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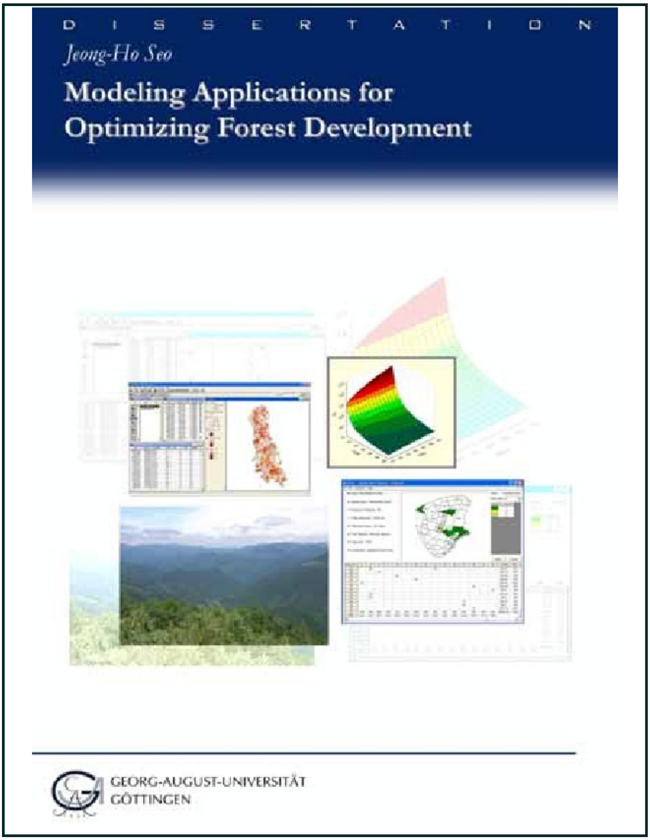
Modeling Applications for Optimizing Forest Development



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1. Introduction

The essential basis for forest planning decisions is statistical and mathematical growth functions and thinning algorithms. These tools are used to predict future yields and to explore silvicultural management options.

There is growing global concern about the importance of environmental values for human life and the need to protect the remaining natural resources. Consequently, the task of natural resource management becomes more important and also more demanding. It is generally accepted that forest management should be science-based (Gadow, 2004) and the accuracy of the information base should be improved. For these reasons, it is not possible to manage large natural resources using traditional and empirical methods, which are based on yield tables for example. Consequently, much research is focused on evaluating different types of resource management and on developing a variety of new modeling techniques which can improve the effectiveness of resource use, based on accurate forecasts of environmental changes.

Among the natural resources, forested landscapes are among the most important ones. Therefore, the priority should be given to forest management and furthermore forest management should be effective and appropriate. Good data about forest growth and management are required for the development of effective forecasting and planning tools. Forest management related to environmental issues deals with the supply of relevant information for decisions, as is the case in any type of planning activity. However, forest management is confronted with various complicating factors. Forests have economical, social and ecological functions that are difficult to harmonize at the same time. For example there are different and sometimes contradictory goals, such as maximizing net income, ensuring sustainable use, or maximizing biodiversity and forest healthy. Furthermore, planning is complicated considerably because of the complexity of forest ecosystem control. Finally, forecasts over long time periods are required in order to represent long-term effects of silvicultural practice realistically (Öhman, 2001).

Therefore to realize forest management goals in an optimal way, ongoing research about effective methods of forest design is crucial. Forest management plans must reflect the variety of goals, the present state of the resource and the expected future forest state resulting from a specific sequence of management activities. The design must be based on the expected set of forest functions, taking into account the great variety of forest types and past management activities. For this reason it is necessary to make available sufficient forest data. Therefore forest surveys, presenting information about the current forest state and growth models, which project information about future forest state are important. The quantity and quality of the required information depends on the goals of management. For example, the required quantity and variety of information for manufacturing wood products will not be the same as that required for environmental planning. Therefore, the design of a forest survey and a forest growth model must correspond with the quality and quantity of information and the goals of management. Various forest growth models have been developed with different levels of resolution, but the appropriate type of growth model is the one which fits the required objectives. The same applies to the techniques of designing the future development of a forested landscape.

1.1 Current state of forest management planning

The theory of sustainable forest management provides a rich assortment of models for planning and harvest control. The Normal Forest Model for example, proposed by Hundeshagen (1826), is used to calculate a sustainable harvest volume, based on the mean annual increment and the ratio of current to normal growing stock. The growing stock which is available for final harvest increases generally with increasing rotation age, which affects the annual cutting area, the total land area required to deliver a sustainable volume of timber, the total growing stock volume, the relative sustainable harvest rate and the mean annual increment. The model of the normal forest is a standard which can be used for comparisons of a current situation with an ideal one. It is a static concept and for this reason its value as a planning tool is limited.

Quite useful, though almost equally simple, are methods based on age class simulation. In the simplest simulation approach, the forest area is subdivided into m age classes each covering an area of a_{ij} ha in the j^{th} felling period ($i=l..m; j=0..n$). The available timber volume in the i^{th} age class is equal to v_{ij} , and the planned total harvest volume for the j^{th} felling period is h_j. Applications of the technique, which is easily implemented as a spreadsheet program, has been demonstrated for various forest types, including fast-growing timber plantations in the tropics and boreal forests, based on a variety of yield models (Gadow and Puumalainen, 2000). Obviously, the method involves considerable aggregation over growing sites, forest types and management options, and the predictions have to be interpreted with caution. However, an age-class simulation is often the only feasible way to predict the dynamic development of a forest resource for a large timber growing region.

A third approach in traditional forest planning involves the use of an area change model. Area change models predict transitions of forest states through time. They project the historical harvesting practice and including random effects have been used for timber supply projections in Japan (Konohira and Amano, 1986) and in Europe (Kurth et al, 1987; Kouba, 1989; Kolenka et al., 1996). One of the most famous applications is Suzuki's (1971) *Gentan* model. The variable $p_i(n)$ may be defined as the probability that a randomly selected forest area is in state i at time n and t_{ji} as the conditional probability that state i moves to state j within a given time step, i.e. as the conditional probability that j will be reached provided the system is currently in *i*. Let $t_{j,1}$ be the probability that a forest stand which belongs to the j^{th} age class is harvested and thus moves to age class 1 (reforestation). Then $t_{j,j+1}$ is the conditional probability that a stand which belongs to the j^{th} age class survives and grows into the $(j+1)^{th}$ age class. The area change approach may have some potential as a tool for forecasting the development of age classes and other strata on a regional and national scale (Nabuurs and Päivinen, 1996). However, some work needs to be done to predict the transition probabilities more accurately (Suzuki, 1971; Blandon, 1985). The transition probabilities are not independent of the current distribution of forest strata, which is a major problem associated with their use (Randall and Gadow, 1990).

The application of new silvicultural systems has become a political reality in many parts of the world. This involves a gradual transformation of traditional silvicultural practice towards *Continuous Cover Forestry.* In a forest managed under the selection system, the stand age is undefined. Forest development does not follow a cyclic harvest-and-regeneration pattern. Instead, it *oscillates* around some ideal level of growing stock. The mean annual increment is not appropriate for measuring productivity and the *Normal Forest* concept and the traditional sustainability criteria are not applicable. Various techniques have been devised for ensuring sustainable harvests in *CCF* systems. The most common type involves recurring visits to a given compartment and to simply skim off the accumulated increment at each visit.

The main problem in a continuous cover forest is to determine which trees are to be removed and which are to remain. The decision may concern tree size or a combination of competition status, tree size, species and timber quality. The aim of the traditional *Plenterwald* harvesting systems practiced in Switzerland, France, Italy, Slowenia and Germany, is to define an optimum forest structure by using an inverse J-shaped diameter distribution model. The target distribution is re-established by periodic removal of trees in the different diameter classes. In mixed fir, spruce and beech forests of the *Trentino* region of the Italian Alps trees are harvested with reference to the model defined by Susmel (1980; see also Virgilietti and Buorgiorno, 1997). Meyer (1930) proposed the function $\ln(n) = \alpha - \beta \cdot D$, where D is the DBH class and n is the number of stems belonging to DBH class D, for specifying the ideal diameter distribution. In a *Femel* forest which is characterized by group harvesting and gap regeneration Meyer's β parameter assumes values ranging from 0.08 to 0.15, depending on the maximum diameter of harvestable trees. In a *Plenter* forest the β-values are usually much lower, ranging between 0.05 and 0.07.

Leak (1964, 1965) proposed the *BDq* method for Northern Hardwoods in New England. If research data are not available, the target values for B, D and q are established using silvicultural considerations. Guldin (1991) proposed a target basal area of 180 ft^2/acre, a maximum retained diameter of 36 inches and a q-factor of 1.21 for the mixed conifer stand on the Challenge Experimental Forest in Northern California (for details of the method refer to Cancino and Gadow, 2002).

In theory, the approach is very simple and logical. By comparing the real and the ideal diameter distributions, it is possible to determine the number of trees that should be harvested in each diameter class. Unfortunately, however, there is no generally accepted ideal distribution of tree sizes, but a rather wide range of distributions found in stable *Plenter* and *Femel* forests (cf. Mitscherlich, 1952). The Plenter guide curves are thus of limited use. The same is true for the so-called basal area normality-approach practiced in some tropical forests (Gadow and Puumalainen, 2000).

There is an increasing need on biodiversity conservation in forest management. Avoiding large clear-cutting areas is a way to protect wildlife habitat and optimizing the spatial distribution of forest management (Öhman, 2000; Van Deusen, 2001). The relative spatial arrangement of patches and interconnections among patches, also plays an important role in maintaining the biodiversity of the forest (Baskent and Jordan, 1996). When the old forest is fragmented into isolated patches, it provides marginal conditions for species that inhabit forest interiors (Harris, 1984). A possible approach to help reduce the amount of edge habitats and minimize the fragmentation is to establish large areas of old forest, free from edge effects (Franklin and Forman, 1987; Gustafson and Crow, 1994; Gustafson and Crow, 1996; Esseen and Renhorn, 1998). A criterion related to the amount of interior habitats is the core-area concept. Öhman et al. (Öhman et al, 1998; Öhman, 2000) investigated the possibility of using the core-area concept in long-term planning of an actual landscape. The planning problem consists of maximizing the net present value (*NPV*) and minimizing the fragmentation of old forest. The core-area is defined as the area of old forest free of edge effects from surrounding habitats (Zipper, 1993; Baskent and Jordan, 1995).

Öhman (1998) solved the model using the method of *Simulated Annealing*. The results indicate that the degree to which stands are clustered depends on the amount of core area demanded and the edge width. The amount of new core area that is allocated adjacent to an existing core area, indicating a continuity of core area information, is increased with core area demand, the minimum age of old forest, and the existence of a U-shaped initial age structure. The cost of attaining the spatial pattern appears to be low compared with the cost of retaining the old forest. Other research results of Öhman show that distinct continuous patches of old forest are created when both a core area requirement and consideration of the amount of edge habitats are included in the problem formulation. The cost of creating a continuous area of old forest was found to be significant.

Another relevant research is Yoshimoto's risk analysis (Yoshimoto, 2000). Events related to forest management are associated with uncertainty. This affects the management decision for forest level planning as well as stand level planning. Yoshimoto used stochastic dynamic programming and estimation of linear models to stochastic phenomena in his risk analysis about timber harvest planning.

Van Deusen (2001) studied scheduling spatial arrangement and harvest simultaneously based on the *Metropolis* algorithm. Spatial configurations are loosely specified and stochastically attained, which contrasts with other adjacency constraints based on a specific block size limit. *Simulated Annealing* was the basic tool in solving the problem. In his simulated example of 40×40 grid of cells, 1090 polygons present forest stands and the remaining ones are ponds. Each of the non-pond polygons is considered to be forested and of an age proportional to its class assignment. (1) When the harvest scheduling objective function contains only an even-flow component, the spatial aspects of the schedule are not controlled; (2) then when the spatial component is added to encourage do-nothing regimes to be close to pond regimes, this has some impact on the spatial juxtaposition of ponds and do-nothing regimes; (3) moreover, when more weight is given to the spatial component, the result shows a very distinct spatial pattern where ponds are almost completely surrounded by do-nothing regimes; (4) Finally, an additional modification is added in the form of a second spatial component to keep do-nothing regimes apart from each other, this cause the do-nothing buffers around the ponds to be somewhat smaller and clusters of do-nothing polygons that are not adjacent to ponds are smaller. This method makes it possible to improve habitat and connectivity, and to create buffer zones as part of the scheduling process.

Heuristics such as *Simulated Annealing* are increasingly used to solve harvest scheduling problems (see for example, Yoshimoto et al., 1994; Murray and Church, 1995; Bettinger et al., 1997; Öhman and Eriksson, 1998; Van Deusen, 2001). They can generate feasible solutions to large problems that traditional mathematical programming techniques are unable to solve. A