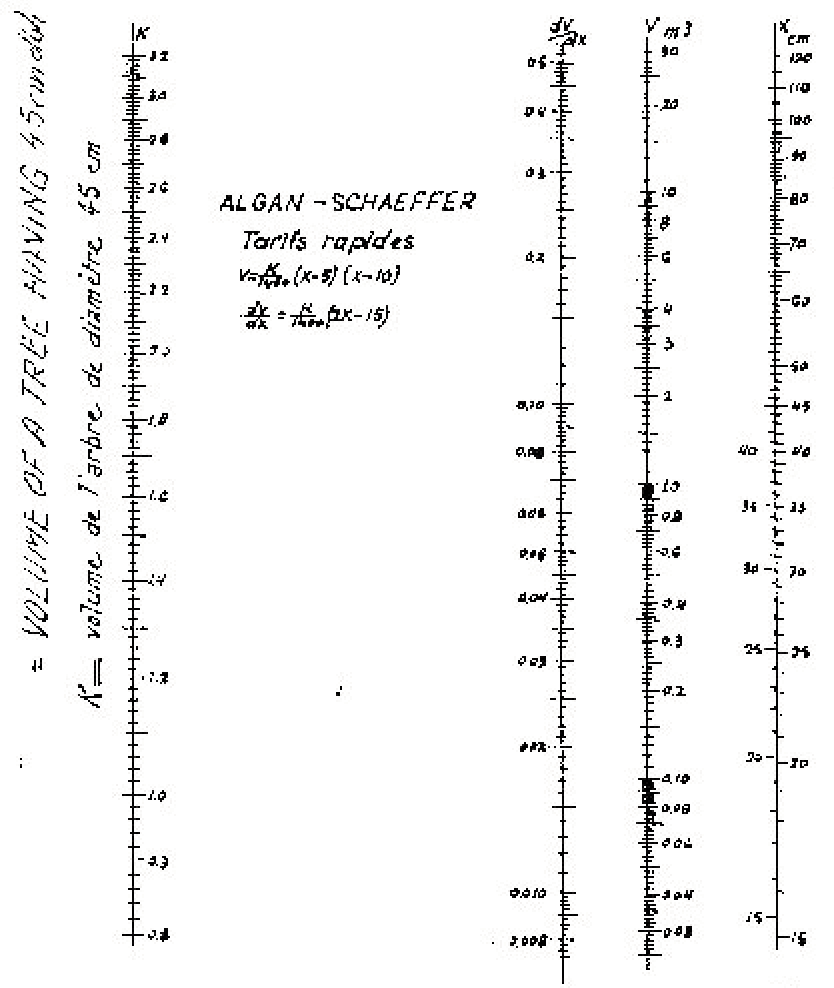

Fig. 5.2.3.–2. Nomogram "Emrovic" for Algan /Schaeffer tariff rapid. For estimation of dV./dx when x<40 cm – use the left part of x axis.
SOURCE : Original: Emrovic, B. 1957, "Nomogrami za Algan–Schaeffer ove Tarife ", Sumarski List nr. 7/8 , p. 293 – 302. Reproduced after Pardé 1961, "Dendrometrie", p. 291, fig. 130.

In 1996 Bruchwald and Rymer–Dudzińska determined the accuracy of the assessment and estimation of spruce stand volume using the IBL tables (IBL = Instytut Badawaczy Lesnictwa, Poland = First Research Institute in Poland). They concluded that in pure spruce stands IBL tables gave a systematic positive error for volume estimation, with a mean percentage of 8.2 % and a standard deviation of 13.6 % over the 414 stands. For mixed spruce – Scots pine stands the mean percentage error was + 14.6 % with a standard deviation of 25,3 % but errors over 25 % occurred in stands of the 1st, 2nd and 3rd age classes. The above-mentioned authors concluded that IBL volume tables “are not precise enough for general use and that they should be withdrawn”.

Cited authors (7.3.2.):

Borowsky 1961, Bruchwald and Rymer–Dudzińska 1978/1980, 1988a, 1986, 1996a, 1996b; Chojnacki 1954, Cichowski 1950, Czuraj 1948, Dyrr 1932, Emrovic 1957, Gieruszynski 1948 a, 1948 b, 1953, 1956; Grochowski 1931, 1932, 1937, 1949, 1953a, 1961, 1962, 1964; Grochowski and Rymerówna 1961, Kavalek and Krupinnski 1988, Klepak 1958, Matusz 1955, Michalak 1988, Radwanski 1955, 1956, 1957; Rymer–Dudzińska 1962, Taraszkiewicz 1931.

5. 2. 4. Application of fractal dimensions as measures of leaf

Borkowski published in 1999 an application of fractal dimensions “as measures of leaf complexity to morphometric studies and automated plant identification”. In this paper an analysis of complexity of more than 300 leaves from ten tree species is reported. The author demonstrated that properly defined fractal dimension based features may be used to discriminate between species with more than 90 % accuracy, especially when used together with other measures. It seems, therefore, that they can be used in computer identification systems and for purely taxonomical purposes” (Author’s abstract p. 1301). Since many branches of natural sciences are used frequently since 1980 the fractal dimensions for determining complexity the cited references are very useful for the readers involved in this field.

5.3. Stand structure

The distribution of trees by diameter categories was studied in Poland by Kusal (1929), Jedlinski (1933), Dudzinski (1960), Bruchwald (1988). Bruchwald used data from 782 plots in Scots pine stands and constructed a simulation algorithm of the distribution of trees by dbh diameters.

Jasienki (1934) investigated the structure and growth of two Scots pine rases using biometrical methods.

Optimal structure of fir stand and their tending was studied by Szymkiewicz in 1951.

Gieruszynski (1960) analyzed the variability of mensurational characteristics of the stem in nature spruce stands. Guminski (1967) investigated the structure of stands taking into account, by selective classes, the growth and the “hartwood”. A comparative analysis of structure and growth of fir, spruce an Spruce–fir stands was performed by Magnuski in 1967.

Bruchwald and Rymer–Dudzińska used Näslund’s function in the development of standard height curves for Norway spruce (1981).

The studies of the social structure of Scots pine stands using Kraft's method were completed by Wróblewski in 1984. His new method of classifying the structure of stands was based on data from 332 stands. A single value, the medium Kraft class (S), is defined as $n_1 + 2n_2 + \ldots + 6n_6$ divided by the number of trees in the stand, where $n_1, n_2, \ldots n_6$ are the numbers of trees in Kraft classes I, II, III, IV_a, IV_b, and V_a, respectively. The S values varied from 1,8 to 4,4 , and the profile of Kraft classes corresponding to different volumes, is presented in tables and graphs. There is a significant negative correlation between S and age. There is a variation of this relation with site class: the higher the value of S, the greater the need to improve stand structure. Wróblewski analysed also the potential fir medium Kraft class as an aid to planning thinnings.

Bruchwald and Rymer–Dudzińska established in 1990 a correlation between the variability of the pine tree height and different variables of the stand: relations are developed by site class between height variation coefficient and height variation coefficient excluding the influence of dbh in one situation and standard deviation of dbh on the other. In the same year the above-mentioned authors investigated the relationship between the height and dbh of pine trees according to various variables of the stand in the site classes. Relations were developed between tree height and dbh on the one hand and average height, average dbh, stand age and the standard deviation of dbh on the other.

Based on the data from 453 stands Bruchwald and Wróblewski (1994) constructed uniform height curves for Norway spruce stands, based on Näslund's function. The constructed equation can be expanded to the form of tables of uniform height curves. This work was done as a part of research project for developing a stead growth model.

Cited authors:

Bruchwald 1988, Bruchwald and Rymer–Dudzińska 1981, 1990 a, 1990 b; Bruchwald and Wróblewski 1994, Dudzinski 1960, Gieruszynski 1960, Guminski 1967, Jasienski 1934, Jedlinski 1933, Kusal 1929, Magnuski 1967, Szymkiewicz 1951, Wróblewski 1984.

5.4. Stand volume

The use of Ulrich's and Hartig's methods for the determination of stand volume in Poland is confirmed in 1933 by Wedzinski. Gieruszynski (1938) underlined the importance of stand volume stimulation based on the Kopezky-Gerhardt method. Trampler (1951) published a set of tables for stand volume determination.

The h-d curve was used in Poland for stand volume calculus using volume tables (in the use of standing trees).

Comparative evaluation of the accuracy in stand volume determination by Hohenadl's and by the method of mean basal area of stand was presented in 1965 by Rymer–Dudzińska, the importance of stand volume determination based on sample trees was underlined by Borowski in 1966.

The use of different volume tables was compared in the case of Scots pine stands by Lemke in 1967 and 1970 (tables Radwanski and Grundner–Schwappach), and Dudek in 1968.

In 1971, Bruchwald described a method for the estimation of stand volume (standing trees) without bark and Rymer–Dudzińska studied the possibilities to determine the average values of a stand dendrometrical characteristics using the techniques of mathematical studies.

Cited authors:

Borowski 1966, Bruchwald 1971, Dudek 1968, Gieruszynski 1938, Lemke 1967, 1970, Meixner 1964, Rymer–Dudzińska 1965, 1972; Trampler 1951, Wedzinski 1933.

5.5. Stand growth and yield

5.5.1. Stand growth

The influence of different methods of thinning on growth and development of trees and stands was analyzed by Grochowski in 1929 who discussed in 1936 the possibilities of improvement and simplification of stem growth determination. In 1938 Gieruszynski explained the computation of stand growth in volume.

Sikora (1951) published studies on the measurements of stand growth using the sample trees of the Draudt method.

A method of investigation the volume increment of stands was presented by Grochowski in 1953. A study on the accuracy of different methods of stand growth determination was completed by Borowski in 1956.

Trampler and Sikora (1956) analyzed how to determine growth during the management works in Poland.

Gieruszinski (1960) discussed in a detailed paper the variability of stem characteristics in mature spruce stands.

A study on the methods of estimation of current increment of stand volume was published in 1960 by Lemke, and Bruchwald (1964) determined precision in the assessment and estimation of current volume stand increment in Scots pine stands using volume tables and plots. Growth and increment of height in Scots pine stands was investigated by Michalak in 1970.

For growth determination of mature Scots pine stands Borowski used special growth tables. The growth of Scots pine stands was investigated also by Dudek

(1971) who used percentage tables for growth volume.

Zabielski (1981) constructed tables for the estimation of current volume increment of pure and mixed stands.

Detailed studies on productive potential of oak forests (*Quercus robur/Q. sessiliflora*), 51–104 years, growing on moist and flood plain sites in the western half of Poland), based on long term investigations of permanent plots were completed by Pirogowicz (1988), who concluded that thinning from below gives better results than thinning from above, in these type of stands.

Rymer–Dudzińska (1990) presented change of the height growth rate in pine stands growing under the influence of industrial emission – data are obtained from stem analysis.

A stochastic growth model for pedunculate oak (*Quercus robur*) stand was developed in Poland, in 1996, by Bruchwald, Dudzińska and Wirowski. In the proposed model functions representing growth, competition and stand structure development are incorporated. The model used empirical data from temporary and 339 permanent plots. The model is based on the following functions: (1) function defining stand quality – the basic model function - which represents the change with age of stand top height; (2) function which represents the change in maximum numbers of trees in the stand by stand quality classes with age; (3) dbh growth; (4) constant height curves; (5) stem form indices. The model has four algorithms: introductory, thinning, tree mortality and increment, and two variants: (1) a model which requires data on stand age, dbh and height, and the size, of the area on which dbh measurements were made, and; (2) a model which required only data on stand age, quality class and density and is suitable for young stands where dbh is not measured (For. Abs. 6896-1997).

At the same time (1996), Bosiak et al. published a provisional growth models for birch, alder, aspen, aspen and larch stands. The model is based on MKG model, developed earlier by the authors for pine but with the basic functions replaced with new ones based on data from Szymkiewicz's (1952) yield tables.

5.5.2. Yield tables and regionalization of yield stands

Early Polish yield tables were constructed for Scots pine stands in Poland by Jedlinski (1932). The next more known yield tables constructed for the same species belong to Wladyslaw Plonski.

An analysis of the use of Schwappach Scots pine yield tables was completed by Pawlak in 1948. In the same year Szymkiewicz mentioned some observation on Scots pine yield tables and next year (1949) he published his recommendation how to use Schwappach's Scots pine tables for pine stand included in *Ia* productivity class.

In 1952 Szymkiewicz compared the result of Polish and foreign yield tables used for the main forest species grown in Poland.

In 1961, 1966 and 1971 Szymkiewicz constructed yield tables for the main Polish species using also data from old permanent plots established early and used for Schwappach and Radziecki yield tables. The most known is the 1996 edition of Szymkiewicz yield tables, which contains five stand productivity classes, age and average stand height as entries characteristics.

Kwiecień and Plotkowski (1985) completed a trial of regionalization of low-yield stands based on data for Bialystok forest province. "The 30 forest districts in the province have been divided into three regions based on analysis of data on 7 indices relating to low yield stands (percentage area of low-yield stands; growing stock in low-yield stands (m^3/ha), loss of timber production (m^3/yr), total loss of production (million zloties), average age of low yield stands; average stocking of low-yield stands, and percentage area of conifers amongst low-yield stands. Districts with most similar composite characteristics are grouped together. Within each region, districts can be ranked according to the urgency of rehabilitation of their low-yield stands using any of the indices or using a synthetic index based on all 7" (For. Abs. 1706/1989).

Cited authors (7.3.5.):

Borowski 1956, 1971; Bosiak et al. 1996, Bruchwald 1964, Bruchwald et al. 1996, Dudek 1971, Gieruszynski 1938, 1960; Grochowski 1929, 1936, 1953 b; Jedlinski 1932, Kwiecen and Plotkowski 1985, Lemke 1960, Michalak 1970, Pawlak 1948, Pirogowicz 1988, Plonski 1937, Rymer–Dudzińska 1990, Sikora 1951, Szymkiewicz 1948, 1949,1952,1961, 1966,1971; Trampler 1956, Zabielski 1981.

5.5.3. Assortment tables

Borzemski seems to be the most representative author in the field of wood assortments at least between 1936 and 1965.

In 1936 Borzemski published assortment tables for Scots pine stands (if not first at least ones of the earliest). In 1957 he developed an improved method for construction of Scots pine stands assortment tables. In 1961 new Scots pine stands assortment tables for mature Scots pine stands were completed by Borzewski, and in 1965 he constructed assortment tables for mature and middle aged spruce stands.

5.6. Biomass studies

The only available work in this field in Poland is the Zajaczowski (1983) estimation of the above ground biomass of Scots pine thicket established in different spacing. In the field a 17-year old *Pinus sylvestris*. L. thicket near Warsaw was investigated. To estimate biomass power equations were used: $w = ad^b$ or $w = a/d^2\ h/^b$, d = dbh, h = height. The authors concluded that: “The most precise way (with using sample trees) to establish the influence of different spacing on above grand biomass of Scots pine thicket is as follows: (1) using d^2h as an independent variable; (2) application of the “every tree summation“ method with the using Finney’s correction (see Madgwick H.A.I, Satto I. 1975: On estimating the aboveground weights of tree stands. Ecology 56, 1446–1450). The less precise methods change the relations between variants (INRA – 31, p. 347). The result of this work was summarized in Table 5.6.–1. and considered to be very useful as Scots pine is the main species in Poland.

TABLE 5.6.-1. The STANDARD model on stand dry weight in different spacing variants.

Variant	Dry weight t/ha					
	Needle	Shoots with needles	Branches live and dead	Bole	Crown	Whole tree
0.8 x 0.8	7.72	11.69	10.68	29.98	16.98	52.28
1.0 x 1.0	6.34	9.60	13.01	34.53	18.29	57.48
1.2 x 1.2	8.05	12.22	14.44	28.33	21.83	55.47
1.2 x 0.55	8.17	12.21	10.22	36.30	18.61	59.04

SOURCE: Zajaczowski 1983, “On estimating the above ground biomass of Scots pine thicket estabilished in different spacing”, LES Colloques de l’INRA Nr. 19, p. 348, table 1, France.

5.7. Tree-ring studies

K. Ermich, the founder of Polish dendrochronology, noted in 1955 the dependence of diameter growth of trees from Tatra Mountains on the climatic fluctuations. In 1963, he investigated the interception and the end of the annual tree ring formation in *Fagus sylvatica* L., *Abies alba* Mill, and *Picea abies* L. in the Tatra Mountains. Later, in 1976 Ermich et al. published an interesting paper on the possibility of using dendrochronological curves as an indicator of site conditions. Data from 13 sites were considered and the results “permitted a reasonable solution to the problem of the selection of forest trees adopted to a given type of habitat, since expressed by the probability of the occurrence - sectors may be used as an indicator of the adaptation of trees to the habitat” (p. 7 Tree Ring Bull., 1976, vol. 36).

Feliksik (1972) used Norway spruce in his dendroclimatological study. In 1980, Wodzicki performed experiments in the stem cambial region and revealed oscillations of polar transport of endogenous auxin along the stem forming wave–like pattern and concluded that “the fact that the wave amplitude modulations may propagate within the plant tissues faster than the known velocities of polar transport of auxin molecules is taken as an evidence of operation of the integrated system of coupled oscillators” (p. 173).

A remarkable textbook on the methods of dendrochronology was published in 1987 by Kairiukstis, with Bednarz and Felikstik as editors.

In 1990 Bednarz and Ptak published the results of the investigation on the influence of temperature and precipitation on ring width of oak (*Quercus robur* L.) in the Niepolomice forest near Kracow, southern Poland. The analysis of the relationship between ring – wide indices with average monthly precipitation (1881–1985) revealed a strict relationship between tree growth and the precipitation of June – July, May – July and June – August. The influence of air temperature on oak ring – width indices was less significant and the highest positive correlation occurs from January to April of the preceding year.

Giefing (1995) developed studies supplementing the dendrochronogical model for the Wielkopolska, Poland.

Problems of dating alluvium using buried subfossil tree trunks as lessons from the black oak (*Quercus petraea, Q. robur*) of the Vistula Valley were discussed by Kalicki and Krapiec (1995). The modern dendrochronological standard for Norway spruce (*Picea abies* (L.) Karst) was established by Szychowska-Krapiec in 1999 for Beskid Zywieki region.

Cited authors:

Bednarz and Ptak 1990, Ermich 1955, 1963, Ermich et al 1976, Feliksik 1972, Giefing and Krapiec 1995, Kairiukstis et al. 1987, Kalicki and Krapiec 1995, Szychowska - Krapiec 1999, Wodzicki 1980.

5. 8. Forest inventory and remote sensing

Untill 1980s forest inventory was practiced in Poland on relatively small areas, like in other Central European countries. In 1981, Rutkowski analysed the errors and practical accuracy of mathematical/statistical systems of forest inventory.

In 1983, an inventory was made for all state forests in Poland. The basic units of this inventory were circular plots of different areas (0.005 ha for stands of age class II a, 0.01 ha for II b, 0.02 ha for III and 0.04 ha for IV and older). A map of provinces classified according to the % trees is given. The best provinces were Lódz, Radom, Bialystok and Lublin, and the worst were Szczecinek, Pila, and Torun (Fuchs 1984).

Inventory data for Scots pine stands of age class III and older located in central Poland were analysed and the results for currently used inventory methods compared with those using stratification of stands into groups based on age class. Stratification reduced sample requirements to about 30 % of that with current methods (Stepień and Borecki 1986, For. Abs. 1401/1988).

A review of the literature referring to sample plot size and random sample plot size was completed in 1985 by Borecki (1985a, 1985b).

Remote sensing was used in the assessment of the condition of forests in the Western Sudety Mountains. Pancromatic and near-infrared aerial photographs (1: 8000 to 1: 17000 scale) supplemented by satellite photographs were used (Polawski and Zawilá-Niedžwiecki 1987). Remote sensing data were used for the assessment of forest quality (Ciolkosz and Zawila-Niedžwiecki 1990, Zawilá-Niedžwiecki 1990).

The first Polish experiences with radar satellite data (ERS-1 images) were developed in 1994 by Zawilá-Niedžwieci who underlined that single radar images were difficult to interpret and classify, while multi-temporal color composites permitted the distinction of mature and young stands, clear cuts, deforested areas, afforested areas, and loose canopy closure due to defoliation and tree mortality. The accuracy of classification was similar to that by TM (For. Abs. 1215/1996).

Cited authors:

Borecki 1985a, 1985b; Ciolkosz and Zawilá-Niedžwiecki 1990, Fuchs 1984, Polawski and Zawilá-Niedžwiecki 1987, Rutkowski 1981, Stepień and Borecki 1986, Zawilá-Niedžwiecki 1990, 1994.

5.9. Chronology of selected works

1926: The theory of the accuracy of forest measurements (T. Wielgosz).

1932: Volume tables for standing trees (O. Dyrr).

1932: Volume and growth tables for Scots pine stands in Poland (W. Jedliński).

1936: Assortment tables for Scots pine stands (E. Borzemski).

1937: Polish yield tables for Scots pine stands (Wladislaw Ploński).

1948: Stem form of forest trees (T. Gieruszynski).

1949: "Dendrometria" (Forest mensuration) (T. Gieruszynski).

1951: Optimum structure of fir stands (B. Szymkiewicz).

1952, 1961, 1966, 1971: Yield tables (volume and growth) for stands of main Polish species (B. Szymkiewicz).

1955: The dependence of diameter growth of trees from Tatra Mountains on climatic fluctuations (K. Ermich).

1955: Volume and taper tables for Scots pine trees (B. Radwański).

1956, 1957: Volume and taper tables for spruce trees (B. Radswański).

1957: “Dendrometria” (Forest mensuration) (J. Grochowski).

1958: “Dendrometria” – vols. I and II (T. Wielgosz and B. Zabielski).

1959: A textbook on measurement of trees and stands (T. Gieruszinski).

1961: Assortment tables for mature and middle aged Scots pine stands (E. Borzewski)

1962: Investigation on the true form factor of stems in Scots pine stands (J. Grochowski).

1963: The interception and the end of the annual tree ring formation in *Fagus sylvatica* L., *Abies alba* Mill., and *Picea excelsa* (L.) Karst. in the Tatra Mountains (K. Ermich).

1965: Assortment tables for mature and middle aged spruce stands (E. Borzemski).

1967: Comparative analyse of structure and growth of fir, spruce and fir + spruce stands (K. Magnuski).

1968: Development of forest mensuration in Poland during the 1918–1968 period (M. Borowski).

1973: “Dendrometria“ (Jerzy Grochowski).

1976: The degree of similarity of dendrochronogical curves as an indicator of site conditions (K. Ermich, B. Rutkowski, Z. Bernarz and E. Feliksik).

1978/1980: Mensurational characteristics of Scots pine stands in Poland (A. Bruchwald and T. Rymer–Dudzińska).

1981: Tables for the estimation of current volume increment of pure and mixed stands (B. Zabielski).

1983: A large-area inventory of the health status of forests (Z. Fuchs).

1984: Studies of the social structure of Scots pine stands using “Kraft’s“ method (L. Wróblewski).

1985: Random sample plot size in statistical methods of forest inventory in Poland (T. Borecki).

1986: “Dendrometria” (Ark. Bruchwald).

1986: “Methods of Dendrochronology “ – a textbook, three volumes (L. Kairiukstis, Z. Bednarz and E. Felikstik, editors).

1987: The use of remote sensing in the assessment of the condition of forests (Z. F. Polawski and T. Zawilá-Niedžwiecki).

1988: The coincident method of diameter measurements of a standing tree: a new Polish dendrometer called codimeter (A. Kawalec and S. Krupinski).

1990: Landsat Thematic Mapper TM data for forest quality assessment (T. Zawilá-Niedžwiecki).

1994: Uniform height curves for Norway spruce stands (A. Bruchwald and L.

Wroblewski).

1994: Radar in forestry oriented remote sensing (T. Zawilá-Niedžwiecki).

1996: Provisional growth models for birch, alder, aspen and larch stands (P. Bosiak, K. Siekjerski and M. Zasada).

1996: A stochastic growth model for pedunculate oak (*Quercus robur* L.) stands (A. Bruchwald, M. Dudzińska and M. Wirowski).

1999: The use of fractal geometry descriptors of leaf complexity and shape (W. Borkowski).

5.10. Selected contributors

Author	Printing years	Field(s)
Jerzy Grochowski	1920s-1960s	1, 4, 01
T. Wielgosz	1920s-1950s	01
E. Borzemski	1930s-1960s	4
T.Gieruszynski	1930s-1960s	1, 4, 01
W. Jedliński	1930s	3, 4, 01
W.Ploński	1930s	1, 4
B.Szymkiewicz	1940s-1970	4, 3
M. Borowski	1950s-1970s	01, 4,1
B. Radwański	1950s	1
T. Trampler	1950s	4
T. Borecki	1980s	7
A.Bruchwald	1960s-1990s	1, 3, 4, 01
T. Zawila-Niedžwiecki	1980s - 1990s	7
K. Ermich	1960s-1970s	6
J. Lemke	1960s-1970s	4
T. Rymer-Dudzińska	1960s-1990s	1, 3, 4, 01

0.1 = textbooks; 1 = tree and primary products, 3 = stand structure, 4 = stand growth and yield, 6 = Tree-ring studies, 7 = forest inventory and remote sensing

5.11. Comments

According to 1815 Treaty the duchy of Warsaw was incorporated into Russian Empire, with an apparent authonomy, untill 1919 when Poland was recognized as an independent country (Versailles Treaty). A Faculty of Forestry was established in 1816 at Warsaw Agricultural University but modern Forest Research Institute was organized in 1930.

In 1860, Russians instituted “a forestry school at Novo-Alexandria, near Warsaw. In this early school as in other Russian forest schools, and in the methods of management, German influence in everywhere visible” (Fernow 1911, p. 271).

Since 1919, Polish forest mensuration is oriented especially towards Scots pine and spruce as major species of the country and less on oak species (*Q. robur* and *Q. petraea*). As Scots pine and spruce cover large areas on the western and eastern neighbours of Poland, German and Russian literature influenced more or less the development of Polish forest mensuration. The German influence has been dominant since the beginning of the 19th century and some decades Grundner–Schwappach volumes table and Schwappach yield tables were used on a large scale in Poland. Growth tables were also largely used and the trends toward growth mathematical models were firmly established in the 1990s. In the field of dendrochronology remarkable works were completed by K. Ermick, the founder of this discipline in Poland.

For the investigated period (1918-1999) we selected 121 references out of which 30% were published after 1980 and 9 % after 1990.

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6. SWITZERLAND

General information

Land area 39,760 sq.km (15,352 sq. mi.), forest and other wooded land 11,860 sq. km (4,579 sq.mi.), forest 1,130,000 ha (4,297 sq. mi.) or 28 % of land area; volume 329 m^3/ha, biomass 176 tons/ha (FAO 1995-124 Forest resources assessment).

Round wood production: industrial round wood 3,7 mil. m^3, fuel and charcoal 0.8 mil. m^3, total round wood 4,5 mil. m^3 (World Resources 1996-97, table 9.3, p. 220).

Forest vegetation: Temperate mixed forests.

- Conifers (70 %)
- Broad-leaved (30 %)
- Main species: Norway spruce (*Picea abies*). European beech (*Fagus sylvatica*), fir (*Abies alba*), Scots pine (*Pinus sylvestris*), European larch (*Larix decidua*), *Pinus cembra*, oak (*Quercus* spp.) alder (*Alnus* spp.), European birch (*Betula pendula*).

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

- ETH, Swiss Federal Institute of Technology Zürich, Division of Forest, Sciences, Zürich, (1855);
- Department of Forest and Wood Research (ETH), Zürich (1990);

Publications (Primary Journals and Serials):

- Schweizerische Zeitschrift für das Forstwesen, Zürich (Journal Forestier Suisse), 1850; publication of Swiss Forestry Association founded in 1843;
- Mitteilungen der Centralanstalt für das forstliche Versuchswesen, Zürich;
- Mitteilungen der Schweizerischen Anstalt für forstliche Versuchswesen.

"A political core of Switzerland was established in 1921 by the league of the three forest cantons (Schwyz, Uri and Unterwalden) which decided to resist encroachments on their rights by the church and by the federal barons". Majority of the country was settled by Germans, especially Burgundians, a free people determined to destroy the Austrian Hapsburg supremacy. In the 15th century Switzerland was composed from various small republics and the final separation from the German empire was completed in 1648 (Peace Treaty of Westphalia). In 1798 Napoleon proclaimed the Helvetian Republic which was reorganized in 1815 and transformed into a federation. In 1848 was brought to existence the

"Bund", the Confederation of Switzerland similar in some ways with the United States. The first forest ordinance regulating the use of a special forest area in Bern dates from 1304. But the first working plan seems to have been made for the city forest of Zürich, the so-caled Sihlwald, in 1680-1697. In 1874 it was created a central bureau of forest inspection for the whole Bund in the Department of the Interior… The execution of the law was, however left to the cantons. The timber forest (high forest) was the most general form of silvicultural management. Selection forest with 150 to 200 year rotations is practiced in the Alps and in the smaller private forest areas. In corporation forests was practiced coppice with standards. Conversion from coppice and coppice with standards into timber forest, and change from clearing systems to natural regeneration (proper for mountain forest), and from pure to mixed forest have became general provisions of the working plans". (Information extracted from B. Fernow, 1911, "A brief history of Forestry in Europe, the United States and Other countries", Switzerland, pp. 185-202).

6.1. Books containing information on forest mensuration, timber management, tree-ring studies and site quality and classification, and forest inventory including remote sensing

A sample of books containing information on timber mensuration, forest management, tree-ring studies and forest inventory is shown in Table 6.1.-1.

TABLE 6.1.-1. A sample of books containing information on timber mensuration, forest management, tree-ring studies and site quality and classification, and forest inventory

Year	Author(s)	Title	Remarks
1903	Ph. Flury	Einfluss verschiedener Durchforstungsgrade auf Zuwachs und Form der Fichte und Buche (Influence of different intensities (grades) of thinnings on growth and form of spruce and beech	246 pp.
1907	Ph. Flury	Ertragstafeln für die Fichte und Buche der Schweiz (Yield tables for spruce and beech in Switzerland)	290 pp.
1909	F. Frankhauser	Praktische Anleitung zur Holzmassenaufnahme (Practical instructions for inventory of woody stock)	3^{rd} edn.
1920	Henry Biolley	L'aménagement des forêts par la méthode expérimentale et specialement la méthode du contrôle [Forest management by the experimental method and especially the method of control (check method)]	

TABLE 6.1.-1. (cont.)

Year	Author(s)	Title	Remarks
1921	J. Braun-Blanquet	Prinzipien einer Systematik der Pflanzengesellschaften auf floristischer Grundlage (Principles of classification of the plant association based on the floristical criterion)	
1922	H. E. Biolley	Die Forsteinrichtung auf der Grundlage der Erfahrung und insbesondere des Kontrollverfahrens [Forest management based on the experimental method and especially the control method (check method)]	
1929	H. Burger	Holz, Blattmenge und Zuwachs. I: Die Weymouthsföhre (Wood, needles quantity and growth. I: Pinus strobus)	
1931	F. Frankhauser	Praktische Anleitung zur Bestandesaufnahme (Practical manual for stand inventory)	
1933	Ph. Flury	Über die Wachstumsverhältnisse des Plen-terwaldes (About growth conditions in the selection forest)	
1945	H. Burger	Holz, Blattmenge und Zuwachs. VII: Die Lärche (Wood, needles quantity and growth. VII: The larch)	
1953	H. Burger	Holz, Blattmenge und Zuwachs. XIII: Fichten im gleichaltrigen Hochwald (Wood, needles quantity and growth. XIII: Spruce in even-aged high forest)	
1953	A. Linder	Planen und Auswerten von Versuchen (Planning and evaluation of experiments)	
1966	H. Leibundgut	Waldpflege (Tending of forest)	
1974	W. Trepp	Der Plenterwald (The selection forest)	
1980	Société forestière Suisse	Biolley Henry – Oevre écrite (B. H. Written works)	Contains all works of Biolley (1901-1930)
1993	T. Fillbranat, D. Morattel, M. Pividori, D. Lüthy.	Wörterbuch für Forsteinrichtung, Waldwachstum und Dendrometrie (Dictionary for forest management, forest growth and forest mensuration)	
1983	Fritz Hans Schweingruber	Der Jahrring: Standort, Methodik, Zeit und Klima in der Dendrochronologie (Tree-ring: site, method, weather and climate in Dendrochronologie)	1st English edn. in 1988: “Tree Rings: Basics and Applications of Dendrochronology 234 pp., German edn., 276 pp

TABLE 6.1.-1. (cont.)

Year	Author(s)	Title	Remarks
1995	M. Kaennel F.H. Schweingruber (compilators)	Multilingual Glossary of Dendrochronology Therms and Definitions in English, German, French, Spanish, Italian, Portuguese and Russian	Berne 467 pp.
1996	Fritz Hans Schweingruber	Tree Rings and Environment Dendroecology (Engl.)	609 pp.
1997	J. P. Schütz	Silviculture. 2. La gestion des forêts irrégulières et mélangées (Silviculture. 2. Administration of irregular and mixed forests)	

The oldest books were written by Coaz, Flury, Frankhauser and Biolley.

In 1896/1900 Coaz published the "Das Baum-Album der Schweiz" (The Swiss Tree Album) considered by Denzler (1999) as a "description of 23 remarkable individual trees" out of which only six of the 22 investigated trees still exist and their conditions are considered to be good.

Henry Biolley (1858-1939) is considered as the most representative personality of Swiss forestry, especially in the fields of forest management and forest mensuration. Biolley's name is strongly bound to the control method (check method) practiced on a large scale in the selection forests of Switzerland. According to this method the allowable cut is equal to the current stand increment which is determined at every six or ten years by forest inventories. The detailed description of this management method is beyond the scope of this book. In connection with this method, Biolley published a set of short articles some refering to determination of increment (1906, 1921, 1928). In 1887, Biolley published some comments on the selection forest aspects discussed by Gurnaud. In fact, from a historical point of view it should be underlined that selection forest on an experimental basis was conceived in France by Gurnaud (in the 19th century - 1890 and earlier) but Biolley (1920, 1922) codified the ideas and derived from them a system of management known as the control method (méthode du control).

Other important personalities involved in forest mensuration are Flury who constructed the first Swiss yield tables for spruce in 1907, Franhauser (1909), Burger (1929, 1945, 1953), Leibundgut (1966), and Schweingruber (1983, 1988, 1996) the most representative Swiss dendrochronologist whose works on tree ring studies are some of the most important in this field.

Cited authors:

Biolley 1887, 1906, 1920, 1921, 1922, 1928; Braun- Blunquet 1921, Burger 1929, 1945, 1953; Coaz 1896/1900, Denzler 1999, Fillbrandt et al. 1993, Frankhauser 1909, 1931; Flury 1903, 1907, 1933; Gurnaud 1890, Kaennel and Schweingruber 1995, Leibundgut 1966, Schütz 1997, Schweingruber 1983, 1988, 1996; Sociéte Forestiere Suisse 1980, Trepp 1974.

6.2. Tree

6.2.1. Measurement and instruments

Among early works on tree measurement should be mentioned these completed by Flury: researches on the accuracy of the volume of felled trees based on the measurement, of length and diameter of the middle of the stem (1892), bark influence on volume determination of stem (1897), and the accuracy of some volume tables in experimental researches on the measurement of trees (especially heights) in the conditions of the middle Switzerland (1905).

Starch (1949) investigated volume determination of stacked wood (steres) and completed a critical analysis of converting factors.

Etter (1952) studied the contraction of felled wood in forest, estimated it at 0,2-0,5 % and evaluated its dependence on the felling period, stored time and soil exposure. Stoffels (1955) analyzed the accuracy of the measurements of modified Christen hypsometer, made in Switzerland at the beginning of the 19th century, and improved by Daalder in 1938.

In 1956, the electronical photoplanimeters (Bachmann and Keller 1956) came in use. Some years before 1960, Lovengreen improved the hypsometer JAL (Pardé 1961, p. 95) which was described in Switzerland by Flury in 1905. The utilization of JAL is recommended by FAO since 1954. JAL's principle is based on four triangles forming the four faces of a tetrahedron.

Badan et al. (1961) described a recording caliper as a new application of mechanization in forest inventory.

In 1973, Mingrad described and tested the Swiss--Transdata caliper constructed in Switzerland by Badan. Rhody and von Gehrts (1984) considered the Finnish caliper as a useful device to measure upper-stem diameters up to a height of 6 m from the ground.

In 1987, Vogel explained how to use the personal computers (PC) in calculating one-entry volume tables (tariffs).

6.2.2. Tree growth

In 1895 Flury published the results of his researches on the development of plants in the earliest period of youth.

Jaccard (1919) developed new investigations on the increment of trees diameter.

In 1926 Burger studied height growth of different forest species and since 1929 he investigated wood, amount of leaves (needles) and growth of species as *Pinus strobus* (1929), larch (1945), spruce (1953).

H. L. Meyer (1932) investigated increment dynamics of diameters as a function of diameters and established in the same year the relation between current increment and mean increment. In the next year (1933), Nägeli noted the influence of fructification on height growth of spruce and fir.

In 1946, Badoux presented the relations between crown development and growth in Scots pine. Prodan (1947) studied the diameter increment in selection forest.

In 1985, Schlaepfer developed relationship between diameter growth and crown parameters, especially foliage loss, of *Picea abies* and *Abies alba* – data refer to a pilot study in Switzerland.

Ebert (1991) studied juvenile growth and the final size attainable-the second of Backman's presumptions. Ebert discussed Backman's view on the aging of trees and noted that during the 1940s the two Backman's rules were predominant in Sweden: (1) the more rapid the juvenile growth, the earlier is the culmination of current annual increment as sexual maturity, and death, and; (2) with rapid juvenile growth the end values of tree height, diameter and volume attainable up to natural death are all smaller than with slow juvenile growth. Ebert considered that the first rule (1) is generally valid, but published research data showing that rule two (2) does not apply.

In 1995 Schneider and Hartman presented a poster at Tampere IUFRO Congress in which they analized spruce trees from the Swiss Plateau (400-800 m) and the Swiss Jura (600-1300 m). "For the single tree analysis the reference is taken in the sample itself. At constant age, we observed a significant increase in radial increment during the 20th century. This trend is more pronounced for young cambial ages than for older ones. After indexation for ageing effect, the same data ploted as a function of the calendar display a continuous and clear increase during the 20th century" (Poster 234 p. 134, 135). These results are very similar to those obtained on Silver fir at breast height by Becker (1989) and Bert (1992) for the same region and for the Vosges mountains in France. To explain this trend the authors of this poster formulated three hypotheses: (1) climate: more favorable; (2) competition in silviculture, and; (3) atmospheric deposition of CO_2 and other potential nutrients for trees.

6.2.3. Other aspects concerning the tree

In 1912, Jaccard proposed the water conduction theory. According to this theory the distribution of growth within the stem is determined by the physiological necessity of water conduction.

Researches on assortment of spruce, fir and beech in central Switzerland have been developed since 1916 by Flury.

In 1922, Biolley used special tariffs based on conventional units named *silve*. Standing volume is expressed in *silve* (sv) which represents the ratio between standing tree volume and net volume cut, the merchantable volume respectively. For every species and stand a transforming coefficient of silve in m^3 was established. Bioley (1937) demonstrated in a study the influence of silvicultural system on the form of trees.

The general crown morphology of a spruce tree and calculation of crown parameters was suggestively presented by Burger in 1939 (Fig. 6.2.2.–1.).

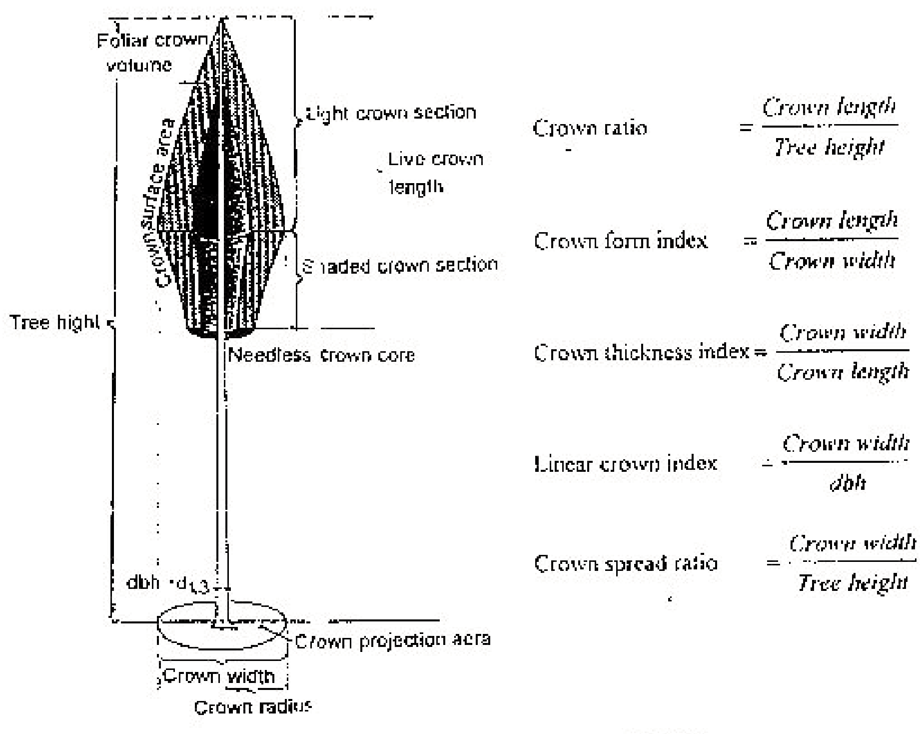

Fig. 6.2.2.–1. Crown morphology of spruce (*Picea abies*)
SOURCE: Burger 1939 – Original. Reproduced after van Laar and Akça, 1997, Forest Mensuration, p. 99, fig. 4.6., Cuvillier Verlag, Göttingen.

A volume tariff for tree species in Switzerland to be used in forest inventories was proposed by Hoffmann (1982) and is based on the following function:

$$V = e^{b_0 + b_1 \ln(d) + b_2 (\ln(d))^4} \qquad \text{where d is dbh.}$$

Several different tree and stand classification schemes are described and discussed by Leibundgut (1989) as the classification schemes: Kraft tree classes (1-5), the Danish tree classification (A, B, C, D), Schadelinis' quality classification for the main and subsidiary stand, and for the stem and crown quality, the IUFRO classification (height classes, vitality classes, development–trend clases), the IUFRO value classification (silvicultural value clases, stem–quality classes), and the stand development classification (young growth, thicket, pole, tree).

In 1987, Rüsch constructed new Aargau tariffs having as entry data of the volume functions: dbh, diameter at 7 m height and total height; if a PC is used it is possible to construct 78 new individual tariff tables giving stemwood volume (without branches) for the conifers, and total wood volume to 7 cm diameter (stem and branches) for the broadleaves; all the volumes are given over bark and under bark.

Cited authors (6.2.):

Badan et al. 1961, Bachmann and Keller 1956, Badoux 1946, Biolley 1922, 1937; Burger 1926, 1929, 1939, 1945, 1953, Etter 1952, 1991; Flury 1892, 1895, 1897, 1905, 1916; Hoffmann 1892, Jaccard 1912, 1919; Laar and Akça 1997, Leibundgut 1989, Meyer H. A. 1932a, 1932b; Mingrad 1973, Nägeli 1933, Pardé 1961, Prodan 1947, Rhody and Gehrts 1984, Rüsch 1987, Schlepter 1985, Schneider and Hartman 1995, Stach 1949, Stoffels 1955, Vogel 1987.

6.3. Plant sociology and site evaluation

The plant associations based on the floristical criterion have been used since the 1920s in Switzerland but they did not satisfy the needs of silviculture and their indications on site quality were relative (Braun–Blanquet 1921, 1925, 1932, 1951).

In 1949, Etter analyzed the yield in connection with sites having different qualities. He considered that it is possible to define, within a region with homogenous characteristics, a potential productivity of a site similar in a way to the one defined by Paterson (in Sweden) and Weck (in Germany), and it is possible to calculate for each site the best productivity (capacity to produce wood) for a given species introduced by man in this site. On the other hand, Etter confirmed the Eichhorn rule and replaced the average stand height of an evenaged stand, by dominant height as an indicator of the site quality (Fig. 6.3.–1.). Etter's stand main height is defined as those belonging to classes 1, 2 and 3 as a quantitative expression for "biological top height".

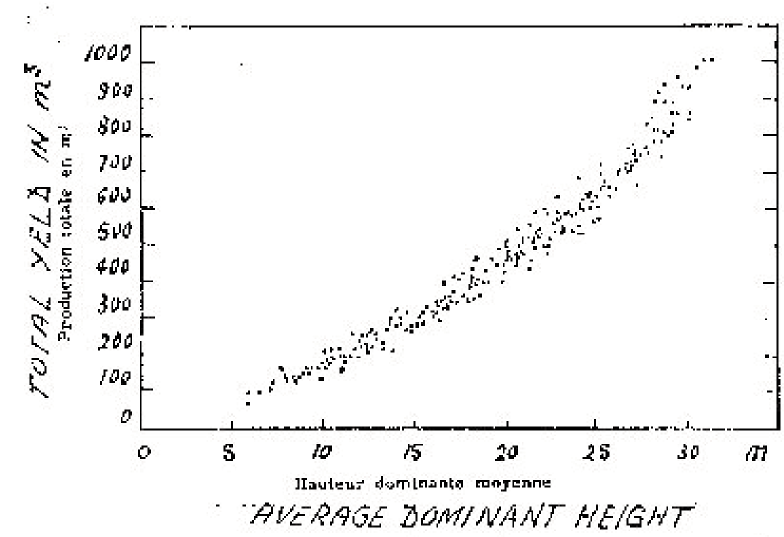

Fig. 6.3.–1. Correlation between average dominant height and total yield in the case of beech in Switzerland.
SOURCE: Original Etter 1949 "Über die Ertragsfähigkeit verschiedener Standortstypen" in Mitteilungen der schweizerischen Anstalt für das forstliche Versuchswesen, Tome XXIV, pp. 91-152, Switzerland. Reproduced after Pardé 1961, Dendrometrie, p. 259. fig. 122.

Some indicators of site, quality, are presented in Richard's (1956) work of spruce located at its lower limit of natural repartition in the Swiss Jura. In the next year (1957) Richard published a more detailed paper in wich presented the advantages of phytosociology for Silviculture in Neuchâtel district connecting the phytosociological units with site quality.

In an extensive work on forest associations and forest sites Ellenberg and Klötzli (1972) produced a complete classification of forest phytocoenoses which is based not on characteristical species but on combination of constant species including the dominant ones. The characteristic species have been identified only for units superior to association but which correspond with that of the Braun–Blanquet school. Ellenberg's and Klötzli's associations are more homogenous from ecological point of view and are characterized in terms of climate, relief, soil trophicity and humidity and the presence of constant species in all forest storeys and dominant species; in the whole country were described 62 association. As an example Table 6.3.–1. presents after Schweingruber (1978) different phytosociological units with forest species in Swiss alpine storey. One can see that the phytosociological units are connected with different site characteristics and trees productivity expressed by the height of mature individuals.

On the other hand, the site quality for a given forest species is appreciated according to site index values (five height classes in the early yield tables (Flury 1907) and $12H_{50}$ classes in 1968 (Eidg. Anstalt f. d. forstl. Versuchswesen, Ertragstafeln für die Fichte und Buche der Schweiz).

In 1999, Kull and Rösler presented a field computer for forest vegetation relevés in Switzerland. In fact this computer has been in use since 1996 by the Swiss Federal Institute for Forestry and Landscape Research (WSL). A database and a vegetation relevé program were developed for this purpose. This field computer is recommended especially for extensive long-term vegetation projects.

Cited authors:

Braun-Blanquet 1921, 1925, 1932, 1951; Eidg. Anstalt f. d. forstl. Versuchswesen 1968, Ellenberg and Klotzli 1972, Etter 1949, Flury 1907, Kull and Rösler 1999, Richard J. L. 1956, 1957; Schweingruber 1978.

6.4. Stand structure

In "Forêts de mon pays" (The forests of my country) Biolley (1930) described different forests belonging to two large groups: high forest and coppice forest.

Leibundgut conceived in 1982 the following definition of a virgin forest: "Virgin forests are original in their structure and have always developed under natural conditions. Their soil, climate, and entire flora and fauna and the life proccesses have not been disturbed or changed by timber management or cattle grazing. All the other direct or indirect anthropogenetic influences are excluded from these areas also." (From "European montainous virgin forests"). Later (1987), when discussing if forest reservations are in danger, Leibundgut defined natural forest: "...forest which have evolved as a sequence of natural succession often showing anthropogenetic influences from the past or has developed from unmanaged postures or from fallow lands fits this category also". “This sets it at a level similar to virgin or secondary forest, leaving the site to natural succession. Forest of this type are often found in Finland, Russian Karelia and Central Sweden as a result of shifhing cultivation in the past” (see Finland: Hejkinheimo 1915 stand development classification: young growth, ticket, pole, tree).

TABLE 6.3.-1. Ecological and phytosociological properties of sites in Swiss alpine storey
SOURCE: Schweingruber, F. H. et al. 1978, "The X-ray technique applied to dendrochronology, Tree-Ring Bulletin, vol. 38, p. 71, table 2, U.S.A

	Chasseral	Chasseral	Rigi-Stafel	Rigi-Klösterli	Arosa	Arosa	Aletschwald
Area	Jura		Northern Prealps		Eastern Prealps		Central Alps
Geographic coordinates	572600/220900	571100/219500	679600/211700	679200/210900	770600/186900	770600/186900	644450/136800
Collection date	25/9/75	25/9/75	16/9/75	16/9/75	2/10/75	8/10/75	23/9/75
Slope direction	N	S	SW	NW	N	N	W
Slope (degrees)	15	20	25	10-20	30	20	30
Substratum	limestone	limestone	limestone-conglomerate	limestone-conglomerate	gneiss	gneiss	gneiss
Elevation of site (m)	1500	1400	1600	1600	1400	1980	2000
Treeline (m)	1600	1600	1800	1800	2100	2100	2200
Tree cover (%)	30-60	50	80	80	50	60	60-75
Herbaceous cover (%)	100	25	10	70	90	75	60-75
Moss cover (%)	0	0	0	60	0	30-Oct	25-Oct
Tree hight (m)	8-12	18-20	18-20	25-30	15-20	22-28	18-25
Phytosociological unit	Sorbo-Aceretum	Abieti-Fagetum	Asplenio-Piceetum	Myrtillo Abietetum-lysimachietosum	Alnetum viridis	Rhododendro-Vaccinietum calamagrostidetrosum	
Site characteristics	Slightly acidic, Wet	basic, moist	neutral, partially moist	acidic, moist-wet	neutral, wet	acidic, moist	acidic, moist
Major species	Picea abies	Picea abies Fagus sylvatica	Picea abies	Picea abies Abies alba	Picea abies	Picea abies	P. abies, Larix decidua, Pinus cembra
No. of cores (=trees)	8	13	14	15	6	12	11/9/14
Ecological position	dominant, codominant	dominant	dominant	dominant	dominant	dominant	dominant
Weather station	Chaumont		Rigi		Zürich		Gr. St. Bernhard
Geographic location	47°3'N,6°59'E		47°23'N,8°28'E		47°23'N,8°33'E		45°52'N,7°10'E
Elevation (m)	1127/1141		1787		493		2479
Type of site	slope/ridge		ridge		slope		pass

SOURCE: Schweingruber, F. H. et al. 1978, "The X-ray technique applied to dendrochronology, Tree-Ring Bulletin, vol. 38, p. 71, table 2, U.S.A.

6.4.1. Influence of thinnings on stand structure

Flury analized in 1903 the influence of different intensities (grades) of thinnings on growth and form of spruce and beech and Biolley discussed the thinnings called "par haut" (intervention in upper story) and thinnings called "jardinatoire"- a more complex intervention in the stand storeys. Later Burger (1936) presented the influence of thinning type on tree heights, pruning, crown density and their coverage in evenaged spruce stands. Badoux (1939) analyzed thinning influence in pure beech stands and later (1946) described the relations between crown development and growth after thinnings. Leibundgut (1956) recommended classification of trees in classes, proposed an efficient method for tending the forest, and presented it later (1966) in a textbook under the title "Waldpflege", (Tending of forest). Bartel-Pleines simulated the evolution of forest (stand) in regular forests and established the influence of silvicultural systems on structure.

6.4.2. Selection forest

In 1933 H. A. Meyer published a mathematical statistics work on the structure of selection forest and proposed for this type of uneven-aged forest equation

$$y = ke^{-\infty x}$$

which can characterize the structure of forest decreasing distribution of trees by diameter categories).

In 1945, Leibundgut developed more detailed researches on spruce + fir + beech selection forest structure, and Prodan (1949) developed theoretical determination of the state of equilibirum in the selection forest. In 1959, Leibundgut presented the scope and the method for structure analysis and growth in selection forest.

Interesting information on selection forest of spruce with *Vaccinium myrtillus* in Alps (*Piceetum subalpinum myrtilletosum*) was presented by Trepp (1961), who wrote in 1974 a monograph: "Der Plenterwald " (Selection forest). Structure, age and growth in a spruce selection forest on subalpine level were investigated in 1978 by Indermühle. In 1999, Bachoffen published an analysis on equilibrium, structure and increment in two different selection forest stands not in their state of equilibrium (the forests "Les Arses" and "Hasliwald").

6.4.3. Other aspects connected with forest structure

Structure of middle-aged spruce growing in mixed forests with broad-leaved species and located in north-eastern Switzerland were studied by Surber in 1950. Wood, amount of leaves and growth in an even-aged spruce high forest were analysed by Burger (1953). A work on the knowledge of forest conditions in the Swiss National park was published by Kurth et al. in 1960.

The species composition and stand productivity was examined by Bachmann (1967) especially in mixed larch and spruce stands. Hillgarter (1971) studied productivity and structure of subalpine spruce forest Scatlè/Brigels - in a doctoral thesis. The problem of competition in mixed stands was a subject for Schütz's researches in 1989.

Matthias Dobbertin and Gregory S. Biging (1998) used the non-parametric classifier CART to model forest tree mortality. CART is a binary classification tree (Breimaan et al. 1984). They used CART models for two conifer species: ponderosa pine and white fir. CART was also compared with logistic regression using a stochastic and a deterministic assignment of mortality.

Cited authors (6.4.):

Bachmann 1967, Bachoffen 1999, Badoux 1939, 1946; Bartet-Pleines 1972, Biolley 1921, 1930; Burger 1936, 1953; Dobertin and Biging 1998, Flury 1903, Hillgarter 1971, Indermühle 1978, Kurth et al. 1960, Leibundgut 1945, 1956, 1959, 1966, 1982, 1987; Meyer H. A. 1933, Prodan 1949, Schütz 1989, Surber 1950, Trepp 1961, 1974.

6.5. Stand growth and yield

6.5.1. Volume of standing timber and yield tables

In 1897 Flury calculated the volume of standing timber using stand form factor.

Practical instructions for the determination of stand volume were completed in 1891 by Frankhauser who took into account the need of forest range and forest management.

Earliest Swiss yield tables were constructed by Flury in 1907 for spruce and beech. In this tables apart from average height of basal area medium tree (h_g) is given also average arithmetical height which is easier to determine. Assortments and silvicultural conditions for spruce, fir, and beech were investigated by Flury in 1916.

The problem of stand productivity as quality of produced wood (biomass) was examined in 1951 by Burger whereas Etter (1952) completed a work on the analysis of forest yield.

New yield tables for spruce were constructed in 1964 by Badoux and in 1968 by the Eidg. Anstalt f. d. forsl. Versuchswesen.

In 1972, Bartet-Pleines used simulation and constructed computerized yield tables. A detailed text on volume determination of standing trees was published by the Swiss federal forest research institute in 1986 (Winzeler).

6.5.2. Stand growth

In 1989, Flury published a paper on conformance to law in the course of growth of species (orig.: "Über die Gesetzmässigkeit im Wachstumgange einiger Holzarten") and later (1923) the aspects (les allures) of growth, and in 1926 he wrote about growth and net yield of mixed forests. Four years later (1930) Flury completed his researches on volume growth and yield value of mixed stands. In 1933 Flury investigated growth conditions in selection forests and concluded that only compensated heights of large diameter categories (38-70 cm dbh) can be used as criteria to establish stand productivity classes. In connection with the determination of current increment should be mentioned Gascard's paper (1936).

Burger, in his serial articles on quantity of leaves and growth, supplied some data on growth of Scots pine and spruce and Scots pine of different origins (1937), 80 years beech stand (1940); spruce and Scots pine of different origins and cultivars (1941), a selection forest in a site of middle quality (1942), larch (1945), spruce in even-aged stands (1953), spruce in selection forest (1952).

The aspect (orig. l'allure) of growth in selection forest was detailed by Badoux (1949) who considered as "true dominant height" the average height of the trees with the biggest dbh. and more than that in a fir selection forest it is possible to obtain stand volume (in m^3/ha) multiplying by ten this true dominant height", expressed in meters.

Loetsch (1954) used in practice and research tariffs diference as a method for determination of stand growth.

Weidmann (1961) introduced in Schwitzerland the determination of stand increment based on lateral area of stems.

In a doctoral thesis, Schütz (1969) studied the growth phenomenon of height and diameter of fir (*Abies alba* Mill.) and spruce (*Picea abies* Karst.) in two stands of selection forest type. The pecularities of middle-aged spruce stand growth were investigated by Leibundgut (1971). Ott studied (1978) the dependence of radial and upper height growth of spruce and larch on high altitude and unfavourable exposition in Lötschental.

Zingg (1995, 1996) and Schneider-Hartman (1995, 1996) established growth trends of forest in Switzerland (positive) and growth trends of trees and stands on regional level (for spruce) respectively. Concerning the spruce stands Schneider and Hartman summerized their conclusion as follows: "The analysed stands are pure and even-aged. They have similar characteristics to those on which the Swiss yield tables were based. Compared to this model, the actual basal area increment per hectare displays different patterns, depending on the plot. But generally, the observed growth level is much higher than according to the reference. Additionally, the relative growth trend during the last 3-4 decades is often positive (Tampere 1995, poster 234, p. 135). Among other studies on local trend of forest growth it will be mentioned that of Bräker (1996), Köhl (1996) and Köhl et al. (1996).

Cited authors (6.5.):

Badoux 1949,1964; Bartet and Pleines 1972, Biolley 1923, Bräker 1996, Burger 1929, 1937, 1940, 1941, 1941, 1942, 1945, 1951, 1952, 1953; Etter 1952, Eidg. Anstalt f. d. forstl. Versuchswesen 1968, Fankhauser 1891, Flury 1897, 1898, 1907, 1916, 1926, 1930, 1933; Gascard 1936, Köhl 1996, Köhl et al. 1996, Leibundgut 1971, Loetsch 1954, Ott 1978, Schneider and Hartman 1995, Schütz 1969, Weidmann 1961, Winzeler 1986, Zingg 1995, 1996.

6.6. Biomass studies

Early biomass studies in Switzerland were performed by Burger in a set of papers out of which it will be mentioned: 1929 (*Pinus strobus*), 1937 (Scots pine and spruce of different origins), 1940 (beech – 80 years stand), 1941 (spruce and Scots pine of different origins and cultivars), 1942 (a selection forest in a site of medium quality), 1945 (larch), 1952 (spruce selection forest), 1953 (spruce in even-aged stands). Some examples of Burger's data on net primary production are given in Table 6.6.– 1.

TABLE 6.6.–1. Early data on net primary production in Switzerland.

No.	Species	Age	Net primary production: Trees, shrubs and herbs $g/m^2/yr$	Reference	
1.	*Fagus sylvatica*	80	967 T, AG, m	Burger	1940
2.	*Larix decidua*	50	492 T, AG, m	Burger	1945
3.	*Larix decidua*	105	426 T, AG, m	Burger	1945
4.	*Larix decidua*	220	76 T, AG, m	Burger	1945
5.	*Picea abies*	98	820 m	Burger	1953

T = trees only, AG = above ground mass only, m = method of estimating production not specified

We have no more available data on this field up to 1997 when Usoltsev and Hoffmann published a preliminary crown biomass table for even-aged *Picea abies* stands in Switzerland. This paper was published in Russia. Authors described a hybrid method to derive regressions for site quality, needle and branch biomass for individual spruce trees by using Swiss stand table data on tree density distributions, and computed a traditional yield table for branch and needle biomass and from these derived regressions which use only age and site quality as independent variables.

6.7. Tree-ring studies

Lenz (1957) was among the early dendrochronologists to use the radiography for the examination of tree-rings and was followed by Polge in 1966.

Early dendrochronological investigations in Switzerland were carried out by the Germans Huber and Merz (1963) and Huber (1967) who constructed discontinous chronologies, placed by radiocarbon: 2400–3000 BC and 952–1282 BC. La Marche and Fritts (1971) analyzed the connection between tree rings, glacial advance and climate in the Alps.

Wilputte (1977) contributed to a dendroclimatological methodology applied to larch in the Swiss Alpes.

Preliminary Schweingruber's et al. data on X–ray densitometric results for subalpine conifer and their relationship to climate were published in 1978. In the same year (1978 b) Schweingruber, Bräker, Schär from Switzerland and Frittss and Drew from the U.S.A. presented in the Tree-Ring Bulletin (U.S.A.) a detailed study on the X-ray technique applied to dendroclimatology. Figure 6.7.–1. reproduced from this study shows the difference between a photograph and a X–ray picture of a group of tree–rings.

An original procedure and a new mathematical technique were developed (which allowed to obtain more reliable climatic reconstructions than with prior methods) by Guiot et al. in 1982. They tested this technique for different sites in Switzerland and Morocoo and compared it with three other methods: polynomial, high-pass filter and spline indexing. New measurements of dendrometric properties of wood were completed by Schweingruber in 1982.

In 1983, Schweingruber published the first edition of his book (in German) and the second edition in 1988 (in English): "Tree Rings: Basics and Applications of dendrochronology".

Ruoff (1981) determined the age with the help of dendrochronology.

In a doctoral thesis Kienast (1985) presented dendrochronological researches of height profile in different climatical conditions, a radiodensitometrical study under different atmospherical conditions, different altitude and sites with resinous species.

A dendrocronological study on effects of the forest fire of 10–14 May 1965 on Monte San Giorgio, Ticino, Switzerland, was carried out by Berli and Schweingruber. The study showed that it is not possible to interpret and understand the species composition and mosaik of an area without taking into account at least a minimum fire history.

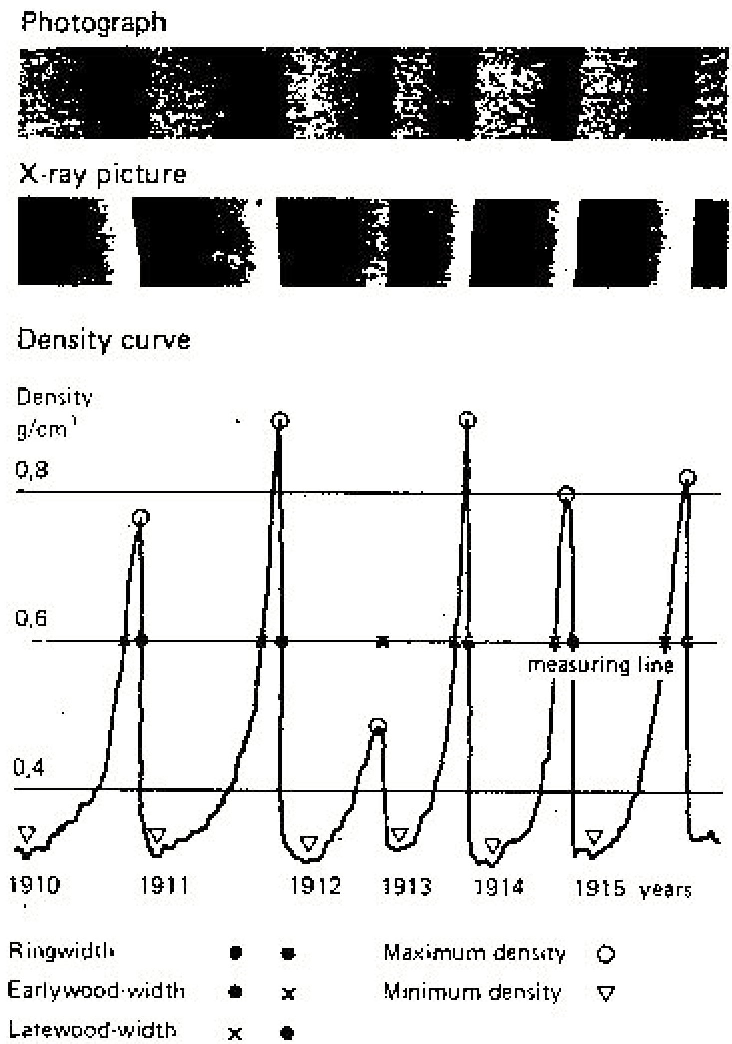

Fig. 6.7.–1. Photograph of an actual wood sample with X–ray photo and line plot. Ring width, early wood width, and latewood width are obtained by measuring the distance on the abscissa between points shown on the plot. Density is obtained as the value of the point on the ordi nate.

SOURCE: Schweingruber et al. 1978, "X–ray technique applied to dendrochronology", Tree–Ring Bulletin, vol. 38, p. 63, fig. 1, U.S.A, Tucson, Arizona.

Kaennel and Schweingruber published in 1995 a 467 pp. multilingual glossary of dendrochronology. The glossary contains 351 key terms used in dendrochronology arranged, and numbered in English chronological order, defined in English, German, French, Spanish, Italian, Portuguese and Russian.

Schmid and Schweingruber (1995) completed an interesting study on dating and identification of landslides with the aid of annual rings. They gave details of a dendrogeomorphological study made in Brungini (Valais Canton, Switzerland) analyzing rings of different forest trees that were affected in different ways by landslides.

In 1996, Schweingruber published a monumental work: “Three Rings and Environment. Dendroecology“ (609 pp.). The contents of this book reflects the actual problems of tree-ring studies: (1) Introduction; (2) Growth factors; (3) Growth Zones in Perennial Plants; (4) Basic Biological Functions Involved in Tree-Ring Formation; (5) Tree-ring Morphology; (6) Annual Tree Growth; (7) Growth in all Parts of a Tree; (8) Influence of Water (Dendrohydrology); (9) Influence of Snow; (10) Influence of Wind; (11) Influence of Fire; (12) Influence of Glacial Movement (Dendroglaciology); (13) Influence of Tectonic and Volcanic Activity; (14) Influence of Mass Movement; (15) Influence of animals; (16) Influence of Fungi and Mistletoe; (17) The Mutual Influence of Competition and Cooperation; (18) Influence of Man; (19) Influence of Climate (Dendroclimatology); (20) Isotope Ratios as Temporal and Ecological Indicators; (21) Literature, Index of Terms.

Schweingruber noted in 1996 that “The modern term “dendrochronology” has different usages which, I believe, can be outlined as follows:

1. dendrochronology *in sensu lato*,

1. a. dendrochronology *in sensu stricto* including all branches that use the uttermost tree ring to date wood, e. g. dendroarcheology

1 b dendroecology – including all branches of science involved in drawing some type of environmental information from tree–ring sequence, e.g. within the scope of: (i) climatology (dendroclimatology); (ii) geomorphology (dendrogeomorphology); (iii) tectonics (dendrotectonics); (iv) glaciology (dendroglaciology); (v) snow research (dendroniveology); etc.

Each new word formation is welcome so long as it is logical and does not lead to confusion “ (from introduction, p. 17).

Schweingruber’s opinion on the development of dendrochronology is optimistical: “I believe that dendrochronology will continue to develop rapidly with emphasis on the following areas: tree–ring formation, the influence of a stand on the growth of the xylem, consideration of all perennial woody plants” – considered as a large research gap.”

In 1997, Sauer et al. experimented with promising results the use of stable carbon isotopes in tree ring research; for instance correlation analysis with climatic data showed that the total precipitation in the month of May, June, July had the strongest effect on the carbon isotopes (R = - 0.73).

Cited authors:

Berli and Schweingruber 1992, Guiot et al. 1982, Huber 1967, Huber and Merz 1963, Kaennel and Schweingruber 1995, Kienast 1985, LaMarche and Fritts 1971, Lenz 1957, Polge 1966, Ruoff 1981, Saurer et al. 1997, Schmid and Schweingruber 1995, Schweingruber 1982, 1983, 1988, 1996; Schweingruber et al. 1978a, 1978b, Wilputte 1977.

6. 8. Forest inventory, monitoring and remote sensing

6. 8. 1. Forest inventory

The early works on forest inventory of management units were published in 1891 by F. Frankhauser who completed in 1909 practical instructions for "inventory of wood stock, and later in 1931 a Practical manual for stand inventory".

"The basic idea of a comprehensive national inventory for Switzerland was first mooted by A. Kurth in 1956. In 1973 a special department "National Forest Inventory" was set up at the Swiss Federal Institute of Forestry Research, and commissioned with the planning and execution of a national forest inventory. After preliminary trials in the canton of Nidwalden, terrestrial surveys were conducted between 1983 and 1985… Sample trees are selected from two concentric plots being systematically distributed over a one km grid covering 0.05 ha and 0.02 ha. On smaller plots all trees with a dbh over 12 cm are surveyed, on the larger ones all those with dbh over 36 cm with dbh, species, storey crown class and degree of stem damage being recorded. All trees with a dbh over 60 cm and an azimuth of 150 g or less towards north are taken as tariff trees; here the height and diameter at 7 m are also measured, so as to allow volume determination by means of volume functions $V= f(d_{1.3}, d_7, h)$. The upper diameter is measured with Finnish calipers." (M. Köhl, 1990, p. 359 in LaBau, V. J.; Cunia, T. (eds).

Plans for a Swiss national inventory were developed in 1998 by Haas Paul Schmid who published in the same year the second edition of the instructions for forest inventory based on sampling.

A short presentation of forest inventories in Switzerland was included in Revue Forestière Française" in 1985 by Schlaepfer.

The improvement in inventory by sampling according to site types was described in 1987 by Keller who concluded that the results were improved when sites were grouped according to phytosociological features while in upper mountaine to subalpine zones better results were obtained when sites were grouped according to site index.

The first Swiss national forest inventory was completed between 1982 and 1986 the results being summarized by Mahrer (ed.) in 1988 and Brassel (1988). This inventory is based on the data from 11000 circular sample plots, representative of Swiss forests laid out systematically, with a density of 1 x 1 km and contains "sections on: methods of data collection and evaluation; categories used; forest area ownership; growing stock; site factors; silvicultural systems/management types, stand charactheristics, species; regeneration; condition of forests; road density, logging costs, actual yields and yield forecasts; and summary of important data" (For. Abs. 4374/1988).

The current volume and change estimation for sampling with partial replacement on two occasions: case of Swiss continous forestry inventory - the methodological aspects is illustrated with reference to a continuous inventory in Switzerland using double sampling with aerial photographs and data from ground plots was analyzed by Yoshida (1988, For. Abs. 1135/1989). A manual for the first Swiss inventory was published in 1988 (Zingg and Bachofen).

Information on the past and future prospects of forest inventories in Europe with special reference to statistical methods were presented for Swiss foresters by Pelz (1991, 1993) and Köhl-Pelz as editors (1991) of the "Proceedings of the International IUFRO S4.02 and S6.04 Symposium" held in May 14-16 at Birmensdorf, Switzerland.

In 1991 Brassel discussed the problems of the second Swiss National Inventory and next year Köhl (1992) proposed a sampling design for this inventory.

Scott and Köhl (1933) described a method for comparing sampling design alternatives for extensive surveys.

An assessment of non productive forest functions in the Swiss National Forest Inventory was proposed in 1995 by Brassel at the Monte Verità conference on forest survey design. Giving an account of the development of sample design Köhl (1995) was referring to the establishement of procedures for permanent monitoring in Swiss forests. Proceedings of the Monte Verità conference on forest survey design - "Sampling versus efficiency and assessment of non timber resources" held in 1994 in Switzerland were published in 1995 by Köhl and other three editors.

The idea of multi-resource forest inventories was promoted in Switzerland especially by Köhl and Brassel (1997).

In 1999, Mandallaz and Ye presented a work on optimal sampling schemes for forest inventory. "The sampling procedures are optimal in the sense that they minimize the anticipated variance for given costs, or conversely, the anticipated variance is the average of the design-based variance under a local Poisson model for the spatial distribution of the trees. The resulting optimal inclusion rules are either probability proportional to size, in one stage procedures, or a combination of probability proportional to prediction and probability proportional to error, in two-stage procedures. Best feasible approximations of the exact optimal sampling schemes are also given." (Authors summary, Can. J. For. Res. p. 1691).

6. 8. 2. Remote sensing

Arial photography was applied in Swiss forestry since the 1940s and "a variety of practical uses was documented in 1962 in an impressive special publication by the Swiss Research Institute." (Hildebrandt 1993, p. 206). Hildebrandt (1993, p. 206) mentioned "the study by Zobeiry in Switzerland on double sampling with regression estimators for application in open mountainous forests, this was the use of airborne and space borne remote sensing combined with fieldwork (multistage concept)". Hildebrandt did not specified clearly his bibliographical sources (figures quoted in brackets).

In 1958, Zehnder published silvicultural evaluation of aerial photographs of the Albisriederberg-Instruction forest taken in 1944, 1951 and 1957.

Gier and Stellinwerf (1990) presented the results of beech timber volume determination by two-phase (aerial photo-field) sampling. In the same year Köhl and Sutter described application of aerial photographs in the estimation of standing volume in the Swiss National forest inventory.

6. 8. 3. Endangered forest inventory and monitoring

Proceedings of a IUFRO Conference (19-24 August 1985, Zurich) on inventory and monitoring of endangered forest was published by Schmidt-Haas (ed.).

Mandallaz et. al. (1987) concluded that simple sampling is more cost-effective and easier to plan and evaluate than "satellite sampling". They compared sampling methods as used in 1984 to evaluate the condition of Swiss forests: "satellite sampling" was based on a 4 x 4 km grid, each "satellite" having 8 plots arranged in a rectangle 200 x 300 m, each plot having a fixed radius of 12.62 m (For. Abs. 5061/1989).

Among the works on inventories of endangered forests in Switzerland and Europe we should mention those published by Schwarzenbach et al. (1986) - aerial determination of forest damage using infrared aerial photography 1:9000, Sanasilva project; Köhl M. (1990, 1991); Jaakkola (1992), Innes (1995) - criteria for the selection of ecosystem monitoring plots in Swiss forests; and Ghosh and Innes (1996) - comparison of the sampling strategies in forest monitoring programs: the greatest difference appears to be between using plots with fixed areas-such as in Switzerland- and plots with a fixed number of trees as in the European forest health monitoring projects.

The ECE worked out guidelines for Forest Damage Surveys [IUFRO 1985(?)]. In 1988 most European countries followed these guidelines in assessing forest decline. In Switzerland it was adopted a 4 x 4 km grid and 500 m^2 plot. Assessment refers to degree of defoliation and degree of discoloration.

Cited authors:

Brassel 1988, 1991, 1995, 1997; Frankhauser 1891, 1909, 1931; Ghosh and Innes 1996, Grier and Stellinwerf 1990, Hildebrandt 1993, Innes 1995, Jaakkola 1992, Keller 1987, Köhl 1990, 1991, 1992, 1995; Köhl and Brassel 1997, Köhl and Pelz 1991, Köhl et al. 1995, Köhl and Sutter 1990, Pelz 1991, 1993; Schaepfer 1985, Schmid-Haas 1978, Schmid-Haas et al. 1978, Schmid-Haas (ed.), Schwarzenbach et al. 1986, Scott and Köhl 1993, Mahrer 1988, Mandallaz et al. 1987, Mandallaz and Ye 1999, Yoshida 1988, Zehnder 1958, Zingg and Bachofen 1988.

6.9. Chronology of selected works

1891 and 1909: Instruction for forest inventory of management units (F. Frankhauser).

1892: Researches on the accuracy of volume determination of felled trees measuring, their lenght and the diameter at the middle of the stem (Ph. Flury).

1898: Conformance to law in the course of growth of species (Ph. Flury).

1905: Influence of different intensities of thinnings on growth and form of spruce and beech. A textbook (Ph. Flury).

1907: First yield tables for spruce and beech in Switzerland (Ph. Flury).

1916: Researches on assortments of spruce, fir, beech growing in central Switzerland (Ph. Flury).

1920: Management check method (méthode du contróle) based on successive detrmination of standing volume in forest (Henry Biolley).

1922: Tariffs for selection forest using conventional units: silve (Henry Biolley).

1926: Researches on height growth of different species (H. Burger).

1929–1953: Researches on net primary production (g/m^2/yr) of different forest species (H. Burger).

1930: Researches on volume growth and yield value of mixed stands (Ph. Flury).

1931: Practical manual for stand inventory (F. Krankhauser).

1933: Growth conditions in selection forest (Ph. Flury).

1933: A mathematical statistics on the structure of selection forest (H. A. Meyer).

1937: Contribution to the study of the influence of silvicultural system on trees form (Henry Biolley).

1939: The influence of various types and grades of thinning in pure beech (Eric Badoux).

1944: Early forest photographs.

1945: Selection forest structure (H. Leibundgut).

1947: Diameter increment in selection forest (M. Prodan).

1949: The theoretical determination of the state of equilibrium in the selection forest (M. Prodan).

1956: The first proposal for a national forest inventory in Switzerland (A. Kurth).

1956: Electronical photoplanimeters (P. Bachmann and B. Keller).

1957: X–ray use in tree–ring measurements (O. Lenz).

1958: Evaluation of aerial photographs of the Albisriederberg instruction forest taken in 1944, 1951 and 1957 (H. Zehnder).

1961: Determination of stand volume increment based on lateral area of stems (A. Weidmann).

1964: Yield tables for spruce (E. Badoux).

1967: Early Swiss dendrochronologies (B. Huber).

1972: Simulation and computerized yield tables (Bartet–Plaines).

1972: Forest associations and forest sites (H. Ellenberg and F. Klötzli).

1973: Swissperfo – Transdata calliper constructed by Badan.

1973: Establishement of special department "National Forest Inventory" of the Swiss Federal Institute of Forestry Research" commissioned with the planning and execution of a national forest inventory.

1974: A textbook on selection forest (W. Trepp).

1978: Structure, age and growth investigation in a spruce selection forest on subalpine level (M. Indermühle).

1978: The X–ray technique as applied to dendroclimatology (F. H. Schweingruber, H. C. Fritts, O. U. Bräker, L. G. Drew and E. Schär).

1980: Henry Biolley Oeuvre écrite (Written works) – (Société forestière Suisse).

1982-1986: The first Swiss national forest inventory (the results summarized by F. Mahrer and P. Brassel in 1988).

1983: A textbook: "Tree rings: Basics and Application of Dendrochronology" 1st edn. in German), 2nd edn. 1988 (in English). (Fritz Hans Schweingruber).

1985: IUFRO Zurich conference on inventorying and monitoring of endangered forests (P. Schmidt-Haas, ed.).

1986: Areal determination of forest damage using infrared aerial photography (F. H. Schwarzenbach et al.).

1989: The problem of competition in mixed stands (Schütz, J. P.).

1990, 1991: National inventories and inventories of endangered forests in Europe. A short review (M. Köhl).

1991: Juvenile growth and final size attainable – the second presumption of Backman (H. P. Ebert).

1992: Proposed sampling design for the second Swiss National Forest

Inventory (M. Köhl).

1995: Growth trends of forests in Switzerland (A. Zingg).

1995: Multilingual glossary of dendrochronology (M. Kaennel and F. H. Schweingruber).

1995: Growth trends of trees and stands: regional studies on Norway Spruce in Switzerland (Oliver Schneider and Philippe Hartmann).

1995: An assessment of non-productive forest functions in the Swiss National Forest Inventory (P. Brassel).

1995: Criteria for the selection of ecosystem monitoring plots in Swiss forest (J. L. Innes).

1996: An outstanding book: "Tree Rings and Environment, Dendroecology". (F. H. Schweingruber).

1997: Questionnaire for multi-resource inventory in Switzerland (P. Brassel).

1999: Forest inventory with optimal two-phase, two stage sampling schemes based on the anticipated variance (D. Mandallaz and R. Ye).

6.10. Selected contributors

Author	Printing years	Field(s)
Henry Biolley	1880s – 1930s	01, 1, 3, 4
F. Fankhauser	1890s – 1930s	01, 4
Ph. Flury	1890s – 1930s	1, 4, 3, 01
H. Burger	1920s – 1930s	5, 4, 3, 1
Eric Badoux	1930s – 1960s	3, 4
H. A. Meyer	1930s	1, 3, 4
H. Etter	1940s – 1950s	2,4
H. Leibundgut	1940s – 1960s	3, 01, 1
W. Trepp	1960s – 1970s	3
F. H. Schweingruber	1960s – 1990s	6, 01
P. Schmidt-Haas	1970s-1980s	7
P. Brassel	1980s-1990s	7
D. Mandallaz	1980s-1990s	7
J. L. Innes	1990s	7
M. Köhl	1990s	7
D. R. Pelz	1990s	7

01 = textbook, 1 = tree, 2 = site, 3 = stand structure, 4 = stand growth and yield, 5 = biomass, 6 = tree ring studies, 7 = forest inventory and remote sensing

6.11. Comments

Selection forest system practiced on a large enough area in Switzerland influenced the development of Swiss forest mensuration: for instance 30 % of selected works published in this country and cited in this book refer or are connected with this system.

The progress of Swiss forest mensuration was a result of an early application of mathematical statistics methods, computerization of calculus (punched cards were introduced in the country in the 1950s according to Weidmann and Thommsen 1959), adequate planning and evaluation of experiments (Linder 1953), and numerous forest inventories, on different levels (Schlaepfer 1985).

The cited papers in the book are distributed as follows: textbooks and books 7 %, tree measurement and instruments 16 %, site evaluation 5 %, stand structure 17 %, stand growth and yield 16 %, biomass 7 %, tree-ring studies 11 %, and forest inventory and remote sensing 21 %. The percentage of the papers on forest inventory stand structure is remarkable. During the investigated period (1891-1999) 167 works have been mentioned out of them 38 % were published after 1980 and 21 % after 1990.

In our opinion the most remarkable feature of Swiss forest mangement (which influenced forest mensuration) consists in avoidance of the development on large areas of pure even-aged stands and preservation and extension of mixed uneven-aged stand under selection forest system enhanced by the application of the check or control method (méthode du contrôle) for which Gurnaud and Biolley deserve respect.

In 1907 (1911), in his forest history Fernow noted in the "Switzerland" section (p. 183, 2nd edition): "Being largely German by origin and sentiment, German influence on the development forestry methods, outside of the administrative measures, has here been as strong as in Austria". It ought, to be mentioned that during the last decades of 20th century Swiss forest mensuration was also been influenced by American and French literature.

In an interview, Swiss forester David T. Mason tried to explain (at the level of the year 1969) the main characteristic of Swiss forestry: "It has seemed to me that forestry as practiced on the soil in France is in accordance with plans that were made locally and then sent to Paris for review and perhaps change, so that ultimately it is really Parisian forestry that gets practiced. In Germany it has seems to me that there is a great reverence and concern and consideration given to the rule laid down by the old masters, so that the old masters are still greatly influencing the practice of German forestry. And then, it has seemed to me that in Switzerland it was not like either of those other countries in that it appears to me that in Switzerland the local man in charge of the forest uses his own ideas in managing his forest. He can pay great attention to all the local conditions that influence his forest and adjust his practice to those local conditions of various kinds…I do not mean that the local forester in Switzerland disregards all the knowledge of forestry that has been accumulated over the centuries. He has due regard for that but in applying it he isn't bound strongly to follow precedent." (Badaux and Zurcher 5/22/1969, pp. 20 and 21).

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