4 Modelling mixed-species stands

4.1 Modelling growth in pure and mixed stands: a historical overview

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Trends in forest modelling

Forest ecosystems may be modelled with varying degrees of temporal and spatial resolution. The time scale may range from seconds to millennia while the spatial scale may encompass anything from cells to continents. The model's ultimate objective and the existing knowledge of the observed system determine how complex the model approach needs to be.

With a history of over 250 years, yield tables for pure stands may be considered the oldest models in forest science and management. They are representations of stand growth within defined rotation periods and are based on a series of measurements of mainly diameter and height. The first generation of yield tables, developed from the late 18th to the middle of the 19th century, were based on a restricted data set (e.g. Hartig 1795; von Cotta 1821; Heyer 1852). These tables soon revealed great gaps in scientific knowledge. A series of long-term data collection campaigns on experimental areas was therefore started.

The second generation of yield tables, tackled towards the end of the 19th century and continued into the 1950's, followed uniform construction principles proposed by the Association of Forestry Research Stations in 1874 and 1888 and had a solid empirical data basis. Well-known yield tables are those designed by Schwappach (1893), Wiedemann (1942) and Schober (1967), that are still being used to this day. A brilliant example of their work are the yield tables for European beech. In the 1930's and 1940's, first models of mixed stands were constructed under the direction of Wiedemann. Data from some 200 experimental areas established by the Prussian Research Station led to the widely used yield tables for even-aged mixed stands of e.g. spruce and beech, and pine and spruce (see Wiedemann 1949). World War II prevented Wiedemann from bringing the development of yield tables for uneven-aged pure and mixed stands to a close, but his studies initiated systematic research on mixed stands. Yield tables for mixed stands were never consistently used in forestry practice as they were restricted to specific site conditions, intermingling patterns and age structures.

Yield tables developed by Gehrhardt (1923) in the 1920's effected a transition from purely empirical models to models based on theoretical principles and biometric formulas and led to a third generation of yield tables. The core of these models (e.g. Assmann & Franz 1963; Vuokila 1966; Hamilton & Christie 1973) is a flexible system of functional equations based on established growth laws and operable by computerized methods.

Since the 1960's a fourth generation has been created, the stand growth simulators (e.g. Hoyer 1975; Bruce et al. 1977; Curtis et al. 1981), which simulate stand development under given growth conditions for different stem numbers at stand establishment and for different tending regimes.

Despite a number of drawbacks yield tables still form the backbone of sustainable forest management planning in Central Europe. Prodan (1965, p. 605) commented on the significance of yield tables in the context of silviculture and forest sciences as follows: "Undoubtedly, yield tables are still the most colossal positive advance achieved in forest science research. The awareness that yield tables may no longer be used in the future except for more or less comparative purposes in no way detracts from this achievement."

Since the 1960's the development of yield tables, predominantly initiated in German-speaking countries, has been followed by distribution-dependent models which simulate stand growth by describing tree frequency distibutions, using differential equations, frequency functions or stochastic processes (Moser 1972; Clutter 1963; Sloboda 1976). Single-tree models (Bella 1970; Ek & Monserud 1974) have gone a step further as far as temporal and spatial resolution is concerned. They think of the stand as a mosaic of single trees and model individual growth and interactions with or without consideration of tree position. This has paved the way for the design of models of pure and mixed stands of all age structures and intermingling patterns. Models on the basis of frequency distributions and single-tree models were primarily developed and perfected for practical use in Anglo-American countries but still lack general approval in Central European forestry practice.

All models mentioned above rely on data from long-term increment series and hence have the advantage of being empirically verifiable. However, there is a drawback to historically deduced data inasmuch as growth conditions undergo changes and reaction patterns from the past can no longer be projected into the future. In the 1970's, yield model research was pointed in a new direction with the creation of so-called process models which account for metabolism, organ formation, assimilation and respiration as well as biochemical and soil chemistry reactions. A vastly improved understanding of processes in forest ecosystems paved the way towards this development and it was the actual modelling of these processes which provided an idea of the functioning of the overall system. A further impetus to process model development was the need to understand and predict the reactions of forest ecosystems to an increasing number of adverse effects such as immissions, increases in atmospheric CO_2 and climate change. The term process model is slightly misleading in the sense that all forest growth models describe actual processes. Merely the temporal and spatial scale of modelled processes becomes more detailed and accurate in the transition from yield table models to process models. Pioneers of the process model concept are Mäkelä & Hari (1986) and Mohren (1987). In the context of environmental instability, process models are certainly the ideal approach towards understanding and predicting forest ecosystem behaviour. However, there are definite constraints in developing and applying process models due to considerable gaps in the knowledge of processes in assimilation organs and in the soil. Also, the up-scaling of part processes to the behaviour of the overall system is still largely unresolved. To date process models are, therefore, primarily research instruments rather than forest management planning tools.

Gap models or 'succession models' as for example designed by Botkin et al. (1972), Pastor & Post (1985) and Leemans & Prentice (1989) try to steer a middle course between classical stand models and process models. They are primarily aimed at mixed stands. However, regarding input and output variables, they are less fixed on information available from or required by forestry practice. They aim at predicting long-term succession in natural forest stands and the effects of altered growth conditions. Succession models gave the impulse that led to the creation of hybrid models: the transfer of specific components of process models into stand or single-tree models on the basis of long-term increment series results in so-called hybrid growth models (Kimmins 1993). Models of this type may be used for pure and mixed stands. Their objective is to make the best possible use of newly acquired knowledge of processes, combined with historical increment observations, to assist in forest planning and management.

Applicability for forest management

In Europe, none of the above model concepts are of any practical relevance in the management of mixed stands. In the past 100 years, mixed stands have gradually become the focus of forest research. However, until now they lack a quantitative planning tool. Only very recently models created by e.g. Pretzsch (1992), Kolström (1993), Sterba et al. (1995) and Nagel (1996) have found wider use in forestry practice. These are site-dependent single-tree models constructed from a broad empirical data base.

To date, yield model research in Europe has had little success in substituting yield tables for pure stands by an improved information system for pure and mixed stands. This can in no way be attributed to a deficit in methodological principles, data or technical equipment. The causes lie in the fact that new models are not properly adapted to practical requirements. Recent growth and yield research and modelling initiatives have furnished a distinct profile of the practical demands to be considered in management models that will be used in decision-making processes at stand and forest enterprise levels:

1. In Europe the natural management of forests is currently making great headway. In the long run only those growth models that are capable of simulating the growth of pure and mixed stands of all age compositions and structural patterns will find approval.
2. Models need to be operable at stand and forest enterprise levels and need to be able to simulate growth behaviour under different thinning regimes and different processes of artificial and natural regeneration.
3. Flexibility of the model is essential so as to permit simulation of growth reactions to site alterations and interference factors on a large regional scale.
4. Apart from tree and stand characteristics such as volume production, assortment yield, wood quality and financial yield, the model should also include structural parameters determining the recreational and protective functions of forests, as well as indicators showing the impact of hazards or ecological instability.
5. Forestry practice is interested, first and foremost, in calculating scenarios at

> stand and forest enterprise levels. This can only be achieved if the input and output data of the model consider what information is available and which data are needed in forestry practice. Furthermore, achieving this goal also depends on whether the model forms part of a comprehensive forestry information system and, lastly, whether hardware specifications are acceptable in practice.

For decades forestry practice has been hoping for improved growth models to assist with planning, operations and control in forest management. The general acceptance of new models by practitioners calls for close cooperation between both parties, from the design and development of the model to its actual introduction in forestry practice.

Synopsis of papers

The first part of this chapter contains research papers on modelling approaches. The first paper, by Garcia Abril et al., focuses on the problems associated with the derivation of diameter distributions for uneven-aged stands. Yield tables for monospecific, even-aged stands are used to arrive at a balanced diameter distribution in uneven-aged *Pinus sylvestris* stands in the central mountains of Spain.

Franc, next, presents the characteristics and possibilities of so-called cellular automata models for the simulation of (mixed) forest growth. The paper presents a model and its application to describe the emergence of spatial patterns and the development of social hierarchy in irregular forest stands.

In the third paper, Bartelink presents the effect of stand composition on light interception and transmission: he presents results of a simulation study in several monospecific and mixed stands of Douglas-fir and beech, emphasizing the impact of light regime in mixtures on intra-specific competitive interrelations.

In the last research paper, by Pretzsch, a previously developed hybrid model (SILVA-2.1), is applied to analyse the effects of silvicultural operations on structural diversity. SILVA reflects the spatial and dynamic character of mixed stands; it models spatial stand structures at five-year intervals. The study reveals that a light or moderate thinning from above offers an effective means to improve stand structure and diversity.

The final contribution comes from Tome et al., who wrote an opinion paper on current mixed-species forests in Portugal and the present and future research strategies needed for the development of management-supporting models.

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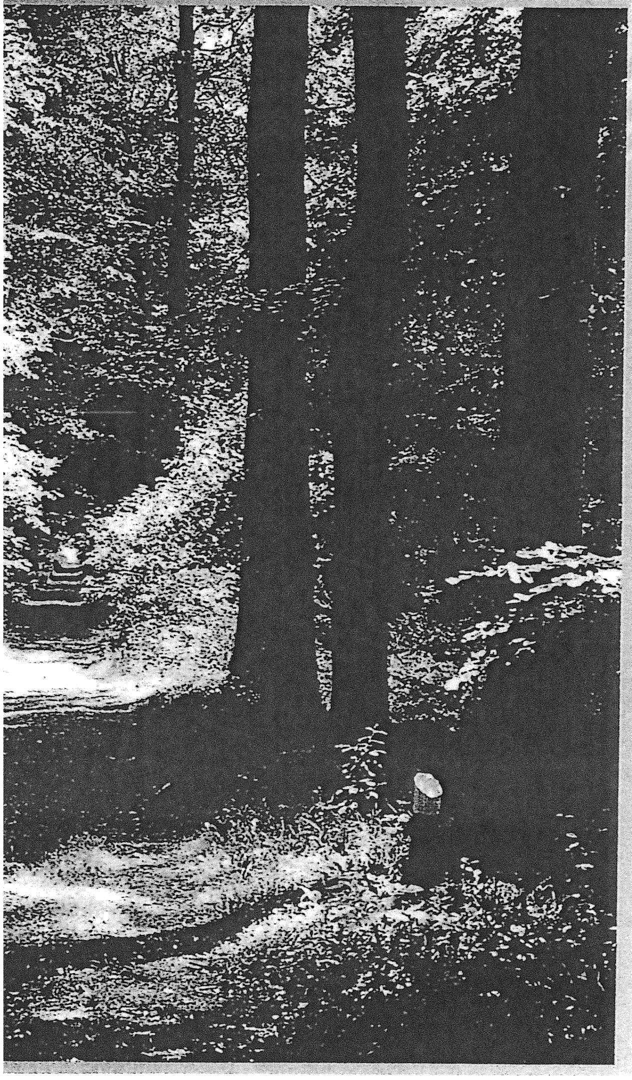

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