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Forest Dynamics, Growth and Yield

From Measurement to Model

Springer

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Preface

How do tree crowns, trees or entire forest stands respond to thinning in the long term? What effect do tree species mixture and multi-layering have on the productivity and stability of trees, stands or forest enterprises? How do tree and stand growth respond to stress due to climate change or air pollution? Furthermore, in the event that one has acquired knowledge about the effects of thinning, mixture and stress, how can one make this knowledge applicable to decision making in forestry practice? The experimental designs, analytical methods, general relationships and models for answering questions of this kind are the focal point of this book.

Forest ecosystems can be analysed at very different spatial and temporal levels. This book focuses on a very specific range in scale within which to analyse forest ecosystems, which extends spatially from the plant organ level through to the stand level, and temporally from days or months to the life-time of a forest stand, spanning decades or possibly even centuries. It is this range in scale addressed in the book that gives it its special profile. General rules, relationships and models of tree, and stand growth are introduced at these levels. Whereas plant biology and ecophysiology operate at a higher resolution, forest management and landscape ecology operate at a broader spatial-temporal resolution. The approach to forest dynamics, growth and yield adopted in this book lies in between; it integrates knowledge from these disciplines and, therefore, can contribute to a cross-scale, holistic systems understanding.

The scales selected have practical relevance, as they are identical to those of biological observation and the environment in which people live. As interesting as fragmented details at small temporal or spatial scales obtained through reductionist approaches might be, system management requires rather an integrated, holistic view of the system in question. In this book I outline some ways to draw information of practical relevance from the scientific knowledge acquired.

Why a new book about structural dynamics, growth and yield in central European forests, why this effort when, in any event, very little is read today? The well-known works from Assmann (1970), Kramer (1988) and Mitscherlich (1970) focus on even-aged pure stands, classic silvicultural thinning methods and wood yield at the stand level. However, over time, the structure, dynamics and tending regimes in, and demands on, the forest in central Europe have changed immensely as evident in the transition from largely evenaged pure stands to structurally diverse mixed stands, from homogenizing thinning regimes to the targeted promotion of individual trees or groups of trees in the stand, from wood production forestry to multipurpose forestry, which is concerned with a broad range of ecological, economic and social functions and services of forest. In short, the forest structure, management activities, and the anticipated effects on the forest in general and forest production in particular have become more complex in the sense that, in a forest ecosystem today, essentially more elements need to be investigated, more relationships among these elements understood, and these need to be taken into account in forest management. In response to this tendency towards increasing complexity, new investigation concepts, analytical methods and model approaches have been developed over the years. They complete the transition from stand-oriented approaches to individual tree approaches, from position independent to functional-structural concepts, from descriptive approaches focussed mainly on the volume growth and yield to interdisciplinary model-oriented ones. As yet these approaches have not been summarised in a textbook.

Given the structures dealt with, which range from plant organs through to the tree, stand and enterprise level, and the processes analysed in a time frame of days or months through to decades or even centuries, this book is directed at all readers interested in trees, forest stands and forest ecosystems. This book has been written especially for readers who are seeking in depth information about individual-based functional-structural approaches for recording, analysing and modelling forest systems. It integrates and imparts essential forest system knowledge to all green-minded natural scientists. The work is compiled for students, scientists, lecturers, forest planners, forest managers, forest experts and consultants.

The book summarises the author's lectures and scientific work between 1994 and 2008 while at the Ludwig Maximilian University, Munich, the Technische Universität München, and at Universities in the Czech Republic, Canada and South Africa. The contents represent the lecture material, the scientific approach and a compilation of the current methods used at the Chair for Forest Growth Science at the Technische Universität München, Germany. This book is dedicated to all students, researchers and colleagues at my Chair who have contributed to the realisation of this book.

For their support in editing specific subject areas, I would like to thank my colleagues Peter Biber (Chap. 8), Rüdiger Grote (Chap. 11), Thomas Rötzer (Chap. 2) and Stefan Seifert (Chap. 11). I also thank Gerhard Schütze and Martin Nickel for their unerring support of the research analysis, Marga Schmid for editing the bibliographical references and Ulrich Kern and Leonhard Steinacker for the cover design. Helen Desmond and Tobias Mette accomplished the overwhelming task of translating and editing the text, Charlotte Pretzsch the compilation of the index, and Ulrich Kern the equally extensive task of preparing the graphic illustrations. I thank you all for the affable and effective collaboration. The willingness to take on the considerable additional workload was founded on the common commitment to all things pertaining to the forest, and it is for all things pertaining to the forest, that is for a better understanding of, and a higher regard for the forest, that this book aims to make a contribution.

Finally, I also extend my thanks to the editors at Springer Publishing, Ursula Gramm and Christine Eckey, for their constructive contribution, and reliable and congenial assistance.

Weihenstephan *Hans Pretzsch*
September 2008

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Chapter 1
Forest Dynamics, Growth, and Yield: A Review, Analysis of the Present State, and Perspective

The study of forest dynamics is concerned with the changes in forest structure and composition over time, including its behaviour in response to anthropogenic and natural disturbances. *Growth* is defined as the biomass (or size) a plant or a stand produces within a defined period (e.g. 1 day, 1 year, 5 years). Yield is the accumulated biomass from the time of stand establishment. Tree growth and disturbances influence and are primary evidence of forest dynamics. They are determined by resources (e.g. radiation, water, nutrients supply) and environmental conditions (e.g. temperature, soil acidity, or air pollution). The first chapter introduces the special characteristics of the forest system. These characteristics are investigated in the study of forest dynamics, of growth and yield science, and of how biological rules are traced systematically and made accessible as practical knowledge. In the course of this chapter, we learn about the past, current, and future challenges to the science of forest growth and yield.

1.1 System Characteristics of Trees and Forest Stands

A system is defined by the system elements that it comprises, the relationships between these elements, and the general rules of the system. The system rules are effective only at the entire system level and not at the individual or subsystem element levels. The functions of the system that are recognized and emphasised depend on the investigator or user's perspective (von Bertalanffy 1951, 1968; Wuketits 1981). The same is true for the system boundaries, which are defined according to specific purposes and seldom correspond to actual natural system boundaries. For instance, in a forest stand, we can distinguish the system elements soil, soil vegetation and trees with roots, stems, branches and needles and/or leaves. The interactions among the system elements create a characteristic system structure, e.g. the shadowing of the trees determines the light conditions for the understory trees and the soil vegetation.

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In general, except for some wearing out, systems that function independent of time (e.g. a chair, a piano) are termed *static systems*. In dynamic systems (e.g. forest stands, animal populations, scientific working team), the chain of events is time dependent. Past system events decisively influence its future behaviour. Since the specific system characteristics of forest stands ultimately determine the approach and methodology of forest growth and yield research, they are presented below.

1.1.1 Differences in the Temporal and Spatial Scale Between Trees and Humans

One fundamental characteristic of trees and forest stands that has important consequences for their analysis, representation, and modelling is their longevity. The following expresses the life span of various organisms on a power-of-10 scale:

Trees	10^4 years
Humans	10^2 years
Large mammals	10^1 years
Grasses, herbs	10^0 years
Insects	10^{-1} years
Bacteria	10^{-2} years

We see that trees and forest stands live two to six orders of magnitude longer than most animal and plant organisms, including humans. For a bacterium, a tree life is 10^6 times longer, an eternity so to speak. In comparison with the oldest trees in the world ($\sim$6,000 years), the life span of humans ($\sim$100 years) attains only about 100th, or 10^{-2}, that of trees. Consequently, whereas experiments on the growth of bacteria, insects, grain types, herbaceous plants, or mammals can be conducted in hours, days, months, or a few years, experiments on tree growth require continuity over many generations of scientists. Yet, even the oldest thinning experiments from long-term experiments in Bavaria, which date back to the 1870s and continue to be surveyed, cover only a comparably small segment of the potential life span of trees and stands.

The North American tree species Bristlecone pine (*Pinus aristata*) can reach an impressive 5,000–6,000 years of age (Fig. 1.1). Yet even when compared to central European tree species such as Silver birch, European ash, Norway spruce, or Sessile oak, the working, research, or entire life span of a human is comparably short. The entire forest science era, beginning with W. L. Pfeil (1783–1859), H. Cotta (1763–1844), and G. L. Hartig (1764–1837) in the late eighteenth century, an extraordinarily long period, only covers a fraction of the life span of our forest trees (Fig. 1.1).

The longevity of trees and forest stands requires specific approaches, from initial measurements in the field to modelling on the computer, that differ considerably from those adopted for organisms with shorter life expectancies. For example,

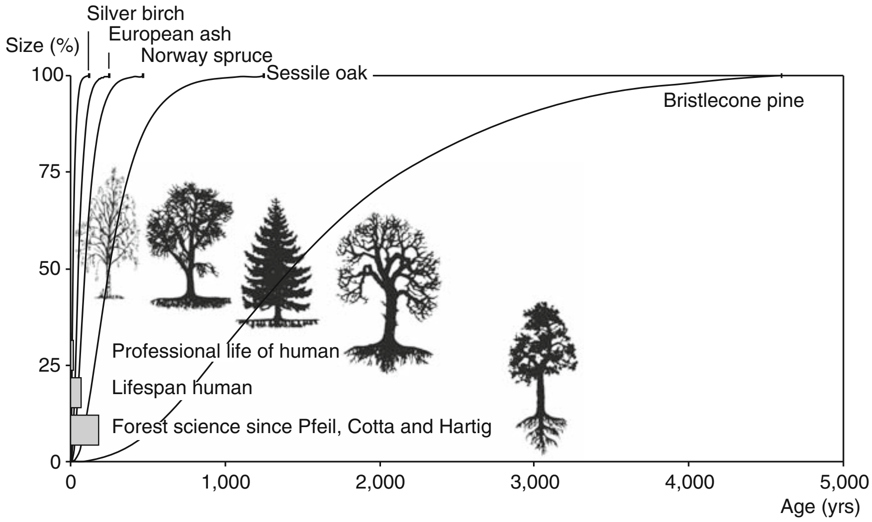

Fig. 1.1 The life span of humans and trees differ by up to two orders of magnitude. The relative size development of individual trees by age is shown for Silver birch (*Betula pendula* Roth), European ash (*Fraxinus excelsior* L.), Norway spruce [*Picea abies* (L.) Karst.], Sessile oak [*Quercus petraea* (Matuschka) Liebl.] and Bristlecone pine (*Pinus aristata* Engelm.). The time bars in the lower part of the graphic point out the superior lifetime of trees are compared to the research time and lifetime of a human, and the entire history of (modern) forest science since its foundation through W. L. Pfeil (1783–1859), H. Cotta (1763–1844), and G. L. Hartig (1764–1837) in the late eighteenth century

investigations of the effect of different thinning regimes on the growth of Norway spruce stands can only be completed after many decades or a century. This is because the long-term effects of the treatments on the growing stock in the final stand are vastly more important than the temporary responses to individual thinning operations. The growth responses after only 5–10 years are, at best, indicative only of tree or stand development over the entire life span.

In the 1860s and 1870s, Franz v. Baur (1830–1897), August v. Ganghofer (1827–1900), Karl Gayer (1822–1907), and Arthur v. Seckendorff-Gudent (1845–1886) outlined a basic approach for the establishment of long-term forestry investigations and initiated a network of widely distributed long-term experimental plots in forest stands in Bavaria. Many of the first experimental plots are being monitored still today, 130 years after their establishment. These long-term experiments are essential in forest science for the derivation of reliable knowledge about forest systems and for the provision of decision support in forestry practice (Fig. 1.2). When no experimental plots are available for observations of forest growth in the long-term (real time series), artificial time series may be established in the form of spatially adjacent stands of different ages (artificial time series). On a suitable site, monitoring plots are set up in stands of different age classes as an artificial time series (Fig. 1.3).

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