Tong HL, Choon KK (eds) Forests and society: the role of research. Proc 21st IUFRO World Congr. Sub Plenary Sessions 1:267
Sterba H, Kleine M, Eckmüllner O (1986) Sortentafeln für Tanne, Lärche, Kiefer und Buche. Österreichischer Agrarverlag, Wien, 182 pp
Sterba H, Golser M, Moser M, Schadauer K (2000) A timber harvesting model for Austria. Comput Electron Agric 28:133–149
Sterba H, Korol N, Rössler G (2001) Ein Ansatz zur Evaluierung eines Einzelbaumwachstumssimulators für Fichtenreinbestände. Forstwiss Centralbl 120:406–421
Vospernik S (2004) Modelle für Holzgüteklassen und Stammschäden. Dissertation, Universität für Bodenkultur, Wien, 151 pp
Wykoff WR (1990) A basal area increment model for individual conifers in the northern Rocky Mountains. For Sci 36:1077–1104

4.4 The Individual-Tree-Based Stand Simulator SILVA

H. Pretzsch[7], P. Biber[8], J. Ïurský[9], R. Sodtke[10]

Abstract. The forest growth simulator SILVA is single-tree based, tree-position-dependent and age-independent. The model's core algorithm evaluates the three-dimensional structure of forest stands in order to determine inter-tree competition. SILVA is parameterised with a large amount of data from long-term research plots in pure and mixed species forests, mainly from southern Germany. SILVA covers the tree species Norway spruce, Scots pine, silver fir, Douglas fir, common beech and oak. It includes a regeneration submodel and modules for conducting and visualising large regional scenario analyses based on inventory data.

4.4.1 Introduction

Since 1989, the Forest Growth Simulator SILVA has been developed at the Chair of Forest Yield Science, Munich, Germany, as an applicable tool for management, research and educational purposes (e.g. Pretzsch 1992, 2001). In this distance-dependent individual-tree approach a stand is regarded as a three-dimensional system of single trees influencing each other mutually. This approach permits the simulation of the development even of complex structured even- and uneven-aged pure and mixed stands, which is not possible by conventional means. As defined by its parameterisation data, SILVA is reliable for most German site conditions, par-

7 (e-mail: h.pretzsch@lrz.tum.de)
8, 9, 10 Chair for Forest Yield Science, Technical University Munich, Am Hochanger 13, 85354 Freising, Germany

ticularly those found in southern Germany. The current version covers the tree species Norway spruce, silver fir, Scots pine, common beech and sessile oak.

An inventory interface serves for inputting information from practical forest management. Further model features exist to substitute incomplete input information (e.g. deriving environmental variables from rough site information, generating tree data from trial plot information). Additional output routines for timber grading and calculating harvesting costs and sales returns are available. For this, SILVA has been applied for various forest management purposes by several German forest services and private forest owners as well as in research and as an instrument for educating forest students and forest managers. A detailed description of SILVA including tree representation, input and output routines, core module equations of growth and mortality, as well as referring parameters can be found in Pretzsch et al. (2002).

4.4.2 Database

The main data source for parameterisation of model functions is the Bavarian trial plot network, maintained by the Chair of Forest Yield Science. The data were gathered on 288 plots on 570 occasions, which means that many plots were observed repeatedly within the period between 1952 and 1998. Over all plots and inventories, 155,000 tree observations were available for model development. Around 30% of these data points were used for parameterisation. All these observations covered trees from a broad range of diameters at breast height and stand structures, respectively (cf. Pretzsch et al. 2002). Additionally, data from the Forestry Research Station of Lower Saxony and the Swiss Research Station for Forest, Snow and Landscape in Switzerland were used for the development of the site-related potential height growth model (see Kahn 1994).

4.4.3 Tree Representation and Model Initialisation

In SILVA, a tree is described by the following set of key variables: tree species, diameter at breast height (*dbh*), total height (*h*), height of crown base (*hcb*), crown diameter (*cd*) and tree coordinates (*x*, *y*). Every tree is assumed to stand straight upright. Species-specific crown models are used to represent three-dimensional crown shapes (Pretzsch 1992). These models assume the crown to be rotation-symmetrical in the horizontal direction and to be divided vertically in an upper and a lower section. Crown shape is species-specific, but the crown is always assumed to be of maximum width (*cd*) at the height where both sections meet each other.

A simulation run is initialised with information about management, site conditions and tree key variables. Incomplete data can be completed using the stand structure generator module of SILVA (Pretzsch 1997). Recently, the structure generator was enhanced in order to derive representative tree data also from stratified sample plot measurements (Ïurský 1999).

Thinning type, grade and frequency define management conditions. SILVA allows, for example, the representation of different types of selective thinning, final crop-tree concepts, target diameter harvesting, thinning from below or above, no thinning and combinations of these concepts.

SILVA processes information from a set of environmental conditions such as mean temperature and precipitation sum within the growing season or atmospheric CO2 concentration, given as long-term mean values (cf. Pretzsch et al. 2002). Since the whole set of variables is seldom available for a single plot, it is possible to initialise most environmental conditions from the ecoregion code number (as defined by the German site classification), height above sea level, slope and exposition.

Species-specific unimodal dose-response functions are used to aggregate environmental information into ecologically significant site variables (Kahn 1994), determining the properties of a potential height growth curve formulated according to the Chapman-Richards equation:

$$h_{pot} = A \cdot \left(1 - e^{-k \cdot t}\right)^p$$

where h^{pot} is potential tree height at age t and A, k and p are species-specific parameters, which are derived from a vector of site variables.

4.4.4 Core Model Description

4.4.4.1 General Considerations

The smallest simulation time step with SILVA is a forest growth period of 5 years. This period corresponds with the time intervals provided by yield tables. It is also the standard time interval between two measurements on the trial plots used for model evaluation. The first step of each cycle is the three-dimensional competition analysis determining the degree of competition for each tree according to a number of indices described below. Then, preliminary tree growth is determined to be used in the mortality module to decide whether the individual is considered alive for the current simulation period. After the removal of dead or harvested trees, competition indices and dimensional changes of each tree are recalculated.

4.4.4.2 Inter-Tree Competition

In SILVA, inter-tree competition of each tree is calculated by the competition index *KKL*. This index is a geometrical competition measure calculated for the three-dimensional space surrounding a particular tree. Competitors are defined by the virtual-reverse-cone method (Pretzsch 1992; Pretzsch et al. 2002). Besides this index SILVA uses two additional measures for quantifying competition aspects affected by type and spatial distribution of the competitor trees.

4.4.4.3 Mortality

After determining the degree of competition, natural mortality within the next simulation cycle is estimated. The mortality module calculates the survival probability from the dimension of a tree and its expected basal area increase by means of a LOGIT function parameterised by empirical data (cf. Durský 1997; Pretzsch et al. 2002).

4.4.4.4 Thinning

Thinning will be performed according to the settings defined by the user at the start of the simulation. The available thinning types represent a great number of concepts relevant to practice. Some of them are based on a fuzzy logic controller (Kahn 1995), whereas others use other algorithms, e.g. the A-value concept defining the degree of selection tree removal.

4.4.4.5 Height and Diameter Growth

Site-dependent height growth potential zh_{pot} is calculated for each tree using Eq. (4.1) (cf. Pretzsch et al. 2002). zh_{pot} is reduced to the expected height growth zh according to the individual tree's conditions defined by its competition indices and crown dimensions. Tree diameter increment is also derived from potential growth similar to height growth. The potential diameter increment serves for determining the potential basal area increment and the expected basal area growth (cf. Pretzsch et al. 2002).

4.4.4.6 Crown Development

New crown dimensions are calculated by directly estimating the height of the crown base and the crown diameter from tree height and diameter. Data used for fitting indicate that the integrated species-specific parameters allow for a good representation of uneven-aged mixed forests (cf. Pretzsch et al. 2002).

4.4.4.7
Output

From the simulated tree dimensions various aspects of stand development can be visualised within SILVA. For illustration of the three-dimensional stand development, perspective stand views and crown charts are provided, which are supplemented by a realistic stand visualisation system (Pretzsch and Seifert 1999), allowing virtual walkthroughs and interactive thinning. In addition, a large set of numerical information is available which can be viewed as diagrams or as text files that are similar to standard yield tables.

Three kinds of output can be distinguished: first, classical growth and yield data are provided on stand and tree level, e.g. stem number, basal area, timber volume, current and mean annual increment and mean height; second, monetary values can be obtained from the calculation of stand assortment distributions with the timber grading routine BDAT (Kublin and Scharnagl 1988). This includes also detailed information about the monetary development of the stand, which is based on timber prices and harvesting costs specified by the user. If different prices and costs should be investigated, various economic scenarios can be evaluated with the same simulation run. The third group of output information describes ecologically important structural values. Several indices are calculated from tree dimensions and stand structure (cf. Pretzsch 1997; Biber et al. 1998), which can be used to judge non-monetary values such as habitat suitability or social forest functions.

4.4.5
Model Evaluation

The basic question is whether the simulator is suitable to be integrated into the information flow of forest practice, including that the available pool of knowledge is used for efficient planning, execution and control of forest management. This is ascertained in SILVA particularly by its input and output structure. The initialisation procedures provide the possibility for simulations even with incomplete data and allow the use of site information at very different resolution levels. The output methods and tools are developed in close contact with forest managers and thus are designed to meet their information demands. In comparison to classical yield tables, SILVA provides additional information that allows the estimation of monetary yield as well as the characterisation of stand structure and – to a certain degree – biodiversity.

Quantitative model validation was carried out in comparing simulated and observed growth using the example of 615 research plot inventories (Pretzsch et al. 2002). Regarding volume increment, validation resulted in a very low bias, which was less than 4.8% over- or underestimation, respectively. Relative precision resulted in deviations ranging from 18.5–38.6% for the respective tree species. Accuracy results did not differ considerably from precision.

With respect to its qualitative behaviour the model is shown to react in accordance with biological knowledge and practical silvicultural experience, such as Assmann's concept of optimum basal area, Reineke's widely accepted maximum density rule and the structure-related growth dynamics of mixed stands (cf. Pretzsch et al. 2002).

4.4.6 Model Application

The SILVA simulator is implemented as a software program for use with the operating systems MacOS, Windows 95/98/2000/NT/XP. In order to gain independence from the current operating system the core modules are transferred from Object Pascal programming language to C++. Input and output interfaces are designed to be appropriate for practical use from interactive operating at stand level to batch operation at enterprise level. The user manual is edited according to recently defined German and International standards (cf. Chap. 3, this Vol.).

SILVA can be used in forest management for operational and strategic planning. For operational purposes management plans or timber production prognosis can be derived for single stands, forest enterprises and landscape units (Pretzsch et al. 1998). In general, this is executed on a short- or medium-term perspective. In strategic planning, which normally covers longer time periods, SILVA helps to develop management guidelines for certain tree species or stand types under particular site conditions (Pretzsch 2003).

Considering forest research, SILVA is intended to investigate tree and stand responses to changing environmental conditions, including those induced by silvicultural management or climate change impacts (e.g. Biber et al. 1998). This is possible because traditionally gained knowledge from long-term experimental plots has been aggregated into the simulator and can thus be used to assess any combination of conditions that are within the range of the implemented information. Since this allows also for new combinations, the implementation of experimental plots can concentrate on the investigation of actually new conditions. In this respect, SILVA can also serve to define the requirements for new experiments.

SILVA can be used for training of non-professional private forest owners, forest managers and students, as well as to support public relations. For example, thinning can be executed and its effect can be impressively demonstrated with the simulator's stand visualisation system (Pretzsch and Seifert 1999). Trees can be marked by the user to be selected for thinning or as final crop-trees, respectively. So the development of the stand may be shown as a consequence of management activities. Additionally, SILVA is useful for the demonstration of biological and ecological principles of forest dynamics. For example, growth of light-demanding and shade-tolerant tree species as well as the dynamics of differently structured stands may be observed and compared over time.

References

Biber P, Rappold C, Pretzsch H (1998) Wuchsverhalten von Fichte, Tanne und Buche in unterschiedlichen Höhenlagen der Alpen bei Veränderung der Wuchsbedingungen, Bayerisches Klimaforschungsprogramm BayFORKLIM. Forstliche Fakultät der Universität München, München/Freising

Ďurský J (1997) Modellierung der Absterbeprozesse in Rein- und Mischbeständen aus Fichte und Buche. Allg Forst Jagdz 168(6/7):131–134

Ďurský J (1999) Zur Verwendung von Rasterstichproben für die Fortschreibung, Nutzungsplanung und Behandlungsverbesserung in einem Forstbetrieb. Forstw Centralbl 118:314–325

Kahn M (1994) Modellierung der Höhenentwicklung ausgewählter Baumarten in Abhängigkeit vom Standort. Forstliche Forschungsberichte 141. Forstwissenschaftliche Fakultät der Universität München und der Bayer. Forstlichen Versuchs- und Forschungsanstalt, München

Kahn M (1995) Rule based modelling of thinning regimes for a distance dependent single tree growth simulator by implementing a fuzzy logic controller. In: Skovsgaard JP, Burhkart HE (eds) IUFRO – recent advances in forest mensuration and growth and yield research. Danish Forest and Landscape Research Institute/Ministry of Environment and Energy, Tampere, Finland, pp 29–44

Kublin E, Scharnagl G (1988) Verfahrens- und Programmbeschreibung zum BWI-Unterprogramm BDAT. Forstlich Versuchs- und Forschungsanstalt Baden-Württemberg, Freiburg

Pretzsch H (1992) Konzeption und Konstruktion von Wuchsmodellen für Rein- und Mischbestände. Forstliche Forschungsberichte München 115. Forstwissenschaftliche Fakultät der Universität München und der Bayer, Forstlichen Versuchs- und Forschungsanstalt, München

Pretzsch H (1997) Analysis and modelling of spatial stand structure. Methodological considerations based on mixed beech–larch stands in Lower Saxony. For Ecol Manage 95:237–253

Pretzsch H (2001) Modellierung des Waldwachstums. Blackwell, Berlin

Pretzsch H (2003) Strategische Planung der Nachhaltigkeit auf Forstbetriebsebene. Beitrag der Waldwachstumsforschung. Forstw Centralbl 122:231–249

Pretzsch H, Seifert S (1999) Wissenschaftliche Visualisierung des Waldwachstums. Allg Forstz/Der Wald 18:960–962

Pretzsch H, Kahn M, Ďurský J (1998) Zur Verwendung von Stichprobendaten für die Entwicklungsprognose und die Nutzungsplanung. Allg Forstz 25:1552–1558

Pretzsch H, Biber P, Ďurský J (2002) The single tree-based stand simulator SILVA: construction, application and evaluation. For Ecol Manage 162:3–21

Hubert Hasenauer (Ed.)

Sustainable Forest Management

Growth Models for Europe

With 110 Figures, 30 in color, and 44 Tables

Springer

Prof. Dipl.-Ing. Dr. Hubert Hasenauer
Institute of Forest Growth Research
Department of Forest and Soil Sciences
BOKU University of Natural Resources and Applied Life Sciences
Peter Jordan Str. 82
A-1190 Vienna
Austria

ISBN-10 3-540-26098-6 Springer-Verlag Berlin Heidelberg New York
ISBN-13 978-3-540-26098-1 Springer-Verlag Berlin Heidelberg New York

Library of Congress Control Number: 2005930001

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer-Verlag. Violations are liable for prosecution under the German Copyright Law.

Springer-Verlag is a part of Springer Science+Business Media

springeronline.com

© Springer Berlin Heidelberg 2006
Printed in Germany

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Editor: Dr. Dieter Czeschlik, Heidelberg
Desk Editor: Anette Lindqvist, Heidelberg
Production: Pro Edit GmbH, Heidelberg
Typesetting: Satz-Druck-Service, Leimen
Cover desing: Design & Production, Heidelberg

Printed on acid-free paper 31/3152Re 5 4 3 2 1 0

Preface and Acknowledgements

Given the change in silvicultural management from being mainly clear-cut-driven to an uneven-aged mixed small-scale and/or individual tree-driven forest management system, existing yield tables will become increasingly unreliable. As a potential alternative, tree growth models have been developed in order to forecast the growth of each tree within a stand independent of tree age, species mixture and silvicultural management, allowing increased flexibility, which is necessary for modeling such managed forests.

The work presented in this book summarizes a joint effort among European tree growth modeling experts, forest policy decision-makers and forest companies to further enhance modeling theories and to investigate problem-solving methods for silvicultural decision-making. From February 2001 to January 2004, a group of 45 individuals worked within the ITM consortium (Implementing Tree Growth Models for Forest Management), an EU-funded effort to enhance and promote tree growth modeling theories within Europe. For our work, a number of tree growth models were selected. After extending the models and research gaps related to tree growth modeling theory (Chaps. 1–8), the following application examples (Chaps. 9–17) were selected by our company representatives to demonstrate the problem-solving potential:

1. Regeneration in uneven-aged mixed-species stands.
2. Timber-harvesting scenarios.
3. Incorporation of tree growth models in information systems.
4. Using tree growth models beyond the calibration area.
5. Assisting forest policy decision-makers.
6. Tree growth models as a decision support system component.
7. Optimizing cork production in southern Europe.
8. Converting even-aged pure stands into uneven-aged mixed species stands.
9. Modeling coppice forests in Greece.

Many individuals contributed to the success of our work. We are very grateful to our 12 company representatives: Thomas Böckmann, Germany; Miguel Teles Branco, Portugal; Morten Elback Jorgensen, Denmark; Gerhard Fischer, Germany; Josef Gasch, Austria; Stephan Göd, Austria; Ivan Herich, Slovakia; Theod-

oros Kostantinidis, Greece; Jens Briand Petersen, Denmark; Wolf Dieter Radike, Germany; Hermann Spellman, Germany; and Johannes Wohlmacher, Austria – as well as the five members of our quality assurance panel – Marijan Kota, Slovenia; Emilia Pinto Preuhsler, Portugal; Janna Maria Puumalainen; Finland; Konstantin von Teuffel, Germany; and Peter Weinfurter, Austria. Their participation in all the meetings and the fruitful discussions are greatly appreciated.

We also gratefully acknowledge the following colleagues for reviewing one or more of the manuscripts: Ralph L. Amateis, USA; Peter Biber, Germany; Mike Bokalo, Canada; Harold E. Burkhart; USA; Georg Gratzer, Austria; Dionys Hallenbarter, Switzerland; Marc Hanewinkel, Germany; Kevin O'Hara, USA; Jens Haufe, UK; Manfred J. Lexer, Austria; Bruce Michie, Finland; Kelsey Milner, USA; Robert A. Monserud, USA; W. Keith Moser, USA; Arne Pommerening, UK; Philp J. Radtke, USA; H. Michael Rauscher, USA; Keith M. Reynolds, USA; Klemens Schadauer, Austria; Paula Soares, Portugal; Paul Tabusch, UK; Harald Vacik, Austria; Sauli Valkonen, Finland; and Andreas Zingg, Switzerland.

Research efforts such as those presented in this book require funding and professional administration. Thus, we thank the European Commission and our two scientific officers from DG-Research in Brussels, Alexandros Arabatzis and Sjur Baardsen, for their support, as well as the office manger of the ITM program, Roland Berger, who kept everything on track throughout the 3 years of our endeavor to promote tree growth modeling theories in Europe.

Hubert Hasenauer
November 2005

Contents