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Evaluation of the forest growth simulator SILVA on dominant trees in mature mixed Silver fir–Norway spruce stands in South-West Germany

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ABSTRACT

Forest growth simulators go beyond a mere tabulation of empirical measurements by employing biometric models that functionally describe the dependence of forest growth of the initial forest structure, growth conditions and management regime. This makes them very flexible and allows predicting growth reactions for unknown and/or complex forest growth scenarios. When simulation outcomes are to be used in silvicultural strategic planning, the results are of direct and delicate importance, and the correct simulator performance must be ascertained. This is especially so when the considered forest situation differs from the forest data used to parameterise the model (e.g. different geographical region).

In this article, the forest growth simulator SILVA (version 2.2) was validated for 55 long-term experimental plots of mature mixed Silver fir–Norway spruce stands in southwest Germany (*Picea abies*, *Abies alba*). The evaluation was restricted to the upper canopy trees during the survey period 1989–2004. Following the general evaluation criteria for ecological models from [Vanclay, J.K., Skovsgaard, J.P., 1997. Evaluating forest growth models. Ecol. Mod. 98, 1–12], a specific methodology was developed to evaluate the simulated height and diameter growth on the basis of forest growth principles.

The qualitative analysis proved the SILVA growth algorithms to be in accordance with physiologically based standard growth equations. The quantitative evaluation was limited by incomplete knowledge of the site conditions. To overcome this problem, the experimental plots were regarded as a "heterogeneous growth series" which allows analysing the growth behaviour in a more general way. It could be shown that for the given data set, the SILVA simulations produced an overestimation of height growth (median: +61% spruce, +12% fir), and an underestimation of diameter growth and competition sensitivity (median: −16% spruce, −70% fir). The errors partially compensated in the volume growth resulting in an overall over-/underestimation of +9% for spruce and −58% for fir (median).

The unbalanced height and diameter growth cannot be compensated by a change in the site conditions because this affects both height and diameter growth either positive or negative. Hence, an adjustment of selected parameterisation values appears to offer the best solution to adapt SILVA to the considered forest situation. This approach of adaptive parameterisation is discussed against a more general background of deductive vs. inductive forest growth modelling.

1. Introduction

The forest growth model SILVA has been developed as a growth simulator for practical use in forest management (Pretzsch, 1992, 2001; Pretzsch et al., 2002). It was parameterised from age series of long-term experimental sites mainly in Bavaria (Germany), and was complemented by more recently established artificial age series (=growth series, Pretzsch, 2002a, pp. 77–79, 309–310) to enlarge the database on mixed and uneven-aged forests. The current version is based on approximately 15 000 spruce trees, 2000 fir trees, 14 000 pine trees, 13 000 beech trees and 3000 oak trees on altogether 288 experimental plot units surveyed between 1952 and 1996 (Kahn and Pretzsch, 1997; Pretzsch and Kahn, 1998; Pretzsch et al., 2002). The conceptualisation as a site condition-sensitive, single-tree-based, spatially explicit growth model renders SILVA highly flexible in terms of forest structures, management regimes and site conditions. Currently, it is implemented in operational forest management planning of the Bavarian state forest institution (BaySF), and used for educational purposes in forest and resource management studies at the Technische Universität München (Pretzsch and Kahn, 1996; Pretzsch, 2001; Pretzsch et al., 2005a,b, 2006; Moshammer, 2006). SILVA simulations have also been included

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in the analysis of current problems in forestry like the potentially beneficial effect of heterogeneous mixed forests (Hanewinkel and Pretzsch, 2000), or growth predictions under climatic change assumptions (Pretzsch, 2002b).

When simulation outcomes are to be used in silvicultural strategic planning, the results are of direct and delicate importance, and the correct simulator performance and handling must be ascertained, or as Yang et al. (2004) put it: "The developers and users of models, and the people affected by the decisions based on the model, are all concerned with whether or not the model are acceptable representations of the real world". In fact, even prominent growth models often proved deficient when applied to practical management questions, e.g. the gap-phase model JABOWA (Botkin et al., 1972; Spilsbury, 1991), STEMS (Leary, 1979, 1997), or PBRAVO (Soares et al., 1995). SILVA has been evaluated in several studies (Albrecht et al., 2009; Schmid et al., 2006; Pretzsch, 2002a; Dursky, 1999; Pretzsch and Dursky, 2001) with a different focus each. This paper focuses on height and diameter growth predictions for heterogeneous Norway spruce and Silver fir stands on research plots in Baden-Württemberg.

A guideline with evaluation criteria for forest growth models was synthesised by Vanclay and Skovsgaard(1997, see also Vanclay, 1994; Soares et al., 1995). Among other arguments they advocate parsimony of model structures, to apply biologically reasonable growth algorithms, to analyse accuracy as well as the nature of the residuals, and to test them statistically. Furthermore, they suggest taking user-requirements like user-friendliness and documentation as important quality aspects into account. Some of the arguments like "reasonable growth algorithms" or "user-friendliness" suggest that the evaluation of a model can never be completely objective, but Yang et al. (2004) showed that also in the statistics "one could apply different parametric or nonparametric tests, accept or reject a model, by 'accidentally' or 'purposely' choosing one or several tests that satisfy a researcher's objectives". In the end, the user has to decide whether the model predictions are close enough to reality and whether decisions based on the model outcomes appear relevant (Vanclay and Skovsgaard, 1997).

Of special importance in the model evaluation is also the choice of the validation data set (Snee, 1977; Vanclay et al., 1995). If the "*original*" *validity* of the model – in the sense of the forest types, growth conditions (regions), management regimes it was developed for – is to be tested, the validation data need to be kept within the specified parameterisation range of the model (species, site conditions, diameter range). If the *transferability* of a model is to be tested, the validation data range exceeds the range of the parameterisation data. A particularly difficult problem is the handling of temporal variation of the growth conditions. Since forests typically grow over decades to centuries, practically no forest can be assumed to have developed under constant environmental conditions (cf. e.g. Mielikäinen and Timonen, 1996; Pretzsch and Utschig, 2000). Also artificial age series (growth series) where stands of assumedly identical genesis but differing in age are observed simultaneously under comparably homogeneous site conditions still carry the traces of the past site conditions (Pretzsch, 2002a, p. 79). Unknown factors and process chains may cause decade-lasting growth depressions, enhancements or trends (Spiecker et al., 1996; Myneni et al., 1997; Pretzsch, 1999). Since these effects are essentially contained in all forest growth data, it is hard to decide what to consider as the "normal" or "to-be-expected" reference forest growth that should be reflected by the model. In the case that long-term growth conditions fluctuate notably over time it might actually be helpful to analyse forest growth behaviour by using model simulations generated by assuming unchanging environmental impact as baseline scenarios. Röhle (1997) for instance found an increased height growth of Norway spruce of 130–315% since the 1950s by using yield tables for Norway spruce from Assmann and Franz (1963) as baseline reference.

In this study, growth dynamics as predicted by the forest growth simulator SILVA are evaluated with a data set of 55 experimental plots of Norway spruce-Silver fir stands (*Abies alba* Mill. and *Picea abies* [L.] Karst) from Baden-Württemberg, southwest Germany. According to the Germany-wide side-mapping classifications (Arbeitskreis Standortkartierung, 1985), Baden-Württemberg is classified as growth region 08 adjacent to Bavaria (growth region 09), from where the majority of the parameterisation data for SILVA originate. A characteristic for Baden-Württemberg is that this growth region holds by far the highest share of Silver fir in Germany (BMELV, 2002). As the plots belong to different experimental series targeting the transformation of even-aged to uneven-aged stands (including seven selection forest stands), the reproduction of the heterogeneous stand structures can be assumed to benefit from the application of a spatially explicit single-tree growth simulator like SILVA.

By comparing actual and simulated height and diameter growth of dominant Norway spruce and Silver fir from the upper canopy, we evaluate two core modules of the SILVA forest growth simulator. The validation procedure is oriented to some degree at the Vanclay and Skovsgaard (1997) criteria. However, as these criteria are formulated essentially in rather general terms to meet all sorts of models and validation demands, we employed a very specific procedure for the validation of height and diameter growth based on forest growth principles. This allows for a differentiated diagnosis of the error sources and may provide not only a guideline to validation but also to the parameterisation of forest growth models. The implications of the results will be discussed against a more general background of deductive vs. inductive forest growth modelling.

2. Methods and material

2.1. Database

Database for the study were 20 experimental installations with a total of 55 different plots managed, monitored and documented by the Forest Research Institute of Baden-Württemberg (Forstliche Versuchs- und Forschungsanstalt: FVA). The experiments can be grouped according to three silvicultural management concepts revolving around growth dynamics during conversion of even-structured to uneven-structured stands (cf. Table 1):

- The first series consists of 34 plots (ca. 0.25 ha) in mature and rather homogeneous mixed Silver fir–Norway spruce stands (with occasional admixture of few European beech or Scots pine). The plots are named "Ta"-plots for Silver fir (=Tanne) as a major species. The stands dominant heights (h100) range from 30 to 35 m. Most plots are surveyed since the early 1980s, some since 1960 (20–40 years of observation). Conversion to uneven-aged structure is to be achieved through long-term natural regeneration by group selection cuttings ("Femelschlag") over a period of 20, 35 or 50 years (Weise, 1995).
- The second series of 14 plots is abbreviated "Mi"-plots and consists of mixed forests (=*Mi*schwald) also dominated by Silver fir and Norway spruce with occasional admixture of few Scots pine. These stands encompass a larger height range than the Ta-plots; h100 varies between 20 and 37 m. The experiments were established and the first surveys commenced in 1993/1994 (10–13 years of observation). The older stands are intended to be converted through group selection type "Femelschlag" harvests, the younger ones through structural thinnings, i.e. thinnings approximating successively stand structures and dynamics characteristic for single-tree selection.