10 Forest decision support tools in Germany

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10.1 Introduction

10.1.1 The forest sector in Germany

Germany is characterized by a temperate and humid climate with more or less cold winters. Only the Alpine area at the southern border also comprises cold climates. Hot and dry summers may appear at irregular intervals. The vegetation period is long due to extended transition periods in spring and autumn. Forest damages from natural hazards occur mostly on smaller scales and are often correlated to the heterogeneous soil conditions. Therefore the natural vegetation of Germany is a fairly closed and productive forest, which would cover almost the whole land area. Only salt marshes and dunes on the coasts, mires which are too wet and poor in nutrients, steep rocks and avalanche tracks in the high mountains as well as the heights above the climatic timber-line would be free from trees. The natural tree species composition is dominated by European beech (*Fagus sylvatica* L.). This tree species derives its exceptional competiveness by a high shade tolerance, which enables it to establish very early below almost closed forest canopies (Ellenberg 2009).

After centuries of deforestation and forest degradation one third of Germany's land area – i.e. 11.1 million ha – was rehabilitated by age-class forest, which is often dominated by conifers. Today Germany's forest consists of 72 tree species - 69% conifers (28% spruce, 23% pine and 8% other conifers) and 31% broadleaved trees (15% beech, 10% oak, 16% other non-coniferous trees). The non-sustainable exploitation of forests and their reforestation in the middle of the 20th century resulted in an overrepresentation of medium-old age-classes today. The artificially large proportion of conifers and stand structures susceptible to storm cause higher levels of forest damage than expected by natural forest conditions. The growing stock amount to approx. 3.4 billion m^3 (36% spruce, 21% pine, 7% other conifers, 17% beech, 9% oak, 10% other non-coniferous trees), i.e. 330 m^3 per ha. The average annual increment is 11 m^3 per year and ha (Bundesministerium für Ernährung 2004; Oehmichen et al. 2011).

The forest has traditionally productive, protective, and recreational functions in the German society. 94 % of the forest area is used for timber production. About 50 million m^3 of timber is cut per year. Three-quarters of the harvested timber is from conifers. One half of the timber cut is processed as round wood. The raw wood is primarily used by the paper, wood-based panel and sawing industries. An increasing portion of wood is used for generating energy. Raw material processed to become half-finished goods is further used for building in timber and system-building, the furniture industry and wood crafts or trade. Further forest products are fish, game and other services. The forest serves with 24% of the forest area for biodiversity conservation, with 56% for the protection of landscapes and specific natural elements, and with 31% as protective forest for soil, water and other ecosystem services. Germany is one of the most densely populated countries in Europe. Due to the importance of forest for the recreation of the general public, the access to the forest area is generally

permitted by the federal forest act (Ministerial Conference on the Protection of Forests in Europe 2007; Bundesministerium für Ernährung 2004, 2009; German Timber Promotion Fund 2007; Statistisches Bundesamt 2009).
The German forest area is divided into 3% German trust, 20% communal, 33% state, and 44% private forest. There are a total of 2 million private forest owners. The majority are responsible for less than 10 ha of forest. Nevertheless Germany has 28,000 forest management companies with more than ten hectares of forest area and 273,000 so-called mixed companies, i.e. companies active in agricultural and forest management. German forest management companies provide 72,000 full-time positions. For this reason, their economic impact in rural areas is important. More than 90% of the income in forestry is acquired from timber sales. Apart from forest management companies and forest owners, the forest industry sector includes more than 3,200 forest service companies and forest managers. They are likewise settled in structurally weak rural areas and employ 15,000 people. The turnover of forestry in Germany accounts close to 5 billion € (Mrosek et al. 2005; Seintsch 2010; German Timber Promotion Fund 2007).

Germany's forest is protected by forest and environmental laws on national and state level. The objectives of the legal framework are to protect the forest area, to form the legal basis for forest ownership as well as the financial and technical support of forest owners, and to provide regulations for the sustainable management of commercial, protective and recreational forests. With respect to the legal framework, the forest owner is the solely responsible person for each parcel of forest. Stakeholders in forestry are the local population depending on the forest functions and income from the forestry sector, the timber industry, and organizations representing interests in agriculture, nature conservation, hunting, recreation and sports (BWaldG 1975; BayWaldG 2005).

10.1.2 Forest management planning

Forest management plans have a long tradition in German forestry. As a result of the timber crisis during the 18th century, Hans Carl von Carlowitz developed a comprehensive concept for the sustainable management of forest (von Carlowitz 1713) and Johann Friedrich Judeich documented (Judeich 1871), that forest management planning has to solve a classical allocation problem: silvicultural activities have simultaneously to be assigned to certain forest locations and time periods of a sustainable management unit. Today, forest planning consists of state regional and sector plans, forest management plans at forest enterprise level, and silvicultural planning on forest stand level. Forest management plans exist for about three-quarters of the forest area – i.e. the whole state forest area, communal forest enterprises larger than 50 ha and private forest enterprises larger than 100 ha.

Long term strategic goals (> 10-20 years) are documented by guidelines for silviculture and sustainable forest management. The goals usually embrace the intended forest management type and tree species composition usually derived from the forest site classification. Forest management plans are then developed for a time horizon of 10-20 years. They are in force for sustainable forest management units, which is usually the forest enterprise. The planning process typically consists of the following steps: (i) The present status of the forest enterprise is investigated by a forest inventory and an operation analysis. The main parameters recorded by the enterprise forest inventory are the tree species composition, the age class distribution, growing stock, increment and the status of the stand regeneration. (ii) Based on the strategic goals, on the results of the status report, and on the present socioeconomic aspects the forest management objectives are defined on the enterprise level. (iii) The forest area is then stratified into silvicultural management units – usually forest stands. According to the silvicultural guidelines and present stand structures, the silvicultural objectives and actions are derived and the expected target values of management objectives are predicted. The silvicultural planning is mostly carried out by a field inspection of the forest stands. (iv) Finally the stand level data are summarized and the silvicultural planning is adjusted to the management objectives on enterprise level. (v) Most commonly the forest management plan consists of a textbook, which contains the results of the status report, a description of the management goals, and target values for the implementation of the forest management plan. The textbook is supplemented by a forest management map, a forest stand management textbook and the site classification. The implementation of the forest management plan is then realized by annual operational plans. At the beginning of each annual planning period the annual cut is specified, balancing the sustainable annual cut defined by the forest management plan with the timber harvest of recent years, the silvicultural treatment options, and the expected timber market. The future amount of forest damages is usually not included into the considerations. Further aspects of the operational plans are the areas for artificial regeneration and pruning, capacity planning, and the game management.

Forest management plans are supervised by the state forestry administration and tax authorities. Forest certification forms an additional and voluntary control level for the sustainable management of forests. In Germany 66% of the forest area is certified by the Programme for the Endorsement of Forest Certification Schemes (PEFC), 4.3% by the Forest Stewardship Council (FSC) and 0.5% by the agricultural organization Naturland e.V. (BMELV 2009).

The different concepts of forest management planning in Germany are described by monographs – i.e. control methods (Paulsen 1797), geometric (Cotta, 1804) and volume approach (Hartig 1795), age class methods (Judeich 1871) and business management (Speidel 1972). Comprehensive descriptions of the present methods exist in several professional textbooks (von Gadow 2005; Kurth et al. 1994; Knoke et al. 2012). Detailed descriptions of the applied forest management principles are documented in the guidelines of the state forest administration and enterprises (e.g. Bayerisches Staatsministerium für Ernährung. Landwirtschaft und Forsten 1982; Bockmann et al. 1998).

10.1.3 Decision problems in forest management planning

Forest management planning in a densely populated country is a complex process. Generally speaking, the most relevant task of forest management is to balance the conflict between the economic interests of the forest owner with the ecological and social requirements of the society. Decision problems in forest management can be found on many different spatial and temporal scales and contexts. Decision problems of forest farmers are mostly restricted to stand level with a planning horizon of one or two human generations. Larger private or communal forest owners and state forest administrations have to manage several thousands of hectares of forest land with strategic production goals for many decades, tactical plans for sustainable yield and complex operational plans for timber harvesting operations. Spatial contexts with the interrelation of different spatial sub-units play an important role in the planning of silvicultural actions, personnel placement, and timber harvest logistics. Finally, the forest policy level defines the framework, how forest management planning is implemented and formulates strategic goals and funding procedures on a provincial level by forest law and administrative orders. Basically, all rights and obligations for decision making in forestry practice are hold by the forest owner. Depending on the ownership structure and the legal regulations or informal business practices for the participation of stakeholders, one or more decision-makers are involved in the planning processes. For instance, forest farmers decide by themselves, but are supervised by state foresters and are involved in official planning processes, when their forest is affected e.g. by the NATURA 2000 management.

Forest planning experts in Germany were scored within the FORSYS COST Action (for methods see section 10.2) to describe decision problems in forest management planning to be supported by computerized tools. They reported 329 problem types according to the FORSYS classification scheme and 118 subject-specific decision problems. A cluster analysis was applied to identify the main problem types. The results show three main groups (A to C) with a correlation of spatial and temporal scales (Figure 13). The classification variables for goods and services build an own cluster (P) with no specific linkage to one of the main groups (A to C). Considering the abundance of these variables a set of seven main problem types important for the application and development of decision support tools is derived (Table 2).

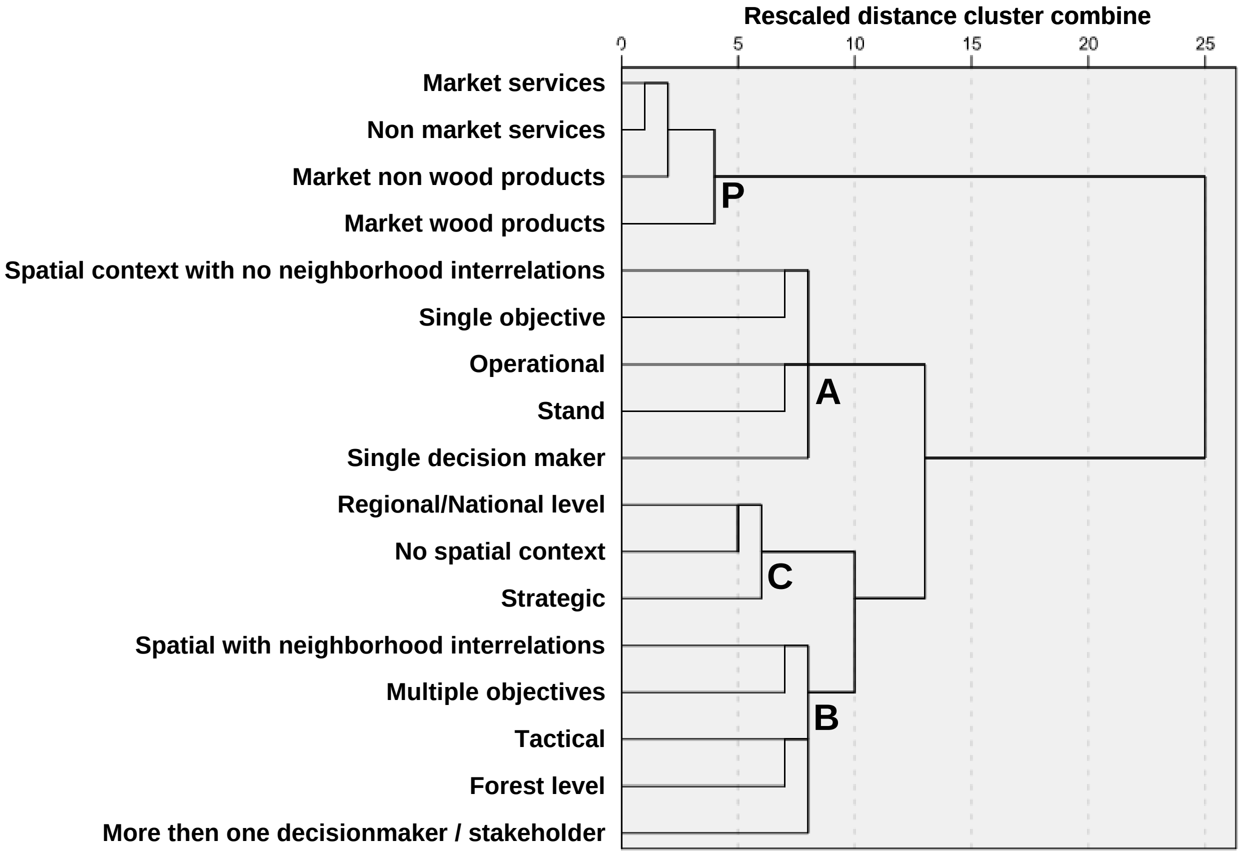

Figure 13. Dendrogram derived from hierarchical cluster analysis using Euclidian distances and the Ward linkage method.

Table 2. Main problem types for the application of computerized decision support tools. Classification derived from the result of the cluster analysis (A, B and C) and the abundance of the classification variables for goods and services (frequencies < 5% of the reported problem types were excluded).

Problem type	Spatial scale	Temporal scale	Spatial context	Objectives	Parties involved	Goods and services
A1	Operational	Stand level	Spatial context with no neighbourhood interrelations	Single Objective	Single decision-maker	Market wood products
A2						Market wood products, Market non-wood products
A3						All products and services
B1	Tactical	Forest level	Spatial context with neighbourhood interrelations	Multiple objectives	More than one decision-maker / stakeholder	Market wood products
B2						All products and services
C1	Strategic	Regional / national level	No spatial context	Multiple objectives	More than one decision maker / stakeholder	Market wood products
C2						All products and services

10.1.4 The objectives of the study

The objectives of this study are (i) to summarize existing approaches for computer-based decision support tools in Germany based on expert knowledge and to specify them by the FORSYS classification schemes for problem types, knowledge management approaches and participatory methods, and (ii) to describe existing decision support tools tested or applied in forestry practice.

10.2 Materials and methods

In order to summarize the existing approaches for computer based decision support tools, a survey was conducted at universities providing forest science, state forest research institutes, state forest administrations, state forest enterprises, forest owner communities, forest owner representatives and forest information industry. Within each organization, the heads of the departments and institutes involved in forest management planning were asked to fill out a postal questionnaire and to forward it to the staff, respectively. A total of 245 experts were scored. 36 respondents answered the request. 24 experts filled in the form. 12 persons replied not to be involved in the development and application of specific DSS.

The questionnaire is divided into three segments: (i) At first the respondents have to define problems, which are solved or intended to be solved by the application of computer based decision support tools. Following the definition of a problem it has to be classified according to the FORSYS classification scheme by temporal and spatial scales, spatial context, type of objectives, parties involved, as well as goods and services addressed. (ii) Then the respondents have to assign developed and/or applied computer-based decision support tools to the problems defined in the first work step. The tool has to be described in detail concerning methods and models applied as well as the deployed methods of knowledge management and stakeholder participation. (iii) The respondent has to register with his name and contact data.

In the second part of this article decision support tools tested or applied in forestry practice are described based on the results of the questionnaire and a review of scientific publications and technical documents. The results of both surveys are organized in a relational database and grouped according to the problem types, applied methods, knowledge management and stakeholder participation aspects.

10.3 Results

10.3.1 Characteristics of the forest sector for computerized decision support tools

When the decision problems reported by forest planning experts (see section 10.1.3) are assigned to the different stages of the management process, the majority of problems are related to the selection of objectives and the planning process (43%) as well as to forest inventory and other control processes (45%). Problems existing in organizations and the implementation of management plans (12%) play a subordinate role. The decision problems are more related to forest enterprise tasks (77%) than to governmental tasks (23%). Within forest enterprises two-thirds of the problems are related to the production and one third to the financial management. Consequently, decision problems focusing on silvicultural tasks form a priority (39%) followed by controlling within forest enterprises (17%) and governmental supervision of sustainable forest management (18%). The remaining problems can be assigned to the fields of accounting (6%), cooperation with partners (2%), forest valuation (5%), timber harvest (6%) and sales (3%), and training of private forest owners by governmental organizations (4%).

The respondents reported 98 mostly end-user specific software applications supporting forest management decisions. Two-thirds of the applications are in operation. Frequently, different problem-specific applications were combined from modules of a larger software collection. Therefore the reported applications could be allocated to 42 software systems. The majority of the systems can be classified as management information systems (28%) followed by computer simulation models (19%), transaction systems (13%), decision support systems (11%), geographic information systems (6%) and combinations of these systems (23%). Management information and transaction systems are also the most applied tools to solve the previously described decision problems, whereby decision support systems in a strict sense play a subordinate role (Table 3). The majority of the systems address planning (48%) and control processes (19%) or a combination of both (9%). 10% of the tools cover the whole management process (Table 4). Several systems are designed to support singular decision problems (e.g. for silviculture problems or harvesting problems), but the majority focus on the support of multiple management tasks i.e. to integrate accounting, controlling, forest valuation, silviculture, and harvesting into one system.

Table 3. Classification of computerized tools and their application to decision problems in forest management planning
(DSS=Decision Support System, GIS=Geographic Information System, MOD = Statistical or Simulation Model, TS = Transaction system)

Type	Proportion in computer tools	Application to forest management
DSS	11%	4%
GIS	6%	3%
GIS+MOD	4%	7%
MIS	28%	30%
MIS+GIS	2%	3%
MOD	19%	9%
TS	13%	21%
TS+GIS	9%	17%
TS+MIS	4%	4%
TS+MIS+GIS	2%	1%
TS+MIS+GIS+MOD	2%	1%

Table 4. Application of decision support tools in different phases of the management process

Objectives & Planning	Organization & Implementation	Inventory & Control	Proportion
+			48%
	+		12%
		+	19%
+		+	9%
	+	+	2%
+	+	+	10%

The respondents reported that 55% of the systems deploy or are related to knowledge management techniques. Mind mapping, database management systems, geographical information systems, data mining and ontologies are used to identify and structure knowledge. Expert systems based on rule-based models and decision trees allow machine reasoning. Handbooks, web portals and visualization techniques are used to transfer and share knowledge.

Participatory methods are applied for the identification of problems, design and problem modelling, and decision-making. Restricted groups of stakeholders and experts are consulted to identify problems by structuring methods and workshops, to model problems by group work and modelling techniques, and support decision-making through forest information systems and scenario analysis. The public is only involved into the problem identification by interviews and through structuring methods.

10.3.2 Decision support tools in German forestry

10.3.3 Data-oriented tools

For the last decades the investment of forest enterprises into information technology has focused on the gathering, storage, and organization of data and information. Therefore most forestry software products aggregate enterprise data to management information by the application of data modelling, database algorithms and information representation techniques (ABIES ITS Gmbh 2010; GISCON Systems GmbH 2011; Genowald 2011; Ostdeutsche Gesellschaft für Forstplanung mbH 2009) (Table 5). The results of these methods are quantitative criteria on different spatial and temporal scales i.e. annual cut, costs and revenues on stand and district level. Approaches for the real-time integration of information from field staff and sensors into the management systems reduce the gap between data pools and actual forest state. They offer the opportunity for a fast operational planning e.g. to react on insect attacks (Baier et al. 2006) and forest fires (Haß 2010) as well as to change from periodical planning schemes into a dynamic forest inventory and planning process (Redmann et al. 2010; Nordwestdeutsche Forstliche Versuchsanstalt 2011b; Bombosch et al. 2011).

Forest valuation methods play a key role in forest management planning. Usually forest assets and timber values can be derived from market data. The computerized methods range from simple value factor methods (Mühlhausen 2010) to sophisticated tools for the calculation of timber assortments (Kublin 2003), harvesting costs (Bombosch 2011), and integrated tools to calculate revenues and forest values (Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg 2002; Weiß 2011). It is more difficult to derive non-market service values. Therefore a set of methods consisting of contingent valuation method, choice experiments, the benefit transfer approach, and the travel cost method are tested and applied for decision support tasks (Elsasser et al. 2007).

Public relations and the support of practitioners via the internet play a major role for forest administrations and NGOs. Mainly content management systems are used to deliver textual and graphical information to target groups (e.g. www.waldwissen.net). These document and communication oriented tools support forest planning by scientific and practical information e.g. recommendations for tree species selection (Lässig 2009).

Data-oriented tools were mostly developed by information industries according to the demands of customers and by state forest administrations to improve governmental workflows. Therefore the acceptance of data-oriented tools is high and the systems are widely applied in Germany’s forestry sector.

Table 5. Examples of data-oriented tools tested and/or applied in forestry
(DBMS = database management system, RDBMS = relational database management system, GIS = geographic information system, prefix Web = web-based component)

Computerized tool/DSS	Models and methods	KM techniques	Methods for participatory planning	FORSYS Problem type
ABIES (ABIES ITS Gmbh 2010), FIP2000 (Ostdeutsche Gesellschaft für Forstplanung mbH 2009), Proforst (GISCON Systems GmbH 2011)	RDBMS, spreadsheet, GIS, business process models	DBMS	Problem modelling by a multi-access system for experts	A1, B2
Waldinfoplan (Genowald 2011)	RDBMS, spreadsheet GIS, business process models	WebDBMS and WebGIS	Problem modelling by a web-based system for experts and forest owners	A1, B1
WebBetriebsplaner (Nordwestdeutsche Forstliche Versuchsanstalt 2011b), DSW2 (Redmann et al. 2010)	RDBMS, GIS, growth and yield model, timber assortment planner, GIS	WebDBMS and WebGIS	Web-based, multi-access system for experts and forest owners	A1, B1
WinForstPro (Latschbacher GmbH 2011)	RDBMS, GIS, spreadsheet, business process models	WebDBMS and WebGIS	Web-based, multi-access system for experts and business partners	A1, B1
BayWIS (Millitzer 2008)	RDBMS, GIS, business applications	DBMS	Problem identification and decision-making for governmental experts	A3, B2, C2 all problem types with spatial context
BDAT (Kublin 2003), HOLZERNTE (Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg 2002)	Timber assortment model based on mathematical equations	Model equations	Planning process by experts	A1, B1
FSMW (Baier et al. 2006)	RDBMS	DBMS	Multi-access system for experts	A3, B2

10.3.4 Model-oriented tools

Due to data gaps induced by the lack of measurability or economic restrictions enterprise data are often not available or insufficient to solve a decision problem and to predict criteria in future environments, respectively. Therefore models are applied to produce synthetic data to fill these gaps and to develop management scenarios. Three model-driven approaches can be distinguished (Table 6):

(i) Statistical models describe the relationship between one and more variables by mathematical equations. They are deduced from scientific or enterprise data by statistical analysis. Examples are computerized yield tables (Nagel 2010; Lembcke et al. 2000), assortment tables and models (Kublin 2003), models to predict risks caused by storm, insects, and climate change (Kohnle 2011; Baier et al. 2007; Hanewinkel et al. 2011; Kölling et al. 2009) as well as different remote sensing based systems to gather information from spectral data (IQ wireless GmbH 2011). Geostatistical models include the spatial interrelation between variables and are applied to depict spatial contexts e.g. potential natural vegetation covers (Ewald et al. 2009) and climate sensitive tree distribution maps (Kölling et al. 2009; Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg 2001).

(ii) Simulation models shape real objects as forest stands in computer systems using theoretical or statistical functional relationships between the system elements and their environment. Forest growth models are applied to simulate the development of forest stands under different management options. The individual tree models SILVA (Pretzsch 2009) and BWinPro (Nordwestdeutsche Forstliche Versuchsanstalt 2011a) are increasingly deployed by forestry to forecast different silvicultural production programs for several decades. They are based on relationships of tree dimensions and growth derived from forest growth experiments. Physiological aspects are investigated in the field and in laboratories to integrate plant processes and their interrelation into forest models to project the forest development in a changing environment on stand (Grote et al. 2002) and enterprise levels (Chertov et al. 2002). The environmental conditions are projected - i.e. by regional climate models to forecast the climatic conditions in the 21st century (Ebell et al. 2008) and soil/water balance models (Federer 1995) to predict forest site conditions under different climate conditions. Another common field is the simulation of the timber harvesting processes. Discrete event simulation is applied to derive management information of different harvesting systems. Software agent systems are used to model the behaviour of different members of the wood supply chain (Ziesak et al., 2004). In many cases not all important factors can be included in a projection, and error terms must be added to the management information. Hence, the Monte-Carlo simulation is widely applied to generate random distributions of criteria and to derive their expected values and dispersion parameters (Hildebrandt et al. 2011).

(iii) Several approaches exist for the integration of different models. The system DSS-WuK incorporates climate, nutrition, water balance, forest growth, and risk models together with financial valuation methods to predict the forest states on regional scales and for any single location in Germany. Specific spatial algorithms were developed to integrate the different temporal and spatial scales (Forschungszentrum Waldökosysteme 2011). The experimental system KOMET integrates solvers for the prognosis of forest growth, timber harvest, and assortment supplemented by methods to compare forest stands and to apply spatial analysis on enterprise levels (Döllerer 2007). A further approach to integrate models from natural and social science is the GLOWA initiative of the German government. On the landscape level, models were combined to complex clusters supporting decision-making for the future development of the main rivers Elbe and Danube (Bundesministerium für Bildung und Forschung 2005).

The majority of model-oriented tools originate from scientific studies. Therefore their concepts are oriented to scientific questions and hypothesis testing. They are implemented in forestry practice by user friendly interfaces (e.g. management models), vivid presentations (e.g. geographic information systems) or by the integration of abstract model components into larger user oriented systems (e.g. DSS-WUK). The application of simulation models is growing due to increasing data demands.

Table 6. Examples of model-oriented tools tested and/or applied in forestry

Computerized tool/DSS	Models and methods	KM techniques	Methods for participatory planning	FORSYS Problem type
Standardised yield tables (e.g. Nagel 2010; Lembcke et al. 2000) and supplements (e.g. Bösch 2003)	Mathematical equations, spreadsheet	Model equations	Planning tasks of experts	A1, B1, C1
Computer supported yield-table models (e.g. Bergel 1985) and supplements (e.g. Reimeier et al. 2001)	Mathematical equations, spreadsheet	Model equations	Planning tasks of experts	A1, B1, C1
WEHAM (Dunger et al. 2004)	Distance independent individual tree model	Model equations	Problem modelling and decision-making for experts	A1, B1 , C1, all problem types without spatial context
SILVA (Pretzsch 2009), BWIN (Nagel et al. 2006)	Distance dependent individual tree model	Model equations	Problem modelling and decision-making for experts	B1 including stand level
PHENIPS (Baier et al. 2007)	Statistical and process model equations, GIS	Model equations	Problem modelling and decision-making for experts	A1 including forest level
Climate risk maps for tree species selection (Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg 2001; Kölling et al. 2010), WINALP (Ewald 2009)	Mathematical equations, GIS	Model equations	Problem modelling and decision-making for experts	C1 including spatial context without neighbourhood interrelations
DSS-WUK (Forschungszentrum Waldökosysteme 2011)	Integration of statistical, stochastic, process and spatial models	Model equations, master model	Prognosis available for the public	C2 including spatial context without neighbourhood interrelation

10.3.5 Decision-oriented tools

Based on data (3.2.1) and model (3.2.2) oriented tools, forest decision support systems model decision processes in forest management planning. They are deployed to support forest managers in the selection of best choices related to management objectives by standardized, but flexible and user-friendly methods. These methods can address single or multiple criteria related to discrete or continuous management options in one- or multi-stage decisions, are able to manage decision under safety, risk or uncertainty, and are capable of supporting single decision-makers or groups of them.

The reported decision methods include the support of silvicultural decisions by multi-criteria- analysis (Felbermeier et al. 2004), non linear optimization (Roessiger et al. 2011) and decision trees (Bachmann 2011). Forest management planning on enterprise level is assisted by multi-criteria-analysis on the operational level (Felbermeier et al. 2007a) and by the optimization of forest enterprise values on the strategic level (Felbermeier et al. 2007b). 2-D-cellular automatons and multi-criteria approaches are developed to provide decision methods in land use and forest landscape planning (Fürst et al. 2010) (Table 7).

Decision-oriented computerized tools are a new development in Germany's forestry sector. The systems are developed by scientists in close cooperation with project partners from forestry practice. The systems achieved prototype status and are used in test applications by forestry operations and forest administrations.

Table 7. Examples of decision oriented tools and systems tested and/or applied in forestry (MCA=multi criteria analysis, LP = Linear programming, DBMS = database management system, RDBMS = relational database management system, GIS = geographic information system)

Computerized tool/DSS	Models and methods	KM techniques	Methods for participatory planning	FORSYS Problem type
ZEUS (Felbermeier et al. 2004)	RDBMS, MCA	DBMS	Problem modelling and decision-making for experts	A3, B2 including strategic level
LIFT (Felbermeier et al. 2007a)	RDBMS, MCA, GIS	DBMS	Problem modelling and decision-making for experts	A2, B1
OPTIM (Felbermeier et al. 2007b)	RDBMS, growth and yield model, natural risks model, assortment model, LP	DBMS, Model equations	Problem modelling and decision-making for experts	B1 including strategic level, excluding spatial context
PYL/GISCAME (Fürst et al. 2010, PI Solution 2011)	2-D-cellular automaton, MCA, RDBMS, GIS	DBMS	Problem modelling and decision-making for experts and stakeholders	B2, C2 including spatial context with neighbourhood interrelation

10.4 Discussion and conclusions

The main results of the study are that forest management problems defined by German experts are very heterogeneous, and data or model-oriented decision support tools are widely applied. Nevertheless decision-oriented tools - meaning decision support systems in the sense of Sprague (1980) - are rarely used, despite their potential to support decision-making in complex situations. The reasons for this can be found in historical developments:

- Sustainable forestry in Germany has a tradition of almost three centuries. Sophisticated methods of forest management are proven applied by professional foresters for many decades and there seems no need for a change.

- Since the middle of the 19th century, powerful provincial forest administrations were established to manage the state forest districts and control the private and communal forest owners. Combined with a long-time forestry education in governmental and university schools, professionals did not see a demand for the application of decision support systems, which provide less information than the analytic capabilities of the local foresters. Therefore only provincial transaction and management information systems were developed to support the administration of the state forest districts.
- Private forest covers 44% of the German forest, which coincides with the mean European conditions, but 57% of the private forest consists of forest enterprises with less than 20 ha, compared to 17% on the European level. The forest owners are mainly farmers, who follow traditional objectives and management options based on local experiences. The application of decision support systems in small-scale forestry is difficult, since there exists almost no information about the forest of a farmer and decision support systems would have to provide a very high local precision to meet the farmer's expectations.
- German forest enterprises and timber industry are traditionally in different ownership. Timber harvest and processing is linked by open regional timber markets, and therefore no decision support systems optimizing the whole timber supply chain were established.

The reorganization of the German forest sector modified this situation in recent years:

- State forest districts were transformed to state-owned forest enterprises, which strengthened financial management goals and led to the development of business information and decision support systems.
- Private forest owners are increasingly organized in forest owner communities to face the market power of a concentrating timber industry. More and more forestry professionals are hired by communities to develop strategies for the optimization of silvicultural treatments, timber harvest and sales. In this sector, a new commercial market develops for forest information and decision support systems.
- The value of forest and timber increased in the last few years due to a higher demand for timber and forest assets in financial portfolios. Therefore the interest to improve the financial performance of forestry increased, and more money is invested in the development of decision supporting systems for financial analysis in forestry.

Summarizing the results of this study and the recent developments of the forest sector in Germany the following conclusions can be drawn:

- An increasing number of forest management information systems are applied in Germany. It can be expected that new capabilities in remote sensing, information harvest and modelling will further increase the availability of management information. Forest managers responsible for the development of forest ecosystems in a densely populated country under changing economic, social and ecological environments will increasingly rely on such systems.
- The investigation shows that there exist no general key problems or standard situations to be solved. Therefore flexible methods are needed to support forest managers in the solution of ill-structured problems and combine the forester's empirical knowledge with computational capabilities.

Two strategies may be pursued to support the development of decision support systems for sustainable forest management:

- A DSS-generator (Sprague 1980) could be established and used as a foundation for the development of specific forest decision support systems adapted to different scales, users and tasks. Such a universal instrument applicable for forestry does not exist and needs research in interdisciplinary teams covering forest science, mathematics, linguistics and computer science. Presently scientific projects do not usually have the lifetime to solve these fundamental scientific questions.
- An alternative step by step strategy can be the formulation of a framework as a standard for the development of decision support tools for forest management purposes. The decision support tools could be used for the development of a DSS-generator as well as for specific forestry decision support systems. The framework could define basic principles for the development, interaction and integration of decision support tools. This would release forest scientists from the technical workloads of software engineering and support them in the rapid development and integration of specific decision support systems for forest research and management tasks.

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