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Forest Ecology and Management 143 (2001) 65–76

Forest Ecology and Management

www.elsevier.com/locate/foreco

Application of a spatial decision support system in managing the protection forests of Vienna for sustained yield of water resources

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Abstract

The development and application of a spatial decision support system (SDSS) for silvicultural planning in forests managed for sustained yield of water resources is presented. The implementation of core components of the SDSS is described. As an example, the development of a decision model for selecting the best silvicultural treatment option for stands scheduled for natural regeneration is discussed. The decision problem is factorized into decisions on the future species mixture (GSO) and on an appropriate regeneration method (RM). A priori defined sets of alternatives (nine species mixtures, seven regeneration methods) are evaluated with respect to a set of stand-specific partial management objectives (water production, timber production, conservation of biodiversity, recreation, protection against rockfall and avalanches) by further decomposing the partial objectives into decision criteria. To circumvent the lack of quantitative knowledge on the value of different species mixtures and regeneration methods with respect to the management objectives, pair-wise comparisons of decision alternatives based on qualitative expert knowledge are utilized to compute preference values. An additive multiple-attribute preference model is used to aggregate the preferences at different levels of the decision hierarchy. The combination of GSO and RM which simultaneously maximizes the expected utility and satisfies all constraints of the forest decision maker is selected as the overall best solution. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Decision support; Silvicultural planning; Preference model; Analytic hierarchy process; Multiple-purpose forestry

1. Introduction

Forest managers usually are challenged by the task to transform a forest-level goal into silvicultural prescriptions for a particular stand. Substantial difficulties arise from the fact that emphasis in forest management planning is being placed not only on timber production but also on values, such as recreation, wildlife and amenities. In the mountainous terrain of Austria, forests provide protection against soil erosion and natural hazards, such as avalanches and rock fall and, thus, play an irreplacable role in the maintainance of alpine landscapes. Recently, the role of forests in securing sustained water resources was emphasized by Kohm and Franklin (1997). From this multitude of functions, it is obvious that in the silvicultural planning process the forest manager most probably will be confronted with concurrent objectives for a stand. Considering the complexity of silvicultural decision problems within multiple-purpose forestry with many site and stand attributes, neither intuitive nor schematic solutions are appropriate

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PII: S0378-1127(00)00506-5

planning approaches. For such problems, a formal decision analysis is strongly recommended. According to Keeney and Raiffa (1993), four phases of decision analysis can be distinguished: (1) structuring the decision problem, (2) assessing the impacts of each possible solution, (3) determining the preferences of the decision maker and (4) comparing the decision alternatives.

Decision support systems (DSS) can provide valuable support to solve ill-structured decision problems (Heywood and Carver, 1994; Leung, 1997; Rauscher, 1999). In general terms, DSS are computer-based systems for integrating data base management systems with analytical and operational research models, graphic display, tabular reporting capabilities and the expert knowledge of decision makers to assist in solving specific problems (Fischer et al., 1996). As DSS are based on formalized knowledge, their application in the decision making process facilitates decisions that are reproducible and as rational as possible. Moreover, through the use of DSS, the way the decision maker arrived at a decision is automatically documented and, thus, the process of decision making can be evaluated. In many silvicultural decision problems, such as the choice of regeneration methods (RMs), information at spatial scales beyond the stand level is needed (e.g. Mayer, 1984; Burschel and Huss, 1997). Decision making on biodiversity and recreation matters requires similar information as they heavily depend on the spatial dimension (Næsset, 1997). DSS featuring mechanisms for the input and use of spatial information as well as for the output of maps are spatial decision support systems (SDSS). Until recently, the main focus of decision support in forest planning has been the optimization of treatment schedules with respect to economic criteria where non-timber values usually were used as constraints in the optimization process. Among the methods most often used for decision support are optimization procedures where limited resources have to be allocated among competing objectives (e.g. Arp and Lavinge, 1982; Johnson et al., 1986).

Increasing uncertainties with respect to changing environmental conditions and a steadily increasing amount of information on the management of forest ecosystems have caused a growing interest in decision support for silvicultural planning at the stand level (e.g. Müller, 1997). In contrast to these needs, most of the available planning models support long-term strategic harvest scheduling problems at the forest level rather than site- and stand-specific silvicultural operations (Davis and Martell, 1993). Howard (1991) generally questioned the applicability of such mathematical programming techniques for ill-structured problems which are quite common in multiple-purpose forestry. An alternative is provided by multiple criteria decision making (MCDM) techniques (Hwang and Yoon, 1981). Applications of MCDM-techniques in forestry are rare (e.g. Tecle et al., 1988; Canham, 1990). For European conditions, Kangas (1993); Kangas and Kuusipalo (1993); Pukkala and Kangas (1993); Lexer et al. (2000) provide examples of MCDM-solutions for multiple-objective and multiple-criteria decision problems including biodiversity and amenity values. However, examples for the application of DSS-methodology for silvicultural decision making in forests where the primary concern is to provide a sustained yield of drinking water have as yet not been developed.

To support silvicultural planning at the stand level in the protection forests of the city of Vienna, a spatial decision support system was developed. In this contribution (i) the main components of the implemented decision support system are introduced and (ii) a MCDM approach for silvicultural planning in a multiple-purpose forest management environment where the sustained yield of quality drinking water is the prior management objective is presented.

2. Implementing a SDSS for silvicultural planning in a multiple-purpose forestry

2.1. The project area

The montane and subalpine protection forests of the city of Vienna were selected as test site to demonstrate the application of SDSS-methodology for the multiple-objective management of forests where objectives other than timber production are of primary concern. Primarily, the forests have to ensure a sustained yield of quality drinking water for the city of Vienna. Subsidiary objectives are timber production, protection against rockfall and avalanches as well as recreation and conservation of biodiversity values (Anon., 1973).

low priority values for water production, mixed coniferous stands are considered to be more suitable.

4. Discussion

Silvicultural decisions often are too complex to be solved in a satisfying manner when entirely based on the cognitive capabilities of the human mind. In solving complex problems, people would rather rely on intuition, experience and preferences than on the structured problem-specific combination of facts and knowledge. This may result in schematic and non-repeatable solutions (Dörner, 1992). This problem becomes especially evident in the multiple-purpose management of forests which presently is considered an inevitable paradigm to satisfy society's needs. Multiple-purpose management imposes an array of ill-structured decision problems. Decision support systems are considered a useful tool to assist the decision maker in solving such complex problems.

The main components of the presented SDSS are specifically designed to serve this purpose. The decision model partitions the complex decision problem into partial problems which are considered independently. By decomposing the originally ill-structured decision problem into decisions on future species mixtures (GSO) and RM, structural clarity could be increased. In the design of the decision space, the constraints given by the forest owner reduced the number of alternatives for GSO and RM substantially. Questions such as 'What is the expected utility from GSO with respect to the partial management objectives?' were further factorized into several hierarchically structured decision criteria. The alternatives then were compared with respect to every single criterion one at a time, thus, avoiding simultaneous consideration of more than one criterion. If more than one decision variable does exist, possible trade-offs with respect to expected utilities have to be considered. The trade-off between a preferable future species mixture (GSO) and an applicable RM is modeled by means of an additive multiple-attribute preference model. One of the advantages of the presented preference model is, that value judgements at the level of objectives and partial objectives are clearly separated from the weighting of criteria and the evaluation of alternatives. In this example, the relative importance of the partial objectives was determined by the local forest manager, whereas the other coefficients in the preference model had been derived from expert ratings. If quantitative information can not be provided the possibility to utilize qualitative expert knowledge is a valuable feature of the AHP. Similar to Kangas (1993) we employed a synthesis of MAUT and AHP methodology.

As with any model there are several problems involved with the presented approach that the user should be aware of. It is important to note, that with the AHP, the set of alternatives is confined to a maximum of 10 (Saaty, 1996). However, this should not be a serious issue for most silvicultural decision problems. A further important feature of Saaty's method is the possible occurrence of rank reversals if additional alternatives are added. Thus, the method is not directly applicable to decision problems where the set of alternatives under evaluation is not equivalent with the total decision space. In other words, the current set of alternatives can not be embedded in a larger set of alternatives (Schneeweiß, 1991). The multiple-attribute preference model generates a cardinally scaled order of all decision alternatives with respect to their expected utility. If an alternative is considered to be best with respect to all evaluation criteria it will yield an utility value of 1. However, even with an overall utility of 1, the decision maker must be aware that the resulting solution may just be a best-compromise solution based on subjective rationality (Mollaghasemi and Pet-Edwards, 1997). The latter point should be emphasized to make the decision maker aware of the fact that his preferences strongly determine the outcome of the evaluation process. Sensitivity analysis is one of the powerful tools of decision support systems. In this example, it was demonstrated how expected utility from a GSO changes if the preferences of the decision maker vary with respect to management objectives.

Lack of flexibility is one of the weak points of the current system implementation. For instance, the structure of the presented decision model for regeneration planning currently has to be modified by an expert in electronic data processing. Future improvements aim at developing a more flexible SDSS generator that will enable the user to combine elements of tool box and modelbase in constructing a decision model. A useful approach could be the development of a model base management system (MBMS) which stores model components in an object-oriented data base (Densham, 1991). To meet the requirements of SDSS in a strict sense, the graphical user interface should be modified to enable the interaction between the user and system components in a flexible way. In the current version the modified user interface of ArcView^R is used to generate output and to link external software routines, which, for instance, allow changes in the preferences of the decision maker. The integration of spatial information and stand and site specific attributes was considered to be inevitable. Geographic information systems provide powerful tools to retrieve and visualize spatial information (overlays, buffer, area calculations) to prepare the ground for the design of decision alternatives. In this case, the capabilities for spatial analysis could be substantially improved by the integration of MapModels (Riedl and Kalasek, 1998) into ArcView^R.

Decision support systems are not meant to provide a ready decision. The decision maker always has to take responsibility for any decision. A 'good' decision is one, that is made based on a thorough understanding and analysis of the problem (Holloway, 1979). The consequences of a 'good' outcome are favorable with respect to the preferences of the decision maker. There is no guarantee that a good decision will always achieve a good outcome. A decision resulting in a bad outcome could still be considered a good decision as long as the decision-making process indicated the possibility of a bad outcome. Beyond the advantages of sensitivity analysis, the presented methods and tools provide a proper documentation of the decision making process. Thus, rationales and information used in arriving at a decision can be compared with the achieved outcome, which enables better decisions in the future. The saying in 'classical' central European silviculture that 'there are no rules in silvicultural decision making' (e.g. Leibundgut, 1981; Mayer, 1984), which presumably originates from the varying site and stand attributes involved, does not imply that in silvicultural decision making the basic principles of decision theory are invalid.

Acknowledgements

We are grateful to the Forest Department, city of Vienna for making the site and stand data available.