THE PRINCIPLES OF
FOREST YIELD STUDY

Studies in the Organic Production, Structure, Increment and
Yield of Forest Stands

BY

DR. ERNST ASSMANN
Professor at the University of Munich

TRANSLATED BY

SABINE H. GARDINER

ENGLISH EDITOR

P.W. DAVIS

PERGAMON PRESS
Oxford · New York · Toronto · Sydney · Braunschweig
CONTENTS

FOREWORD xiii

INTRODUCTION 1
1. Historical Development 1
2. The Place of Forest Yield Theory in Forest Science 3
3. Research Objects and Methods Employed in Forest Yield Studies 4

SECTION A  WOODY GROWTH AS PART OF THE TOTAL PRODUCE OF PLANT SOCIETIES 7
1. Soil, Climate and Plant Production 7
   Mutual interactions between soil, climate and plant cover 7
   Yields in agriculture and forestry 8
   Soil factors of primary importance in the formation of plant material 9
2. The Assimilation Process from the Point of View of Quantitative Ecology 10
   (a) The Principal Factors in the Assimilation Process 11
      The factor of light 11
      The part played by temperature 13
      The CO₂-content of the air 14
      Transpiration and water requirements 18
      The influence of nutrient supplies 20
      Mitscherlich's activity law 20
   (b) The Characteristic Behaviour of Different Forest Trees in the Assimilatory Process 23
      The respiration economy of our native tree species 25
      Respiration of the root system 26
      The economy of transpiration 27
   (c) Assimilation Rates and Leaf Quantities of Trees and Stands 28
      Leaf area and stocked ground area 29
      Relative performances of sun-leaves and shade-leaves 30
      Leaf quantities and increment 31
3. The Organic Production of Forest Stands and its Components 33
   The production equation of Boyesen-Jensen 34
   Foliage and increment 35
   Production spectra of Mat:\Møller 36

SECTION B  TREE GROWTH AND FORM 39
1. Annual Shoot Growth and Height Increase 39
   (a) Seasonal Changes of the Annual Height Increment 40
   (b) Height Growth Related to Age 41
      Curves of total growth and increment 41
      The Backman growth law 42
   (c) Factors Influencing Height Growth 44
2. Width of Annual Rings and Diameter Increment 48
   (a) Seasonal Start, Duration and Rate of Formation of the Annual Ring 49
   (b) The Growth Rhythm of Diameter and Basal Area in Relation to Age 51
   (c) Annual Ring Width, Diameter, and Sectional Area Increments at Different Stem Heights 53
      Characteristic increment distribution on the tree stem 53
      Changes of the increment distribution on the stem 55
3. The Shape of the Tree Stem
   (a) The Stem Profile 57
   (b) The Form of Stem Cross-sections 58
   (c) Form Factor, Volume and Assortment Tables 64
   The problem of form and form factor 64
   Stem measurement according to Hohenadl 66
   Assortment tables 70
   (d) Formation and Dimensions of the Root System 70
   (e) The Bark Fraction 73
   (f) Units of Volume and Weight employed in the Determination of Growth and Yield 75
   Forestry measurements of standing and felled trees 77
   Timber production in terms of dry weight; volume/weight relationships 78

4. Volume Increment
   Current and mean annual increment 79

SECTION C THE CONSTITUTION AND DEVELOPMENT OF STANDS 83

1. The Social Structure of Tree Crops 83

1. Tree Classes 83
   Natural tree classes 83
   Technical and economic aspects of classification 87

2. Typical Structure of Stands according to Tree Classes and Storries 92
   Numerical tree classes 92
   Examples of crop classification 96
   Growth comparisons among the tree classes 98

II. Growing Space and Increment 101

1. Growing Space and Ground Coverage of Individual Trees in the Stand 101
   Basal area and crown canopy 101
   Square or quadrant spacing 102
   Triangular spacing 102
   Severe breaking of canopy, extent of ground coverage and degree of disengagement 106
   The "growing-space index" of v. Seebold 108

2. Tree Crown and Increment Efficiency 111
   (a) Structure and Form of the Crown 111
      Descriptive crown measures 111
      Crown morphology 112
      Calculation of the volume and surface of tree crowns 115
      Mean needle and leaf quantities for individual trees 115
   (b) Leaf Quantities, Crown Dimensions and Increment Efficiencies 116
      (i) Factors which influence the efficiencies of given leaf quantities 116
      The influence of site, climate, age and seed origin 116
      Social position and productive capacity 117
      Vertical distribution of the radiation consumption on 7.7.1952 118
      (ii) Crown size and area-related efficiency with different structures of stands and different
      silvicultural treatments 119
      Crown size and capacity in even-aged stands 120
      The effects of thinning on crown dimensions and increment efficiency 123
      Crown size and efficiency in stands of several storeys and mixed ages 127
      Crown size and performance in selection forests 130
      Crown size and productivity in natural mixed forests 136

III. The Pattern of Development and Growth of Pure Stands in Dependence on Age and Site Quality 139

1. Dependence on Age 139
   The Age Problem of Our Forest Trees 139
   (a) The Development of Stem Numbers 141
<table>
<thead>
<tr>
<th>CONTENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) The Height Development</td>
<td>143</td>
</tr>
<tr>
<td>Mean height—top height</td>
<td>143</td>
</tr>
<tr>
<td>(c) Progress of Diameter Growth</td>
<td>147</td>
</tr>
<tr>
<td>(d) Basal Area and Volume Increment</td>
<td>149</td>
</tr>
<tr>
<td>Relationships between basal area and volume increment; the form-height</td>
<td>151</td>
</tr>
<tr>
<td>The volume increment</td>
<td>152</td>
</tr>
<tr>
<td>Culmination and decline of the mean annual increment of stands</td>
<td>155</td>
</tr>
<tr>
<td>The course of the mean annual increment for a crop anticipates the mean annual increments of individual trees</td>
<td>155</td>
</tr>
</tbody>
</table>

2. Dependence on Site: Growth Performance of Tree Crops in Relation to Site | 158|

(a) The Problem of Site Quality                                           | 158|
| The basic relations                                                      | 160|
| The so-called Eichhorn’s rule                                            | 161|
| Gehrhardt’s Norway spruce yield table of 1921                           | 163|
| Yield tables and reality                                                | 164|
| Height and total crop yield                                              | 165|
| Height quality class and total crop yield                               | 168|
| Peculiarities of the customary yield tables for spruce                  | 172|
| Macro-climatic and local site influences on the total crop yield        | 173|
| Height quality classes or m.a.i. quality classes?                       | 177|
| “Static” or “dynamic” quality classification?                          | 188|
| Further development of yield tables                                     | 181|
| General tables and local tables                                         | 181|
| Essential corrections of commonly used yield tables                     | 181|
| Construction of local tables                                            | 183|

(b) Productive Efficiencies of Native and Exotic Tree Species on Different Sites | 186|

3. Disturbances in the Normal Trend of Increment                          | 196|
| Climate, weather during the year, and increment                         | 196|
| Seed development and wood increment                                     | 201|
| Increment reductions through pathological influences                    | 202|

4. Growth Patterns and Their Interpretation                                | 203|
| Attempts to develop mathematical formulae from yield study observations  | 204|
| Growth laws or growth patterns?                                          | 205|

SECTION D STRUCTURE, INCREMENT AND YIELD OF STANDS IN RELATION TO SILVICULTURAL TREATMENT 207

I. Concept and Scope of Cultural Measures in Stands                       | 207|
| Site restrictions upon silvicultural units                              | 208|
| Classification of cultural measures by thinning                       | 208|

II. The Research Projects of the Verein der Forstlichen Versuchsanstalten (Association of Forest Research Institutes) | 210|

1. Characterization of Thinning Methods                                   | 210|
| Working plan of 1873                                                    | 210|
| Work project of the Association of Forest Research Institutes drawn up in 1902 | 211|
| The kind of thinning                                                   | 213|
| Criteria of grading in measuring severity of thinning                  | 214|
| The mean basal area over a period (p.m.b.a.)                           | 216|
| The intensity of thinning; beginning and frequency of intervention     | 217|
| Levels of thinning intensity                                           | 218|
| Conflict between biological and techno-economic points of view         | 218|

2. Experimental Methods and the Accuracy of Growth Determinations         | 219|
(a) Layout of the Experiments                                            | 219|
(b) Methods of Field Inventory and Computation                           | 220|
| Measurement of the basal area                                          | 220|


CONTENTS

Height measuring 221
Measurement of form factors 222
Calculation methods 222
(c) Accuracy of the Increment Determination 223
Is the basal area increment suitable as a criterion of performance in thinning experiments? 225
Correction and smoothing out of faulty experimental results 225
III. The Effects of Different Thinning Methods on Growth and Yield 227
1. Typical Increment Reactions to Thinning 227
   The experimental Norway spruce series at Dalby, Sweden 227
   Characteristic values of the basal area for different periods 228
   The natural critical degree of stocking and the “optimum basal area” 231
   An attempt to explain the progress of the optimum curve 232
   The acceleration of growth 233
2. Typical Changes of the Average Tree Dimensions 235
   The thickening of the stem 235
   Reduced length of the harvested stems 236
   The change in the distribution of the total production by diameter classes and grades of produce 239
3. Enlargement of Dimensions, Improvement of Timber Quality and Financial Yields 239
   Timber prices and price differentials 240
   Comparison of the value yields, with and without computation of future value of thinnings 241
   Selective and quality-promoting effects of thinning 244
IV. Results of Thinning Experiments carried out to Date in Pure Even-aged Stands 245
1. Common Beech 245
   A brief characterization of the species Common beech 245
   The most important experimental thinning series 246
   Outdated conclusions from former experimental results 247
   (a) Volume and Value Efficiencies in Low-thinning Experiments 248
      Thinning of A-grade plots, not in accordance with plans 248
      Periodic mean basal areas and volume increments of some typical low-thinned series 249
      Brief site-description of the research series 250
      Results of the Bavarian low-thinned beech series 256
      Results of Danish thinning experiments 258
      Recent attempts at a total statistical evaluation 261
      Optimum and critical basal areas in Common beech 263
      Changes in value efficiency due to low thinning 263
      Reduction in average length of harvested stem 265
      Value performance in the experimental series, Rothenbuch 266
   (b) Volume and Value Yields with Crown-thinning Experiments 270
      Volume yield in crown-thinning experiments 270
      Changes in value yield with crown thinning 270
      Experimental crown-thinning series of Common beech, Dalheim 116 271
      Disadvantages of the early and inflexible selection of “future stems” 277
      The experimental crown-thinning series at Wieda 278
      Prospects for success by treatment in the early growth and thicker stages according to Schädelin’s doctrine 284
   (c) Summarizing Conclusions about a Suitable Thinning Technique for Common Beech 286
2. Norway Spruce 287
   Brief characterization of the species Norway spruce 287
   The most important experimental Norway spruce thinning series and their treatments 288
   (a) Volume and Value Yields of Norway Spruce under Different Thinning Régimes 290
      Periodic basal area content and volume increment in the Bavarian experimental Norway spruce series 290
      is the total growth performance a suitable measure for comparisons? 298
      The three characteristic periods of treatment of the Bavarian experimental Norway spruce series and their yields 298
      The average percentage reduction in basal area as a quantitative measure of thinning 302
CONTENTS

Periodic basal area and increment in experimental Norway spruce series of other countries 304
Crown thinning in pure Norway spruce stands? 309
Changes in the total volume and value production as a result of a medium early start of low thinning 312
Changes in the volume and value efficiency with early low thinning: "Rapid growth management" 313
Advantages and disadvantages of rapid-growth management 310
(b) Summarizing Conclusions for Suitable Thinning Techniques in Norway Spruce Stands 322

3. Scots Pine

Brief characterization of the species Scots pine 323
Shortcomings and disturbances of Scots pine thinning experiments 324
Mean basal area and volume increment in Scots pine, based on examples 325
Thinning and value production of Scots pine 328
Summary of conclusions for a suitable thinning technique in Scots pine stands 329

4. Oak

Characterization of oak 330
Mean, periodic basal area and volume increment of sessile oak 331
Thinning treatments and financial production of sessile oak stands 335

V. The Influence of Methods of Establishment and Plant Spacing on Production

The Norway spruce cultural trials at Wermsdorf 338
Norway spruce spacing experiment Dietzhausen 37 341
South German Norway spruce spacing experiments 342
Summary of conclusions from cultivation and spacing experiments 345

VI. Increment and Yield of Mixed Stands without Large Age Differences and in Underplanted Stands 346

1. Fundamental Problems of Growth in Mixed Species 346

2. Results of Experiments in Mixed Stands 348
(a) Combinations of Light-demanding and Shade-tolerant Species 348
   (i) Mixed stands of oak and common beech 348
   (ii) Mixed stands of Scots pine and common beech 350
   Scots pine open-stand thinning experiment with underplanted beech, Eberswalde 16 351
   Mixed Scots pine-common beech experiment, Eberswalde 21/22 352
   The value production of the common beech fraction 356
   (iii) Mixed stands of Scots pine-Norway spruce (Silver fir, Douglas fir) 356
   (iv) Mixed stands of larch-common beech 358
   (v) Mixed stands of common beech and high-grade hardwoods 359
(b) Combinations of Shade-tolerant and Semi-shade-tolerant Species 360
   (i) Mixtures of beech and spruce 360
   Financial production of mixed common beech-Norway spruce stands; mixed stands or pure stands? 364
   (ii) Mixed stands of Silver fir-Norway spruce-common beech 365
   Characteristics of the species Silver fir (Abies alba Miller) 366
   Growth production of Silver fir stands and mixed stands of Silver fir-Norway spruce-common beech 366
   Financial production of mixed stands of Silver fir-Norway spruce-common beech 368

VII. Increment and Yield in Open-stand Systems and Stands which are Felled in Several Cutting Operations ("Mehrhiebig") 369

1. Open-stand and High Forest with Reserves System in Common Beech 369
   v. Seebach's classic open-stand system 369
   (a) Performance of the "Seebach System", based on Experimental "Seebach" Series 370
   (b) Modern Increment-felling Procedure ("Lichtwuchsbestreich") in Common beech 374
   The Lichtwuchs indicator plots of Common beech in Fabrikschiefach forest 376
   Results of Lichtwuchs experiments in the Taunus, Solling and Harz 377
   The effect of the Lichtwuchs system on the stem laver, specific gravity and quality of timber 379
   Freist's (1960) new yield table for the Lichtwuchs treatment of Common beech 381
   Financial production in the Lichtwuchs treatment of beech 382
CONTENTS

(c) Two-storeyed High Forest and High Forest with Reserves System
The beech crop under Lichtwuchs treatment in the locality of "Kleinengeleia", in Hundelshausen forest
Two-storeyed beech high-forest system in Walkenried forest
System of reserves
Proportionality limit in beech; degree of disengagement and production per unit area

2. The Scots Pine Standards (or Reserves) System
(a) Scots Pine Standards System with Pure Scots Pine in the Under Storey
(b) Scots Pine Standards System with a Large Proportion of Shade-tolerant Species in the Under Storey
Lowered production in the under storey
The growth of standards
Total volume production and financial production

3. The "Perpetual Forest" System of Bärenthorn

VIII. Yield Changes Consequent on Deterioration or Improvement of the Local Site Conditions

1. Deterioration of Yield
Degradation by the cultivation of pure crops
Lowering of the ground water level
Edge effects
Litter utilization

2. Yield Improvements by Amelioration and Fertilizer Treatments
Amelioration and fertilizer experiments and their consequences
The fertilizer experiment at Owingen
The fertilizer experiment in the municipal forest of Speyer
Summary of the results of forest fertilizer experiments prior to 1953
Results of more recent fertilizer experiments
The economic aspect of fertilizer treatment in the forest
Improvement of soils after litter exploitation
Fertilizer treatment of forest soils, soil biology and the living community

SECTION E  FOREST ORGANIZATION AND YIELD

I. Growth and Yield Relationships in Working Sections of the Normal High Forest

1. Model of the Normal Working Section

2. Changes in the Characteristic Values of Working Sections due to Different Grades of Thinning and Different Rotations
The place of thinning yields in the concept of rotation

3. Age Divisions and Increment of Working Sections with an Irregular Structure

II. Growth and Output of Selection Forests

1. The Selection Forest as a Special Case of a Working Section
(a) Diameter Distribution Curves and Height Curves for a Working Section of an Even-aged High Forest and for a Selection Forest
The mean height curves of working sections
(b) The Quality Classification of Selection Stands
Flury's selection forest qualification by class heights
The range of ages within diameter classes of the selection forest
Mitscherlich's quality classification by the diameter increment
The taper and form of trees in a high forest cut by compartments and in a selection forest
Size classes, the lower limit of measurement, and recruitment
The control method. Growing-stock, yield, increment and optimum stocking

2. Production of Selection Stands and Comparison with the Production of Normal Even-aged High Forest Stands
Results from long-term selection experiments
CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Results of temporary (once-measured) selection-forest sample plots</td>
<td>471</td>
</tr>
<tr>
<td>Comparisons of production and tree age</td>
<td>473</td>
</tr>
<tr>
<td>Comparison of production according to Flury. Selection or normal high forest?</td>
<td>475</td>
</tr>
<tr>
<td>III. Structure and Increment of Natural Forest Stands</td>
<td>479</td>
</tr>
<tr>
<td>Stages of development in natural forests</td>
<td>480</td>
</tr>
<tr>
<td>Increment production of natural forest stands</td>
<td>484</td>
</tr>
<tr>
<td>IV. Organization and Production of Intensively Managed Economic Forests</td>
<td>487</td>
</tr>
</tbody>
</table>

**APPENDIX 1. Hohenadl's Method**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPENDIX 2</td>
<td>491</td>
</tr>
<tr>
<td>Conversion Table of Metric into English Measurements</td>
<td>492</td>
</tr>
<tr>
<td>Dimensions of German Assortments</td>
<td>492</td>
</tr>
<tr>
<td>Classification of Timber</td>
<td>492</td>
</tr>
<tr>
<td>Assortments of Poles</td>
<td>493</td>
</tr>
</tbody>
</table>

**REFERENCES**

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INDEX</td>
<td>504</td>
</tr>
</tbody>
</table>
FOREWORD

The progress made during the past 15 years in the field of forest yield studies is so significant that, for the sake of forest science as well as practical forestry, a summary of the present state of knowledge appeared to be of some pressing urgency.

Effective and reliable information in this field must be sought mainly by attentiveness to the concepts of natural science. It is this fundamental attitude which has led the author to endeavour to establish closer connecting links with the natural sciences, and especially with plant physiology, soil science and meteorology.

Recent works have so successfully contributed to our awareness of the basic processes of organic production in forests—and this includes the quantitative aspects—that it is now possible to make a rough estimate of the influence and importance of the main factors. The study of forest yield is in a favourable position in this respect, because it enables the integrated result of complex individual growth processes to be assessed quantitatively. Thus it has been possible to widen the bridges built by Robert Hartig, Boysen-Jensen, Burger and Mar:Möller. The new Handbuch der Pflanzenphysiologie, the 16th volume of which has been published recently, conveys an idea of the extent of research in plant physiology. The subject of CO₂-assimilation alone occupies two volumes and a total of 1881 pages.

The central core of this study of forest yields appertains to the research into growing space and increment which is summarized in section C (The constitution and development of stands). In these studies, new insight is obtained into the intrinsic relationships between crown dimensions and basal area increment. In general, the hitherto commonly practised silvicultural techniques can be regarded as attempts to achieve an optimal allocation of growing space. With the help of the latest discoveries it has now become possible on the basis of natural laws to solve the problems of ordinary thinning (Durchforstung), heavy thinning which results in a permanently interrupted crown canopy (Lichtung) and thinning of multi-storey stands. In silviculture, therefore, one is no longer exclusively dependent on the summary results of experiments which in layout, methods and interpretation have been largely inadequate.

On this new basis it has been possible in section D (Structure, increment and yield of stands in relation to silvicultural treatment) to give a clear and indisputable interpretation of the complicated relationships and apparently contradictory results of former thinning experiments. The natural laws which have been worked out in section C have, moreover, helped to simplify the critical interpretation of experiments with mixed stands. In these, as well as in open stand systems and stands with more than one storey, new results have been discovered which are important to practical forestry.

In the chapter headed "Yield changes" the amelioration and treatment by fertilizers of forest soils are discussed from the standpoint of yield studies. The results of new fertilizer experiments open up very hopeful prospects. Not only is it possible by such methods to achieve a considerable increase in the organic production of the forest, but—by means of improved nutrition of forest trees, and a general improvement of the site—also to promote the health and security of the forests under our management.
Among the subjects discussed in the final section, headed “Forest organization and yield”, a clarification of important points about selection forest systems has been given. This entailed the unavoidable disappointment of exaggerated expectations which, even now, are often attached to an uneven-aged structure of the growing stock. Sober discoveries, however, are more profitable to forestry, with its long rotations and the important consequences of early decisions, than hopeful illusions.

In all questions treated by the author, he has endeavoured to draw inferences which are sufficiently extensive for their serviceable application in silviculture, yield regulation, and practical forest management. It is hoped that it will be evident that short-sighted profit motives have not been among the determining ideas and that the diverse functions of the modern forest have been sufficiently considered. Owing to the expense of the work involved in a critical study of the extensive data hitherto published, it has, unfortunately, not been possible to give full consideration to works published in languages other than German.

If, today, the results of 80 years of research work in experimental forests and forest research institutes have made it possible to clarify numerous problems, we must remind ourselves of the large amount of selfless and patient work which has been done to produce these results. Thus for a start, thanks must be rendered to all those persons who, by laborious measurements and calculation, have compiled the data which are now susceptible of interpretation. The author's particular thanks are given to those gentlemen who have so readily contributed valuable field inventory results, namely: Prof. Dr. E. Badoux of the Eidgenössische Anstalt für das Forstliche Versuchswesen, Zürich; Prof. Ch. Carbonnier of the Swedish Forest Research Institute, Stockholm; Dr. E. Holmsgaard, Head of the Danish Forest Research Institute, Springforbi; Dr. H. A. Henriksen, Copenhagen; Dr. A. Horki, former Head of the Österreichische Bundes-Versuchsanstalt, Mariabrunn; Prof. Dr. Erteld, Eberswalde; Prof. Dr. G. Mitscherlich, Freiburg; and Landforstmeister K. Hauser, Hechingen. Sincere thanks also go to the heads of the different Landesforstverwaltungen, Oberforstdirektionen and various private forest administrations as well as to the head foresters and foresters of the different forest districts who have kindly assisted the author and his staff of fellow workers. Thanks are also due to the Deutsche Forschungsgemeinschaft who, by generous research grants, have made possible the undertaking of several research projects. Particularly sincere thanks go finally to my fellow workers, especially Dozent Dr. R. Magin, Forstmeister Dr. R. Mayer, Forstassessor R. Kenneth, Ingenieur K. Balling and Fräulein E. Hodurek.

In this translation it has been possible to give consideration to some supplementary information and corrections in accordance with the latest state of research.

The author expresses his thanks to the publishers, Springer-Verlag, Berlin, and to Professor Dr. Pisek, Innsbruck, for their kind permission to reproduce some figures.

*Munich*

*ERNST ASSMANN*
INTRODUCTION

PRODUCTION techniques in forestry depend on the utilization and systematic control of growth processes. In the course of these processes, smaller or larger quantities of vegetable substance are produced, of which, in the case of a forest, we are mainly interested in the woody substance. It is the task of yield studies to examine the quantitative extent of growth processes in the forest in relation to time, site and the economical and technical measures available to man.

Every year, forest trees add to their volume by means of a further layer of wood. If, by measurement, we have determined the volume of an individual tree or of a whole stand at the beginning and at the end of a certain period of time, the difference between the two volumes represents the increment of that tree or stand for that particular period. Because of the central importance of increment as a measure of performance in our forest stands for a particular period, the subject is, in technical language, known as increment theory.

The increment produced by a forest is not identical with the yield. If we aimed at harvesting the actual annual increment we should need to detach the individual increment layers which have grown on the trees of this forest and this, of course, would be absurd. Timber harvesting in a forest requires the felling of entire trees, including their successive increments added over many years. Yield, in the sense used in this book therefore, is the harvested growth or increment of tree stands.¹ This explains why, even today, the double title “increment and yield theory” is often used in this special context. If we use the shorter terms “yield theory” or “yield studies”, it becomes evident that, on the one hand, the subject is concerned with the growth processes and the quantitative measure of growth conditions of trees and stands, and on the other hand, it has to examine the quantities, method of formation, and dimensions of the harvested timber contributing to the yield.

1. Historical Development

Scientific endeavours in this respect are as old as planned forest management. Sustained forest management requires not only a knowledge of the existing stock of a forest but also a knowledge of the yields to be expected in the future. Thus, practically all great foresters of the eighteenth and early nineteenth centuries have themselves undertaken yield studies or have caused them to be made. As early as 1795 Oberförster J. Ch. Paulsen (1748–1825) from the Lippe province issued usable yield tables for the most important tree species. Ch. v. Seebach (1793–1865), whose name has become known for the open stand system for beech, was one of the first to study yield by systematic and scientific methods. M. R. Pressler (1815–86) created a wealth of methods and devices for the determination of the timber volume and increment of growing trees and stands. Robert Hartig’s

¹ From the point of view of management it would be possible to visualize non-harvested yields, i.e. timber stocks which could be harvested consistently with sustained management but which, as a result of a personal decision by the forest owner, are not harvested, being conserved instead.
THE PRINCIPLES OF FOREST YIELD STUDY

(1839–1901) work was a pioneering effort. We not only have to thank him for the first faultlessly constructed yield tables but we must also regard him as the founder of research which is based on plant physiology and only lately brought to fruition by Boysen-Jensen, Burger and Møller. By contrast, F. von Baur (1830–97) laid stress on the collection of extensive data for the purpose of constructing auxiliary tables for practical use.

R. Weber gave us the first summary of the theory of increment in one section of his textbook on forest management. He entitled it "Die Lehre vom Holzzuwachs" (app. 180 pages). Amongst other subjects dealt with by R. Weber is an attempt to impart mathematical formulation to the natural laws of woody growth.

V. Guttenberg supplied a short summary of increment theory in his timber mensuration studies within the framework of the well-known Handbuch der Forstwissenschaft (Textbook of Forest Science) by Lorey.

As a result of the extensive experimentation carried out by forest research institutes, vast quantities of data have been amassed since the seventies of the last century. These have since been partially interpreted in important publications by Schwappach, Dieterich, Flury, Wiedemann, Zimmerle and others.

In his Einführung in die Forstliche Zuwachs- und Ertragslehre, of which the first edition was published in 1941, Vanselow has, for the first time, treated this particular aspect separately. The 2nd edition of Forstliche Zuwachs- und Ertragslehre by Weck, published in 1955, gives a stimulating representation of the subject of yield studies though from a slightly biased viewpoint. Finally, Wiedemann, in his work Ertragstundliche und waldbauliche Grundlagen der Forstwirtschaft, published in 1949 (2nd edition 1955), provided a summarized interpretation of the very extensive basic material hitherto compiled by the former Prussian Research Institute. In this excellent work, a large section is given up to the discussion of silvicultural and ecological relationships and to conclusions reached in the broader field of forest economics. The precision of experiments in connection with yield studies and the inferences drawn therefrom are somewhat prejudiced by unreliable increment determinations and the summarization for statistical purposes of non-homogeneous data.

A review of the development which has taken place so far in this field leads us to make the following statement: Whereas earlier yield studies were treated as a mere appendage to forest management or the theory of forest mensuration, the situation has changed with the passing of time. Forest mensuration has today become an auxiliary subject of yield study. It furnishes methods for the assessment of increment phenomena and their results. Thus an objective has been achieved which Dieterich (1935) indicated in a far-sighted thesis wherein he suggested that the principles of forest mensuration should be extended to comprise "the biological principles of forest yield or forest growth". It is on this basis that the author wishes to employ the term "principles of forest yield" (Waldertragwissenschaft) to define his subject. Apart from emphasizing a biological approach, this title is also intended to seize upon the concept of forest yields in their entirety. The main considerations which will determine the possible size and extent of a sustained yield will be the constitution and treatment of the forests. Both these will be taken into consideration in the course of this book.

1 The term "forest yield theory" is used synonymously with this.
2. The Place of Forest Yield Theory in Forest Science

With Dieterich (1953) we start from the basic assumption that forest science must deal with an examination of the mutual relationships which exist between human society and the living community of the forest:

- **Human society makes many diverse demands on the forest, for example**
  - **In economics:**
    - Wood utilization
  - **In hygiene:**
    - Water supplies
    - Air filtration
  - **In culture:**
    - Amenities of the forest

The connection of the two complexes is examined by *forest science*.

- *The natural bases of forest production offer many diverse possibilities*

A division of forest science into different sections on a systematic basis will show the position, confines and tasks of these respective fields (Table 1). We shall find the theory of forest yields among the “basic subjects” the task of which is to inquire into the underlying principles and methods applied in forest production. As this invokes the logical and causal coherence of facts, it merits the title of a theoretical science. In so far as it is, however, concerned with the rational application of discoveries it assumes the features.

**Table 1**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Characterization</th>
<th>Main objects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest history</td>
<td>General economy</td>
<td>Investigation of the relationships between political economy and forest economy; examination of the demands made on forest economy; critical review of the economic objects; balancing expense against yield; purposeful organization of management</td>
</tr>
<tr>
<td>Forest law</td>
<td>Intermediary</td>
<td>Ascertaining and ensuring sustained yields; implementation of economic objectives by long-term planning</td>
</tr>
<tr>
<td>Forest prices and timber market studies</td>
<td>Technical</td>
<td>Development of the best possible biological production techniques</td>
</tr>
<tr>
<td>The working economy (incl. forest utilization)</td>
<td>Basic</td>
<td>Investigation of basic biological and technological problems</td>
</tr>
<tr>
<td>Forest administration studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest management incl. forest measurement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest protection (forest health studies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silviculture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest utilization (timber extraction, work studies)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wild life management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest pathology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest yield studies incl. timber measurement (forest biometrics)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological timber studies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil science incl. soil biology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Botany</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematical statistics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meteorology</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of a practical science or technology, and it can safely be said that this “Janus face” characterizes forest science as a whole, which circumstance renders satisfactory systematization\(^1\) difficult.

3. Research Objects and Methods Employed in Forest Yield Studies

The research work in this field has, until recently, been mainly the task of forest research institutes. The working methods employed in such institutes and the results which have been achieved are a warning example of the insufficiency of a way of thinking which leans mainly on technical and economic considerations and of the short-sightedness of the outlook entertained on such a foundation. The object of yield research should be the quantitative assessment of growth phenomena in relationship to site and silvicultural methods of treatment. However, the technical expediency cannot be examined or the economic objects discussed until the purely biological inferences of the growth processes have been clarified. A research method having as its sole object the solution of some urgent current problem in technical economics is unable to throw light on the basic biological problem. There is a danger that, owing to the length of time required for experiment, the desired solution may be found much too late because the development in technical operations which has taken place in the meantime has long since outpaced the original problem. A comprehensive multilateral attack on the problem from the biological angle would, during the same period of experimentation, have supplied answers which might serve as basis for many and varied conclusions in technical economics.

We shall therefore try to use a generalized percept of the phenomena and their conformity to law as our main point of departure. From thence, we shall be able the more successfully to enter into questions involving special forest techniques. We shall soon discover that the production of timber represents only part of the organic accretion which goes on in a forest. Problems and methods which are confined to an arbitrarily limited part of this production, for example the technically utilizable timber of and exceeding a certain minimum size, are unable to uncover for us the laws governing this output. Only a comprehensive and penetrating research method, as for example the one used by Boysen-Jensen in his profound work Die Stoffproduktion der Pflanzen, can lead to new and fundamental discoveries.

The quantitative assessment of biological processes poses a difficult task for yield research. The main complicating factor is the size of forest trees which are not—as with agricultural food plants—harvested once every year, and which cannot therefore easily be measured by weight and volume. The annual changes in dimensions are relatively small and assessable only by careful measurements. It becomes accordingly necessary to develop a special timber mensuration technique with appropriate methods of measurement. If we examine the relationships between characteristic values of biological material which are either directly or indirectly related to age, we shall meet with marked irregularities which remain even after the exclusion of errors of measurements. This is properly known as “natural variability”. The organisms which we examine are, after all, living beings and are able, each one of them, to develop in their own individual ways. Moreover, a large number of factors exert their influence on the organisms, and the resultant effects induced by these are of corresponding diversity. The resulting natural variability excludes

\(^1\) On the systematic theory of the forest economy see also H.W. Weber (1929).
the possibility of obtaining strict "functional" relationships. We must therefore be satisfied with "stochastic" relationships, i.e. those assumed on the basis of probability theory. The importance of employing precise methods for measurement and calculation which have been developed to a high degree of perfection in mathematical statistics, becomes evident. Thus it is possible to define the research methods used in modern yield studies simply as biometrics, as biometrics applied to forestry. This science attempts, through a method of calculation adapted to the characteristics of large numbers of living beings, to assess biological relationships, to describe hypotheses with the help of suitable statistics and on appropriate occasions to express them by approximate mathematical functions.

If we attempt an orderly assessment of the motley and multi-shaped reality of organic life in its bearing upon technico-economic relationships, we shall find ourselves unable to manage without abstractions and mental aids. One is reminded of yield tables—often scorned without reason—and the model of a normal working section. We shall attempt to make a survey of the extensive complex of biological inter-relationships and their relevance to technology and economics. If we thus strive, wherever possible, to replace hitherto predominantly subjective ideas by definite knowledge and the quantitative framing of such discoveries, we must remain aware of the fact that practical forestry cannot be expressed in purely mathematical calculations. In practice—as in real life—the professional forester will always be confronted with fresh tasks, the solution of which should never be sought without giving consideration to all those relationships which hold between human society and the living community of the forest.