Modelling wood quality of Norway Spruce (*Picea abies*) depending on silvicultural treatment

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ABSTRACT

The position-dependent single tree simulator SILVA, a well established forest management system for pure and mixed species stands is extended for a quality model to increase the economic output, which has been based on the volume growth only until now. The integration of the quality modules for branchiness, butt rot, and wood density in the SILVA framework is described. The module of branchiness is presented to show the interaction between the wood quality model and silvicultural treatment provided by the thinning model of SILVA. The branchiness module is realised by a model of plastic crown deformation depending on inter-tree competition. First results show a clear relevance of stand structure and hence silvicultural treatment on wood quality considering branchiness.

INTRODUCTION

For half a century computerised management models have been providing us with more or less sufficient predictions for volume growth in even-aged stands and plantations. More recent models are also able to cope with uneven-aged mixed stands using distance-depending approaches. One of these models is SILVA (Pretzsch, 1992, 1997 ; Pretzsch & Kahn, 1995), which has been developed at the Chair of Forest Yield Science of the Ludwig-Maximilians-University, Munich since the beginning nineties. SILVA predicts the growth and yield, allows ecological description of the stand by structural indices and simulates the economic results of the stand. The economic prediction has been based on volume growth until now. To increase the precision of these predictions it is necessary to include wood quality aspects into the model, too.

The approach discussed here covers a wood quality model concerning the means of knottiness, wood density, and butt rot caused by *Heterobasidion annosum* in Norway Spruce (*Picea abies*). Especially the connections and interrelations between the management model SILVA and the module for the prediction of wood quality are an important factor for the success of such a model.

FOREST GROWTH SIMULATOR SILVA

SILVA provides a profound basis for the single tree based simulation of pure and mixed species forests in Southern Germany. The programme is designed to meet the needs of forest practices concerning different aspects.

The first is the input data, which is a crucial factor in management, because the decision about the application of such a model is mainly influenced by the input costs. SILVA therefore provides different resolutions for the input data. It is able to handle exact measurements of every single tree including 3D-coordinates of the stem base and a broad variety of site parameters as well as it can expand summarised data from sampling plots (for example forest inventory data) to plausible stands with a realistic distribution of trees (Pommerening, 1998). These broad input possibilities offer the chance for the user to choose the adequate method for his problem and foster model acceptance.

This high model flexibility is achieved by using a distance-depending single tree approach taking into account the spatial stand structure. Therefore SILVA calculates the morphological data, position, and the resulting competition to the neighbour trees for each single tree. The competition alters a growth potential, which is defined to be the possible maximum on given site under a certain climate without competition provided by another submodel of SILVA called STAOPROD. This distant-depending single tree approach makes it possible to model pure and mixed stands with heterogeneous age structure.

The thinning regime as the expression of silvicultural treatment is implemented as a rule-based method to model a great variety of thinning operations with different intensities and frequencies (Kahn, 1995). Thereby the user has the choice between thinning from below, high thinning, several kinds of selective thinning, and a chosen-tree system. The thinning submodel uses the spatial information of the single trees in the stand described above.
The simulation output covers assortment yield, harvest costs and financial return to predict the economic management results and additionally offers some structural indices to describe the dynamic behaviour of stand structure and biological diversity in order to make ecological predictions for the management and scientific purpose (Biber and Weyerhaeuer, 1998). The visualisation tool TREEVIEW (Pretzsch & Seifert, 1999) gives the user the possibility to move in the virtual stand in realtime at the computer and to view the trees from all directions.
All these calculations can be conducted on stand level as well as on the level of a whole forest management district. Another model provides the connection to a GIS-system and wraps the entire SILVA-application as seen in Figure 2 in a management model for a management district (Dursky, 1998 ; Pott, 1998 ; Pretzsch et al., 1998). This possibility to scale the output concerning the spatial area is also an important factor for the model acceptance in forestry.

INTEGRATION OF THE WOOD QUALITY MODEL

Adding the ability of wood quality prediction to SILVA a high integrated solution for a wood quality model was chosen in order to consider the existing interactions between stand structure, silvicultural treatment, and wood quality. A key-connection between SILVA and the wood quality model is the thinning model which offers the possibility to alter the structural growth conditions and hence to influence crown and branching structure (both drawn as rounded boxes in Figure 2) as well as diameter and height growth of the bole, being important parameters for the resulting wood quality. The aim of this quality modelling approach is to establish a model with a high sensitivity to silvicultural treatments. This has to be integrated in the framework of the existing management simulator SILVA.
The quality prediction model is based on three main parameters of wood quality in a first step : branchiness / knottiness, expansion of butt rot in the bole, and wood density. The concept demands a further step in model resolution. With its single tree approach SILVA already provides detailed information about crown length, crown width, crown recession, and stem form. The level of detail in the model is further increased to the level of tree compartments regarding whorls, branches, and wood properties inside the bole (see Figure 1).

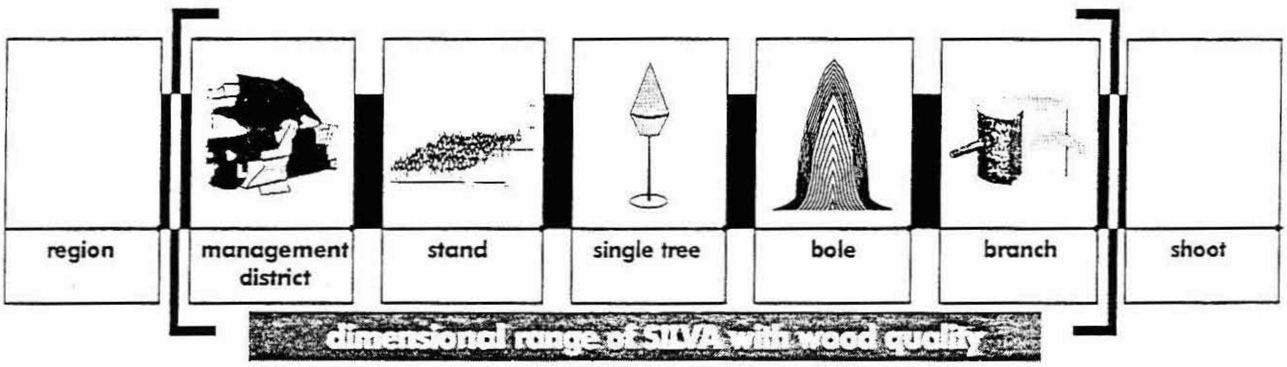


Figure 1 : Above the dimensional operating range of SILVA is shown.
The bole and branch dimension is added for the quality model.

The quality model consists of modules for branchiness with an attached pruning model, for calculation of wood density and for extent of butt rot in the log. The latter module is closely connected to a separate model for the spread of *Heterobasidion annosum* at stand level (Müller in press). The results of the quality model are integrated to a virtual log that can be graded in a log-grading module. As seen in Figure 2 there are several interactions of the original SILVA-components (drawn as white boxes) on different levels with the quality prediction modules (drawn as dark grey boxes).

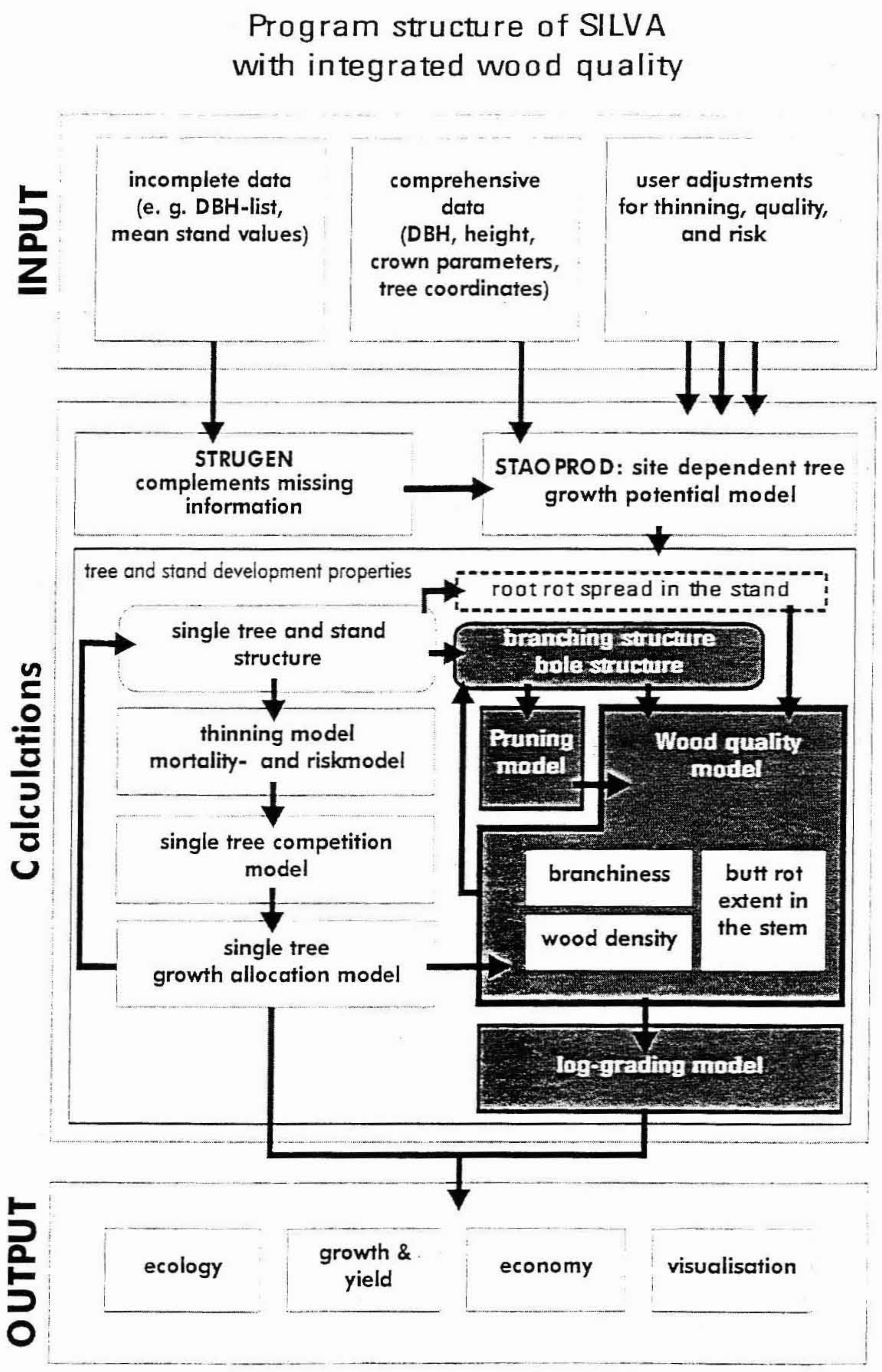


Figure 2 : The diagram shows the structure of original SILVA (white boxes) expanded for the root rot (dotted box) and wood quality model (dark grey boxes) and the interaction between the submodels.

As the work on both, the butt rot and the wood density module is still in progress the branching module may serve here exemplary to demonstrate the approach of a wood quality model reacting flexible to silvicultural treatment.

BRANCHING MODULE

At first the existing crown model of SILVA based on rotational symmetry was refined to a dynamic crown model which provides plastic reactions of the modelled crown hull to changes in the vertical competition, in the way that different competition in different heights and directions leads to a deformation of that hull and hence an asymmetric crown shape (see Figures 3 and 4). For the computation of this competition the crown is sliced in a discrete number of pieces horizontally. For each piece a competition with a distinct value and direction is calculated. Competitors are not only single trees but their crown slices again which leads to very accurate competition scan for each crown part. Depending on the strength and direction of their competition the crown slices are shifted away from the direction of most competition. Linking the slices again to a hull by linear interpolation an asymmetric crown hull with a plastic behaviour is realised.

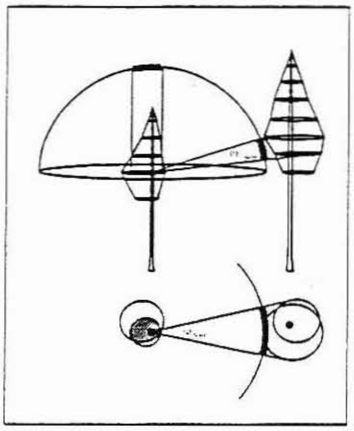


Figure 3 : The competition calculation used.

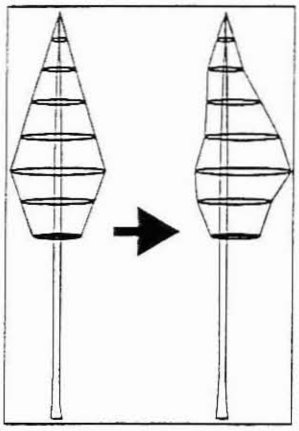


Figure 4 : Refined plastic crown model.

This crown hull is used as a boundary for the projected length of branches, which are modelled in branch whorls. The distance of the whorls depends directly on the simulated height growth of SILVA. These two structural parameters enable a simulation of the basal branch diameter as a function of projection length of the branch.

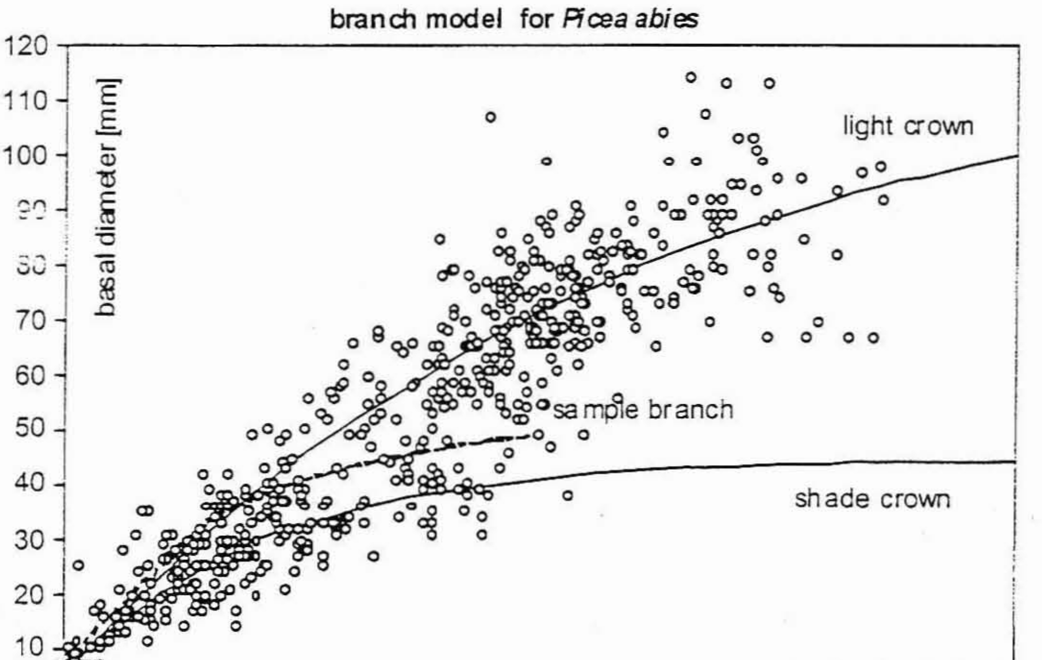


Diagram 1 : The branch model for Norway Spruce predicts initial basal diameters separately for light and shade crown as a funtion of projection length of the branch. The transition from sun to shade crown due to mutual shading in the crown is modelled for a sample branch in the diagram.

Two different functions were used for light crown and shade crown and a transition function was developed to simulate the movement of a branch from the light crown to the shade crown while the tree and its neighbours are growing (see diagram 1).

A nonlinear function of the following form is used in the branch diameter model of both crown parts :

$$d = a1 \cdot (1 - e^{-\frac{lproj}{a2}}) + 5$$

d = *basal branch diameter*
lproj = *projection length of the branch*
a1, a2 = *regression parameters*

Additionally another submodel calculates the branch insertion angle as a function of branch age, diameter, and projection length per height above ground.

The model for the branch insertion angle φ uses a logarithmic function of the form :

$$\varphi = (a0 + a1 \cdot d) + b0 + b1 \cdot \left(\frac{lproj}{h}\right) \cdot \ln(age)$$

φ = *branch insertion angle,*
age = *branch age,*
d = *basal branch diameter,*
lproj = *projection length of the branch,*
h = *height of the branch above ground,*
a0, a1, b0, b1 = *regression parameters.*

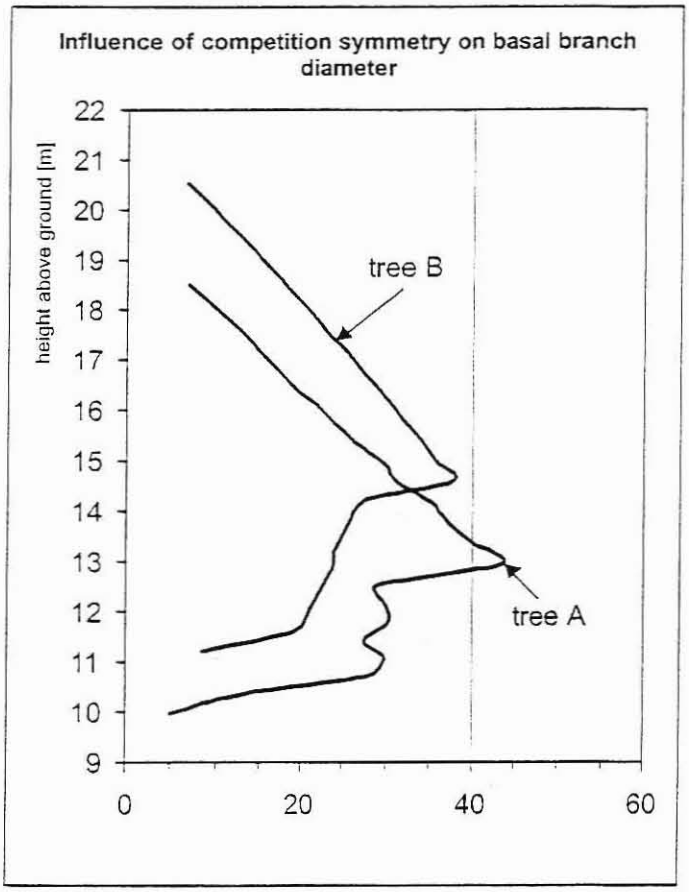
Further functions cover the radial distribution and branch number per branch whorl. A model for natural self-pruning will be available in the near future combined with an artificial pruning algorithm which is able to predict the occlusion of the knots depending on the stem growth in diameter. This is another important part of the model, which is influenced by silviculture.

The resulting branch model is able to predict the branchiness of a tree in different heights for different competitive situations. The simulated results for a tree with a extremely asymmetric crown compared to a symmetric crowned tree seen in diagram 2 make evident that the impact of silvicultural control on the crown structure has an clear influence on the radial branch diameter in a certain height. Tree A formed its crown under asymmetric competition. Although it is almost equal in crown width with symmetrical crowned tree B and even less high, tree A shows significant larger branch diameters due to crown asymmetry. The diameters represent the biggest branch in a whorl and are calculated without the application of the residual model. Tree A exceeds the critical log-grading limit of 40mm in diameter for class B of the new European grading rule (EN1927-1) in 13m, whereas Tree B does not.

It can be seen that stand structure and deduced crown structure, being both results of silvicultural control, influence branchiness evidently. It is obvious that the branchiness calculated over the whole life of the tree results in the knottiness of the bole, a key-predictor for timber quality.

CONCLUSIONS

The scope of this approach was to combine a wood quality model with an already established management model on a high level of integration exemplarily for Norway Spruce. Therefore the central aim was and still is to achieve a maximum explanation of reaction of quality to silvicultural treatment. The importance can be shown already with the branch model. But also other models of wood quality which are thought to be added later (e.g. spiral grain, tracheid length, resin pockets etc.) have to be on the same level of integration to provide a whole system which reflects the silvicultural treatment of the stand. The woody quality modules are written in object oriented C++ which enables a future extension of the whole model and adaptation to new parameters easily.



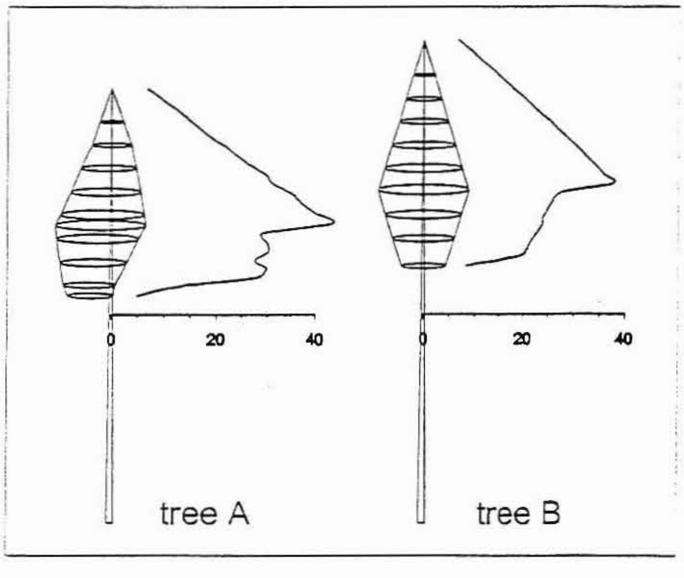


Diagram 2 : The diagram shows two trees and their branch diameter distribution. Tree A with an asymmetrical crown shape due to onesided competition and tree B with a fairly symmetric crown. Although the mean crown width of both trees is equal, tree A has significant larger branch diameters due to asymmetry. The branch diameter of tree A exceeds the critical 40 mm of the log-grading rule EN1927-1 for live branches in class B in Norway Spruce.

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