Contents

1 Forest Dynamics, Growth, and Yield: A Review, Analysis of the Present State, and Perspective .............................................. 1
  1.1 System Characteristics of Trees and Forest Stands .................. 1
    1.1.1 Differences in the Temporal and Spatial Scale Between Trees and Humans .............................................. 2
    1.1.2 Forest Stands are Open Systems ................................. 6
    1.1.3 Forests are Strongly Structurally Determined Systems ..... 8
    1.1.4 Trees, Forest Stands, and Forest Ecosystems are Shaped by History ..................................................... 11
    1.1.5 Forests are Equipped with and Regulated by Closed Feedback Loops ..................................................... 12
    1.1.6 Forest Ecosystems are Organised Hierarchically .............. 14
    1.1.7 Forest Stands are Systems with Multiple Output Variables ..................................................... 20
  1.2 From Forest Stand to Gene Level: The Ongoing Spatial and Temporal Refinement in Analysis and Modelling of Tree and Forest Stand Dynamics .............................................. 21
    1.2.1 Experiments, Inventories, and Measurement of Structures and Rates .............................................. 22
    1.2.2 From Proxy Variables to “Primary” Factors for Explanations and Estimations of Stand and Tree Growth .............................................. 24
    1.2.3 From Early Experience Tables to Ecophysiologically Based Computer Models .............................................. 26
  1.3 Bridging the Widening Gap Between Scientific Evidence and Practical Relevance .............................................. 29
    1.3.1 Scale Overlapping Experiments ...................................... 29
    1.3.2 Interdisciplinary Links Through Indicator Variables .......... 31
    1.3.3 Link Between Experiments, Inventories, and Monitoring by Classification Variables .............................................. 32
2 From Primary Production to Growth and Harvestable Yield and Vice Versa: Specific Definitions and the Link Between Two Branches of Forest Science

1.3.4 Model Development ........................................... 33
1.3.5 Link Between Models and Inventories: From Deductive to Inductive Approaches ........................................... 35
Summary ........................................................................ 37

2 From Primary Production to Growth and Harvestable Yield and Vice Versa: Specific Definitions and the Link Between Two Branches of Forest Science ........................................... 41
2.1 Link Between Forest Growth and Yield Science and Production Ecology ........................................... 41
2.2 General Definitions and Quantities: Primary Production, Growth and Yield ........................................... 42
  2.2.1 Gross and Net Primary Production ........................................... 44
  2.2.2 Gross and Net Growth ........................................... 46
  2.2.3 Gross and Net Yield ........................................... 47
2.3 Specific Terminology and Quantities in Forest Growth and Yield Science ........................................... 48
  2.3.1 Growth and Yield of Individual Trees ........................................... 50
  2.3.2 Growth and Yield at the Stand Level ........................................... 56
2.4 Stem and Merchantable Volume Growth as a Percentage of Gross Primary Production ........................................... 64
  2.4.1 From Standing Volume or Stem or Merchantable Wood Volume to Total Biomass ........................................... 66
  2.4.2 Ephemeral Turnover Factor \( t_{org} \) for Estimation of NPP ........................................... 72
  2.4.3 Deriving Harvested Volume Under Bark from Standing Volume over Bark ........................................... 76
  2.4.4 Conversion of Merchantable Wood Volume to GPP ........................................... 78
2.5 Dead Inner Xylem ........................................... 81
2.6 Growth and Yield and Nutrient Content ........................................... 84
  2.6.1 From Total Biomass to the Carbon Pool ........................................... 85
  2.6.2 Nutrient Minerals ........................................... 85
2.7 Efficiency of Energy, Nitrogen, and Water Use ........................................... 89
  2.7.1 Energy Use Efficiency (EUE) ........................................... 90
  2.7.2 Nitrogen Use Efficiency (NUE) ........................................... 93
  2.7.3 Water Use Efficiency (WUE) ........................................... 94
Summary ........................................................................ 95

3 Brief History and Profile of Long-Term Growth and Yield Research ........................................... 101
3.1 From Rules of Thumb to Sound Knowledge ........................................... 101
3.2 Foundation and Development of Experimental Forestry ........................................... 104
3.3 From the Association of German Forest Research Stations to the International Union of Forest Research Organizations (IUFRO) ........................................... 105
3.4 Growth and Yield Science Section of the German Union of Forest Research Organisations ........................................... 105
3.5 Continuity in Management of Long-Term Experiment Plots in Bavaria as a Model of Success ........................................ 107
3.6 Scientific and Practical Experiments .................................. 110
3.7 Establishment and Survey of Long-Term Experimental Plots .... 112
  3.7.1 Establishment of Experimental Plots and Trial Plots ............ 112
  3.7.2 Measuring Standing and Lying Trees ................................ 115
Summary ............................................................................... 118

4 Planning Forest Growth and Yield Experiments .......................... 121
  4.1 Key Terminology in the Design of Long-Term Experiments ....... 121
  4.2 The Experimental Question and its Four Component Questions ... 123
    4.2.1 Which Question Should Be Answered? ............................ 123
    4.2.2 With What Level of Accuracy Should the Question be Answered? .................................................. 124
    4.2.3 What Level of Spatial–Temporal Resolution is Wanted in the Explanation? ........................................ 124
    4.2.4 Why and for What Purpose Should the Question be Answered? .................................................. 124
  4.3 Biological Variability and Replicates .................................. 125
    4.3.1 Total Population and Sample ........................................ 125
  4.4 Size of Experimental Plot and Trial Plot Number ................... 126
  4.5 Block Formation and Randomisation: Elimination of Systematic Error .................................................. 128
  4.6 Classical Experimental Designs .......................................... 129
    4.6.1 One-Factor Designs .................................................. 130
    4.6.2 Two-Factor or Multifactor Analysis ................................. 133
    4.6.3 Split-Plot and Split-Block Designs ................................. 137
    4.6.4 Trial Series and Disjunct Experimental Plots ..................... 139
  4.7 Special Experimental Designs and Forest Growth Surveys ......... 141
    4.7.1 From Stand to Individual Tree Experiments ..................... 141
    4.7.2 Experiments and Surveys of Growth Disturbances ............. 144
    4.7.3 Artificial Time Series or Growth Series .......................... 145
Summary ............................................................................... 148

5 Description and Quantification of Silvicultural Prescriptions .......... 151
  5.1 Kind of Thinning ......................................................... 154
    5.1.1 Thinning According to Social Tree Classes by Kraft (1884) ....................................................................... 154
    5.1.2 Thinning According to Combined Tree and Stem Quality Classes from the Association of German Forest Research Stations (1902) ..................................................................... 156
    5.1.3 Thinning After the Selection of Superior or Final Crop Trees ..................................................................... 160
    5.1.4 Thinning Based on Diameter Class or Target Diameter .......... 164
  5.2 Severity of Thinning ......................................................... 166
    5.2.1 Thinning Based on a Target Stand Density Curve .............. 167
5.2.2 Approaches for Regulating Thinning Severity and Stand Density ........................................... 167
5.2.3 Selection of Density Classes ................................................................. 170
5.2.4 Management of Stand Density in Fertilisation and Provenance Trials ................................. 171
5.2.5 Individual Tree Based Thinning Prescriptions ........................................ 172
5.3 Intensity of Thinning ................................................................. 175
5.4 Algorithmic Formulation of Silvicultural Prescriptions for Forest Practice and Growth and Yield Models ......................................................... 177
Summary ................................................................. 178

6 Standard Analysis of Long-Term Experimental Plots ......................................................... 181
6.1 From Measurement to Response Variables ................................................................. 183
6.2 Importance of Regression Sampling for Standard Analysis ........................................... 184
6.2.1 Principle of Regression Sampling ........................................................................ 184
6.2.2 Linear Transformation ......................................................................................... 184
6.3 Determination of Stand-Height Curves ................................................................. 186
6.3.1 Function Equations for Diameter–Height Relationships ........................................ 187
6.3.2 Selection of the Most Suitable Model Function ................................................. 188
6.4 Diameter–Height–Age Relationships ................................................................. 189
6.4.1 Method of Smoothing Coefficients .................................................................. 191
6.4.2 Growth Function Methods for Strata Mean Trees ........................................... 193
6.4.3 Age–Diameter–Height Regression Methods ......................................................... 195
6.5 Form Factors and Volume Calculations for Individual Trees ................................. 196
6.5.1 Form Factors ................................................................................................. 197
6.5.2 Volume Calculations for Individual Trees ......................................................... 199
6.6 Stand Mean and Cumulative Values at the Time of Inventory and for the Periods Between Inventories ................................................................. 199
6.6.1 Reference Area ............................................................................................... 199
6.6.2 Tree Number ................................................................................................. 199
6.6.3 Mean Diameter and Mean Diameter of the Top Height Tree Collective .................. 200
6.6.4 Mean and Top Height ...................................................................................... 201
6.6.5 Slenderness h/q/dq and h100/d100 ...................................................................... 203
6.6.6 Stand Basal Area and Volume ......................................................................... 203
6.6.7 Growth and Yield Characteristics ...................................................................... 204
6.7 Results of Standard Analysis .................................................................................... 205
6.7.1 Presentation in Tables ...................................................................................... 205
6.7.2 Stand Development Diagrams ........................................................................... 211
Summary .................................................................................................................. 220

7 Description and Analysis of Stand Structures ................................................................. 223
7.1 Structures and Processes in Forest Stands ....................................................................... 225
7.1.1 Interaction Between Structures and Processes ................................................... 225
7.1.2 Effect of Initial Structure on Stand Development ................................................. 227
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>Descriptions of Stand Structure</td>
<td>229</td>
</tr>
<tr>
<td>7.2.1</td>
<td>Tree Distribution Maps and Crown Maps</td>
<td>230</td>
</tr>
<tr>
<td>7.2.2</td>
<td>Three-Dimensional Visualisation of Forest Growth</td>
<td>234</td>
</tr>
<tr>
<td>7.2.3</td>
<td>Spatial Occupancy Patterns</td>
<td>239</td>
</tr>
<tr>
<td>7.3</td>
<td>Horizontal Tree Distribution Patterns</td>
<td>242</td>
</tr>
<tr>
<td>7.3.1</td>
<td>Poisson Distribution as a Reference for Analysing Stand Structures</td>
<td>243</td>
</tr>
<tr>
<td>7.3.2</td>
<td>Position-Dependent Distribution Indices</td>
<td>246</td>
</tr>
<tr>
<td>7.3.3</td>
<td>Distribution Indices Based on Sample Quadrats</td>
<td>252</td>
</tr>
<tr>
<td>7.3.4</td>
<td>K-Function</td>
<td>256</td>
</tr>
<tr>
<td>7.3.5</td>
<td>L-Function</td>
<td>260</td>
</tr>
<tr>
<td>7.3.6</td>
<td>Pair Correlation Functions for Detailed Analysis of Tree Distribution Patterns</td>
<td>261</td>
</tr>
<tr>
<td>7.4</td>
<td>Stand Density</td>
<td>266</td>
</tr>
<tr>
<td>7.4.1</td>
<td>Stocking Density</td>
<td>266</td>
</tr>
<tr>
<td>7.4.2</td>
<td>Percentage Canopy Cover (PCC)</td>
<td>267</td>
</tr>
<tr>
<td>7.4.3</td>
<td>Mean Basal Area, mBA, by Assmann (1970)</td>
<td>269</td>
</tr>
<tr>
<td>7.4.4</td>
<td>Quantifying Stand Density from the Allometry Between Mean Size and Plants per Unit Area</td>
<td>270</td>
</tr>
<tr>
<td>7.4.5</td>
<td>Crown Competition Factor CCF</td>
<td>273</td>
</tr>
<tr>
<td>7.4.6</td>
<td>Density of Spatial Occupancy and Vertical Profiles</td>
<td>274</td>
</tr>
<tr>
<td>7.5</td>
<td>Differentiation</td>
<td>276</td>
</tr>
<tr>
<td>7.5.1</td>
<td>Coefficient of Variation of Tree Diameters and Heights</td>
<td>276</td>
</tr>
<tr>
<td>7.5.2</td>
<td>Diameter Differentiation by Füldner (1995)</td>
<td>276</td>
</tr>
<tr>
<td>7.5.3</td>
<td>Species Richness, Species Diversity, and Structural Diversity</td>
<td>279</td>
</tr>
<tr>
<td>7.6</td>
<td>Species Intermingling</td>
<td>284</td>
</tr>
<tr>
<td>7.6.1</td>
<td>Species Intermingling Index by Füldner (1996)</td>
<td>284</td>
</tr>
<tr>
<td>7.6.2</td>
<td>Index of Segregation from Pielou (1977)</td>
<td>285</td>
</tr>
<tr>
<td>8</td>
<td>Growing Space and Competitive Situation of Individual Trees</td>
<td>291</td>
</tr>
<tr>
<td>8.1</td>
<td>The Stand as a Mosaic of Individual Trees</td>
<td>292</td>
</tr>
<tr>
<td>8.2</td>
<td>Position-Dependent Competition Indices</td>
<td>292</td>
</tr>
<tr>
<td>8.2.1</td>
<td>Example of Competitor Identification and Competition Calculation</td>
<td>293</td>
</tr>
<tr>
<td>8.2.2</td>
<td>Methods of Competitor Identification</td>
<td>295</td>
</tr>
<tr>
<td>8.2.3</td>
<td>Quantifying the Level of Competition</td>
<td>299</td>
</tr>
<tr>
<td>8.2.4</td>
<td>Evaluation of Methods</td>
<td>302</td>
</tr>
<tr>
<td>8.3</td>
<td>Position-Independent Competition Measures</td>
<td>305</td>
</tr>
<tr>
<td>8.3.1</td>
<td>Crown Competition Factor</td>
<td>305</td>
</tr>
<tr>
<td>8.3.2</td>
<td>Horizontal Cross-Section Methods</td>
<td>306</td>
</tr>
<tr>
<td>8.3.3</td>
<td>Percentile of the Basal Area Frequency Distribution</td>
<td>307</td>
</tr>
<tr>
<td>8.3.4</td>
<td>Comparing Position-Independent with Position-Dependent Competition Indices</td>
<td>308</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
<td>------</td>
</tr>
<tr>
<td>8.4</td>
<td>Methods Based on Growing Area</td>
<td>311</td>
</tr>
<tr>
<td>8.4.1</td>
<td>Circle Segment Method</td>
<td>311</td>
</tr>
<tr>
<td>8.4.2</td>
<td>Rastering the Stand Area</td>
<td>312</td>
</tr>
<tr>
<td>8.4.3</td>
<td>Growing Area Polygons</td>
<td>313</td>
</tr>
<tr>
<td>8.5</td>
<td>Detailed Analysis of a Tree’s Spatial Growth Constellation</td>
<td>315</td>
</tr>
<tr>
<td>8.5.1</td>
<td>Spatial Rastering and Dot Counting</td>
<td>315</td>
</tr>
<tr>
<td>8.5.2</td>
<td>Calculation of Spatial Distances</td>
<td>318</td>
</tr>
<tr>
<td>8.5.3</td>
<td>Crown Growth Responses to Lateral Restriction</td>
<td>320</td>
</tr>
<tr>
<td>8.6</td>
<td>Hemispherical Images for Quantifying the Competitive Situation of Individual Trees</td>
<td>321</td>
</tr>
<tr>
<td>8.6.1</td>
<td>Fish-Eye Images as a Basis for Spatial Analyses</td>
<td>321</td>
</tr>
<tr>
<td>8.6.2</td>
<td>Methodological Principles of Fish-Eye Projection in Forest Stands</td>
<td>323</td>
</tr>
<tr>
<td>8.6.3</td>
<td>Quantifying the Competitive Situation of Individual Trees in a Norway Spruce–European Beech Mixed Stand</td>
<td>325</td>
</tr>
<tr>
<td>8.7</td>
<td>Edge Correction Methods</td>
<td>326</td>
</tr>
<tr>
<td>8.7.1</td>
<td>Edge Effects and Edge Correction Methods</td>
<td>326</td>
</tr>
<tr>
<td>8.7.2</td>
<td>Reflection and Shift</td>
<td>327</td>
</tr>
<tr>
<td>8.7.3</td>
<td>Linear Expansion</td>
<td>328</td>
</tr>
<tr>
<td>8.7.4</td>
<td>Structure Generation</td>
<td>332</td>
</tr>
<tr>
<td>8.7.5</td>
<td>Evaluation of Edge Correction Methods</td>
<td>333</td>
</tr>
<tr>
<td>Summary</td>
<td>334</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Effects of Species Mixture on Tree and Stand Growth</td>
<td>337</td>
</tr>
<tr>
<td>9.1</td>
<td>Introduction: Increasing Productivity with Species Mixtures?</td>
<td>337</td>
</tr>
<tr>
<td>9.1.1</td>
<td>Fundamental Niche and Niche Differentiation</td>
<td>338</td>
</tr>
<tr>
<td>9.1.2</td>
<td>Maximizing Fitness isn’t Equivalent to Maximizing Productivity</td>
<td>340</td>
</tr>
<tr>
<td>9.1.3</td>
<td>The Balance Between Production Promoting and Inhibiting Effects is Important</td>
<td>341</td>
</tr>
<tr>
<td>9.2</td>
<td>Framework for Analysing Mixing Effects</td>
<td>343</td>
</tr>
<tr>
<td>9.2.1</td>
<td>Ecological Niche</td>
<td>343</td>
</tr>
<tr>
<td>9.2.2</td>
<td>Site–Growth Relationships</td>
<td>344</td>
</tr>
<tr>
<td>9.2.3</td>
<td>Risk Distribution</td>
<td>344</td>
</tr>
<tr>
<td>9.2.4</td>
<td>Comparison of Mixed Stands with Neighbouring Pure Stands: Methodological Considerations</td>
<td>348</td>
</tr>
<tr>
<td>9.3</td>
<td>Quantifying Effects of Species Mixture at Stand Level</td>
<td>351</td>
</tr>
<tr>
<td>9.3.1</td>
<td>Cross–Species Diagrams for Visualising Mixture Effects</td>
<td>351</td>
</tr>
<tr>
<td>9.3.2</td>
<td>Nomenclature, Relations and Variables for Analysing Mixture Effects</td>
<td>352</td>
</tr>
<tr>
<td>9.3.3</td>
<td>Mixture Proportion</td>
<td>354</td>
</tr>
<tr>
<td>9.3.4</td>
<td>Examining Effects of Species Mixture on Biomass Productivity in Norway Spruce–European Beech Stands: An Example</td>
<td>356</td>
</tr>
<tr>
<td>9.3.5</td>
<td>Examining Mean Tree Size in Norway Spruce–European Beech Stands: An Example</td>
<td>360</td>
</tr>
</tbody>
</table>
9.4 Quantifying Mixture Effects at the Individual Tree Level ........ 363
  9.4.1 Efficiency Parameters for Individual Tree Growth ........ 363
  9.4.2 Application of Efficiency Parameters for Detecting
      Mixture Effects ............................................ 365
9.5 Productivity in Mixed Forest Stands ............................. 371
  9.5.1 The Mixed Stands Issue: A Central European Review
      and Perspective ............................................. 371
  9.5.2 Benchmarks for Productivity of Mixed Stands
      Compared to Pure Stands .................................... 372
  9.5.3 Spatial and Temporal Niche Differentiation as a Recipe
      for Coexistence and Cause of Surplus Productivity ......... 375
  9.5.4 Crown Shyness ........................................ 376
  9.5.5 Growth Resilience with Structural and Species
      Diversity ................................................ 377
Summary ...................................................... 378

10 Growth Relationships and their Biometric Formulation .......... 381
  10.1 Dependence of Growth on Environmental Conditions
      and Resource Availability ..................................... 381
      10.1.1 Unimodal Dose–Effect-Curve ........................ 381
      10.1.2 Dose–Effect-Rule by Mitscherlich (1948) .......... 383
      10.1.3 Combining the Effects of Several Growth Factors .... 386
  10.2 Allometry at the Individual Plant Level ...................... 387
      10.2.1 Allometry and Its Biometric Formulation .......... 387
      10.2.2 Examples of Allometry at the Individual Plant Level.. 389
      10.2.3 Detection of Periodic Changes in Allometry ........ 391
  10.3 Growth and Yield Functions of Individual Plants .......... 393
      10.3.1 Physiological Reasoning and Biometrical Formulation
            of Growth Functions ..................................... 393
      10.3.2 Overview Over Approved Growth and Yield Functions .. 394
      10.3.3 Relationship Between Growth and Yield .............. 397
  10.4 Allometry at the Stand Level: The Self-Thinning Rules
      from Reineke (1933) and Yoda et al. (1963) .............. 399
      10.4.1 Reineke’s (1933) Self-thinning Line and Stand
            Density Index ............................................ 400
      10.4.2 −3/2-Power Rule by Yoda et al. (1963) .......... 402
      10.4.3 Link Between Individual Tree and Stand Allometry .... 405
      10.4.4 Allometric Scaling as General Rule ................. 406
  10.5 Stand Density and Growth .................................. 407
      10.5.1 Assmann’s Concept of Maximum, Optimum and Critical
            Stand Density ............................................ 409
      10.5.2 Biometric Formulation of the Unimodal Optimum
            Curve of Volume Growth in Relation to Stand Density
            and Mean Tree Size ...................................... 411
## 10.6 Dealing with Biological Variability

### 10.6.1 Quantifying Variability

### 10.6.2 Reproduction of Variability

<table>
<thead>
<tr>
<th>Summary</th>
<th>420</th>
</tr>
</thead>
</table>

## 11 Forest Growth Models

### 11.1 Scales of Observation, Statistical and Mechanistic Approaches to Stand Dynamics

#### 11.1.1 Scales of Forest Growth and Yield Research and Models

#### 11.1.2 From the Classical Black-Box to White-Box Approaches

#### 11.1.3 Top–Down Approach vs Bottom–Up Approach

### 11.2 Model Objectives, Degree of System Abstraction, Database

#### 11.2.1 Growth Models as Nested Hypotheses About Systems Behaviour

#### 11.2.2 Growth Models as a Decision Tool for Forest Management

### 11.3 Growth Models Based on Stand Level Mean and Cumulative Values

#### 11.3.1 Principles of Yield Table Construction

#### 11.3.2 From Experience Tables to Stand Simulators

### 11.4 Growth Models Based on Tree Number Frequencies

#### 11.4.1 Representing Stand Development by Systems of Differential Equations

#### 11.4.2 Growth Models Based on Progressing Distributions

#### 11.4.3 Stand Evolution Models – Stand Growth as a Stochastic Process

### 11.5 Individual Tree Growth and Yield Models

#### 11.5.1 Overview of the Underlying Principles of Individual-Tree Models

#### 11.5.2 Growth Functions as the Core Element of Individual-Tree Models

#### 11.5.3 Overview of Model Types

### 11.6 Gap and Hybrid Models

#### 11.6.1 Development Cycle in Gaps

#### 11.6.2 JABOWA – Prototype Model from Botkin et al. (1972)

### 11.7 Matter Balance Models

#### 11.7.1 Increasing Structural and Functional Accordance of Models with Reality

#### 11.7.2 Modelling of the Basic Processes in Matter Balance Models

#### 11.7.3 Overview of Matter Balance Model Approaches

### 11.8 Landscape Models

#### 11.8.1 Application of Landscape Model LandClim
11.9 Visualisation of Forest Stands and Wooded Landscapes .......... 482
  11.9.1 Visualisation Tools TREEVIEW and L-VIS .......... 484
11.10 Perspective ............................................. 488
Summary .......................................................... 490

12 Evaluation and Standard Description of Growth Models ........ 493
  12.1 Approaches for Evaluation of Growth Models and Simulators .......... 494
    12.1.1 Suitability for a Given Purpose ......................... 494
    12.1.2 Validation of the Biometric Model ...................... 496
    12.1.3 Suitability of the Software .............................. 499
    12.1.4 Customising Models and Simulators for End-Users .......... 500
  12.2 Examples of Model Validation .................................. 503
    12.2.1 Validation on the Basis of Long-Term Sample Plots 
and Inventory Data ........................................... 503
    12.2.2 Comparison with Growth Relationships .................. 508
    12.2.3 Comparison with Knowledge from Experience ............. 510
  12.3 Standards for Describing Models and Simulators .............. 510
Summary .......................................................... 512

13 Application of Forest Simulation Models for Decision Support 
in Practice ......................................................... 515
  13.1 Model Objective and Prediction Algorithm ..................... 516
    13.1.1 Model Objective ...................................... 516
    13.1.2 Prediction Algorithm ................................ 516
    13.1.3 Database ............................................ 519
  13.2 Site–Growth Model ........................................... 519
    13.2.1 The Principles of Controlling Individual Tree Growth 
by Means of Site Factors ......................................... 520
    13.2.2 Modelling the Potential Age–Height Curve 
in Dependence on Site Conditions ................................ 520
  13.3 Generation of Initial Values for Simulation Runs ............. 525
    13.3.1 Stand Structure Generator STRUGEN ................... 526
  13.4 Spatially Explicit Modelling of the Growth Arrangement 
of the Individual Trees ........................................ 528
    13.4.1 Index KKL as the Indicator of the Crown Competition ... 528
    13.4.2 Index NDIST as the Indicator 
for Competition Asymmetry ..................................... 528
    13.4.3 Index KMA for the Species Mixture 
in the Neighbourhood of Individual Trees ...................... 529
  13.5 Application for Scenario Analysis at the Stand Level: 
A Pure Norway Spruce Stand vs a Norway Spruce – European 
Beech Mixed Stand ................................................. 530
    13.5.1 Growth and Yield at the Stand Level .................... 530
    13.5.2 Growth and Yield on Tree Level ......................... 532
    13.5.3 Modelling Structural Diversity .......................... 532
    13.5.4 Multi-Criteria Considerations ............................ 534
13.6 Growth Models for Dynamic Enterprise Planning .............................. 535
  13.6.1 Simulation at the Enterprise Level for Long-Term Strategic Planning .................................................. 536
  13.6.2 Application of Models for Decision Support ...................... 537
  13.6.3 Application of the Munich Forestry Enterprise Forest Management Plan .............................................. 540
13.7 Estimation of Growth and Yield Responses to Climate Change .... 543
  13.7.1 Dependence of Response Patterns on Site and Tree Species ........ 544
  13.7.2 Sensitivity Analysis at the Regional Level ...................... 545
  13.7.3 Development of Silvicultural Measures for Mitigation and Adaptation to Climate Change ......................... 548
Summary ................................................................................. 549

14 Diagnosis of Growth Disturbances .............................................. 553
  14.1 Growth Models as Reference ........................................... 556
    14.1.1 Comparison with Yield Table .................................. 556
    14.1.2 Dynamic Growth Models as Reference ..................... 557
    14.1.3 Synthetic Reference Curves .................................... 559
  14.2 Undisturbed Trees or Stands as a Reference ....................... 560
    14.2.1 Increment Trend Method ....................................... 560
    14.2.2 Pair-Wise Comparison .......................................... 565
    14.2.3 Reference Plot Comparison ..................................... 566
    14.2.4 Reference Plot Comparison by Indexing ................... 570
    14.2.5 Regression–Analytical Estimation of Increment Decrease ........................................................................... 572
  14.3 Growth Behaviour in Other Calendar Periods as Reference .... 576
    14.3.1 Individual Growth in Previous Period as Reference .... 576
    14.3.2 Long-Term, Age-Specific Tree Growth as Reference (Constant Age Method) ............................................. 579
    14.3.3 Growth Comparison of Previous and Subsequent Generation at the Same Site ........................................... 580
    14.3.4 Diagnosis of Growth Trends from Succeeding Inventories ........................................................................... 582
  14.4 Dendro-Chronological Time Series Analysis .......................... 585
    14.4.1 Elimination of the Smooth Component ...................... 586
    14.4.2 Indexing ............................................................ 587
    14.4.3 Response Function ............................................... 588
    14.4.4 Quantification of Increment Losses .......................... 589
Summary ................................................................................. 590

15 Pathways to System Understanding and Management .................. 593
  15.1 Overview of Knowledge Pathways in Forest Growth and Yield Research ......................................................... 594
    15.1.1 Observation, Measurement, and Collection of Data ...... 595
    15.1.2 Description .......................................................... 597
15.1.3 Formulation of Hypotheses for Elements of Individual System Elements ........................................ 597

15.1.4 Test of Hypotheses .................................... 599

15.1.5 Models as a Chain of Hypotheses ....................... 602

15.1.6 Test of Model Hypothesis by Simulation ............... 603

15.1.7 Application of the Model in Research, Practice, and Education .................................................. 604

15.1.8 Relationships, Rules, Laws, and Theories ............. 604

15.2 Transfer of Knowledge from Science to Practice ........ 611

15.2.1 Concept of Forest Ecosystem Management ............. 611

15.2.2 Long-Term Experiments and Models for Decision Support ............................................................. 613

Summary ............................................................................ 615

References ........................................................................ 619

Index .................................................................................. 655
Forest Dynamics, Growth and Yield
From Measurement to Model
Pretzsch, H.
2009, XIX, 664 p., Hardcover
ISBN: 978-3-540-88306-7