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RESEARCH ARTICLE

A web-based ToolBox approach to support adaptive forest management under climate change

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The design and implementation of the adaptive forest management (AFM) ToolBox is presented. Design principles derived from previous experiences in decision support system (DSS) development include support for (1) modularity, (2) accessibility via the Internet, (3) inclusion of different types of knowledge and information, (4) the use of different data sources, and (5) specific problem types. As major components of the AFM ToolBox DataBase, Vulnerability Assessment Tools (single user version, group mode) and an optimization tool to generate optimized management plans at the level of management units or landscapes are highlighted. A key feature is the distinction of two archetypical user profiles (manager, analyst). The AFM ToolBox is evaluated against eight criteria for the assessment of DSS. It is concluded that the ToolBox approach setting focus on modularity while avoiding to over-emphasis technical integration provides the right frame to secure the flexibility regarding tools and decision-making processes which is mandatory if a DSS should be taken up by practice.

Keywords: decision support systems; multi-criteria analysis; optimization; knowledge transfer

1. Introduction

Climate change may strongly impact on forests and affect the provisioning of forest ecosystem services. The identification, design, selection, and implementation of adaptive measures in forest management require a sound knowledge base as well as tools to support the forest manager in decision-making. Decision support systems (DSSs) are considered particularly useful to assist in dealing with unstructured, ill and semi-structured decision-making problems (Reynolds et al. 2008). Such problems typically deal with situations in which human judgment is vital for problem solving and limitations in human information processing may impede the decision-making process (Rauscher 1999; Martinsons & Davison 2007). Following a pragmatic functional approach, McNurlin and Sprague (2004) define DSS as “computer-based systems that help decision makers confront ill-structured problems through direct interaction with data and analysis models.” Fischer et al. (1996), Leung (1997), and Rauscher (1999) use a combined functional and technical approach and define DSSs as computer-based tools which provide support to solve ill-structured decision problems by integrating database management systems with analytical and operational research models, graphic display, tabular reporting capabilities, and the

expert knowledge of scientists, managers, and decision makers to assist in specific decision-making activities. A major feature which has been used frequently to distinguish simulation tools from DSS is that DSS are designed to support a specific decision-making procedure (Muys et al. 2010) and are thus emphasizing the way a decision problem is analyzed, alternative options are compared and promising solutions are identified.

Numerous attempts to develop DSS and introduce them in real life decision-making processes are reported in the literature (see e.g. Rauscher 1999; Reynolds et al. 2005; Reynolds et al. 2008). Despite huge enthusiasm in the 1990s when technical advances in information technology fostered new developments (see for instance Reynolds et al. 2005), recently an increasing number of contributions also conclude that there has been only limited uptake of DSS into practice (e.g. McIntosh et al. 2011).

In assessing possible reasons for slow and hesitant adoption of DSS in practice, a few major general challenges can be identified. First, it is vital to target the right user(s) of a DSS. This is a crucial issue as acceptance of DSS by users depend largely how well the tools meet the usage profiles of specific user types. A typical setting in forest resource management combines

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one responsible decision maker and a heterogeneous group of stakeholders having a diversity of partly contrasting interests and expectations toward forest management and who are usually not formally involved in decision-making processes about forest management. Usage profiles relate to planning tools and approaches and levels of complexity a user is able or willing to handle. Another important prerequisite for DSS adoption is that the problem type featured by the DSS is actually reflecting the decision-making problem of a user. Characterizing the problem type includes external drivers such as land use and socio-economic changes and global phenomena such as climate change. The specific combination and relevance of these components may vary strongly among potential application cases. For the development of DSS, this broad range of variability in problem type characteristics is particularly challenging in the context of international cooperative research and development (R&D) projects such as within the framework programs of the European Union.

Second, it is difficult to handle the inherent complexity of forest management in knowledge transfer processes. Planning and decision-making regarding forest resources deal with highly complex socio-ecological systems with multiple interacting spatial and temporal dimensions. Finding ways and means to communicate findings about forest ecosystems and their management via information technology is a challenge in itself. This is amplified if decision problems include land-use and climate change issues because the inherent uncertainty in planning outcomes will increase.

And third, it is challenging to produce DSS software at high quality standards, which meet the demands of the users (Eom & Kim 2006). The expectations of users of DSS are high and the benchmark for DSS prototypes are commercial software products (Hannerz et al. 2010). It is almost impossible to design and implement software that may meet robustness or scalability requirements for effective and continuous use by forest managers as well as integration, cooperation, and interoperability requirements to support the interactions among forest managers and stakeholders involved in each stage of the decision-making process (Borges et al. 2013) within a 3- to 4-year R&D project.

The R&D project MOTIVE (models for adaptive forest management, AFM) within the 7th Framework Program of the European Union (<http://MOTIVE.project.net>) was a 4-year project dealing with forest management decision-making under climate change. A core element of MOTIVE is a network of 10 case study regions across Europe. The major deliverable is a DSS for AFM.

In the context of the MOTIVE project, we set out to design and implement a decision support tool box for AFM which is based on a thorough analysis of contemporary DSS development activities. The objectives of

this contribution are fourfold: (1) we present major hypotheses for DSS design derived from a review of recent DSS development work, (2) we introduce the conceptual frame of the MOTIVE AFM ToolBox DSS, (3) outline the technical implementation of the ToolBox, and (4) evaluate the ToolBox against a set of criteria considered relevant for successful DSS development.

2. Conceptual frame for DSS development

2.1. Some hypotheses about DSS design

DSS development within larger R&D projects is usually confronted with several challenges. The user is weakly defined (i.e. “forest managers, policy-makers”), the decision problem not well identified, and no generally accepted decision-making process can be defined (see e.g. Reynolds et al. 2005; Vacik & Lexer 2013).

If the intended user community is heterogeneous with regard to institutional background, role in decision-making processes, available expert knowledge and interests regarding forest products and services it is likely that a DSS featuring a highly predetermined decision-making process (i.e. the decision model) will not be accepted. Moreover, beyond the different procedural approaches to decision-making, it is obvious that a single decision support tool will not be sufficient to cover all needs of all decision makers and stakeholders. However, the consideration that context specificity and flexibility are key requirements for acceptance of decision support tools by end-users calls for a tool box approach in which a diverse set of tools is made available to potential users and in which the mode of using these tools can be adjusted according to various decision-making processes. Examples which follow a similar conceptual approach, although not necessarily implemented as software, are the Climate Adaptation Platform of the EU Environmental Protection Agency (<http://climate-adapt.eea.europa.eu/adaptation-support-tool>) and the tool box for public engagement in forest and woodland planning in the UK (Ambrose-Oji et al. 2011).

Recent technological advances provide new options for the implementation of DSS. Technical integration of DSS components (e.g. Fischer et al. 1996) is feasible, although high resource input is mandatory. However, emphasizing technical integration of DSS components may lead to decreasing flexibility with regard to decision-making processes that a DSS can support and with regard to tools included in a DSS.

Furthermore, seen from a larger perspective, a tool box approach provides the opportunity for continuing development work over several project life cycles. This may help avoiding the need to start DSS development multiple times from scratch.

2.2. The concept of the AFM ToolBox

Based on prior experiences with the development of DSS, a number of principles were derived for the design of the AFM ToolBox.

(1) *Support modularity.* The metaphor of a “tool box” points already at modularity: it should be easy to add new tools (also from third parties) or to exchange existing tools. Similarly, tools should be able to share common elements (e.g. administrative functionalities such as user management, data import and export, saving DSS sessions, printing).

(2) *Support accessibility via the Internet.* Recent technological advances allow the development of web-based decision support tools. Improved Internet browsers can run complex web applications which can be accessed with increasing ease due to the widespread availability of broadband Internet connections. Specific advantages of a web-based approach are the reduced access barrier (no downloads and installations required) and the utility of decision support in a collaborative decision-making situation. Through the technical achievements and the increased interactivity offered by Web geographical information systems (GIS) and social networks, active participation even of large groups becomes possible.

(3) *Support different types of knowledge and information.* The ToolBox should support both interactive, data-driven tools and “softer” types of information such as demonstration examples, documents, maps, and frequently asked questions (FAQs).

(4) *Support the use of different data sources.* The AFM ToolBox should offer easy try-out of tools with *ready-to-use data* from MOTIVE case study regions. Ultimately, the usefulness of available tools can be efficiently evaluated with data that represent the intended application domain. Users who find a tool useful for her problem domain can then invest in preparing their *own customized data* for use with AFM ToolBox tools. These customized data for the interactive tools are produced externally to the actual ToolBox using various types of models (e.g. forest ecosystem models, optimization tools).

(5) *Support well-defined problem types.* The AFM ToolBox in its current version is designed for (1) the comparative analysis of management alternatives at stand or landscape level with regard to portfolios of ecosystem services which may comprise timber production, carbon sequestration, and nature conservation and biodiversity under current climate, and climate change scenarios; (2) the generation of optimized management plans at landscape level. Assessment entities are either stands or a collection of stands (i.e. landscape). The time frame extends up to 100 years. The temporal resolution and the type of

ecosystem service indicators depend on the forest model used.

2.3. AFM ToolBox components

2.3.1. Overview and data flow

The components of the AFM ToolBox are the ToolBox DataBase, the tools and a content management system (CMS). The input data for the tools in the ToolBox are stored in the ToolBox DataBase. The CMS makes the “knowledge base” available to the end-user by means of static and dynamic web pages. The CMS is an integral part of the ToolBox, but not directly connected to DataBase and Tools. The ToolBox client serves as interface between external models and the DataBase of the AFM ToolBox (Figure 1).

The ToolBox DataBase supports a harmonized data format and contains simulated or measured data characterizing stand level management programs which can be used to test and demonstrate the tools in the ToolBox. A large number of forest models are available for European forests. However, most have a clear regional focus and no general model exists which can be used for all kind of forest types. Given the limited resources, the ToolBox development did not aim at arbitrarily picking one or two models for integration into the ToolBox. For customized applications (i.e. data), external forest models are required to simulate forest development in dependence of management and climate scenarios and to provide performance indicators of different forest management alternatives either directly as output of forest models, via linker functions establishing a relationship between forest model output and a suitable ecosystem service indicator, or to feed other specialized models of ecosystem services with information on forest structure and composition. Such raw data are transferred to the DataBase by a special tool, the AFM ToolBox client (Figure 1). The client is highly customizable and has the ability to handle the outputs of a diverse set of forest models. From the MOTIVE project, the client is already prepared to link several forest simulators with the ToolBox (e.g. LandClim; Schumacher et al. 2004, PICUS; Seidl et al. 2005, GOTILWA; Cotillas et al. 2009, FinnFor; Pyörälä et al. 2012, 3PG calibrated for Portugal; Fontes et al. 2006), but is not limited to them and can be applied quite universally. The AFM ToolBox data format defines a set of possible forest state and flow attributes as well as metadata providing context information to the numerical simulation outputs (see later).

The ToolBox CMS (“knowledge base”) is an integral part of the ToolBox providing various kinds of “soft” information, but does not directly utilize the ToolBox DataBase (compare Figure 1). The ToolBox Framework provides the necessary technical means for integrating both the tools and the CMS but is not directly visible to the user.

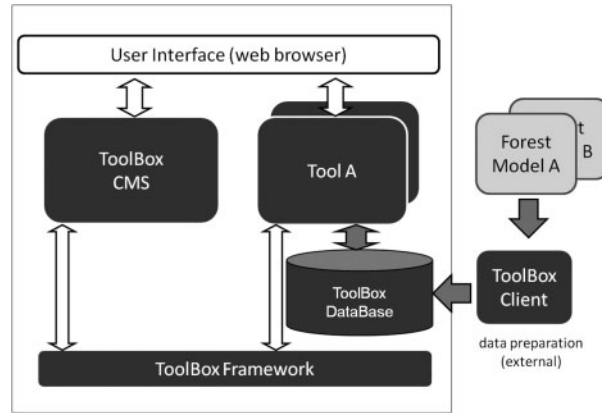


Figure 1. Conceptual scheme of the AFM ToolBox. Gray arrows indicate the flow of data, white arrows indicate interactions. The ToolBox Client serves as interface between external models and data and the AFM ToolBox.

2.3.2. ToolBox DataBase

The data format of the AFM ToolBox DataBase contains two types of data: first, it stores the indicators describing the development of the simulated forest stands. The time resolution is annual or lower (e.g. 10-year periods), and the data is on stand and/or species level (see Table 1). Second, it includes metadata providing context information to the numerical simulation data (see Table 1). The definition of the metadata strives to keep a balance between simplicity and content. As an example, the “site type” is defined using seven attributes (soil type, soil texture, water influence, stoniness, water holding capacity, water supply rating, and nutrient supply rating). Attributes are either numerical (e.g. water holding capacity) or use a predefined classification scheme (e.g. soil texture is either “sandy,” “loamy,” or “clay”). For each data-set (e.g. a case study region), a number of site and stand types can be built using the attributes of the global classification scheme. Additionally, each defined entity can be enriched with textual descriptions. Subsequently, simulation output data is linked to this metadata types. This approach provides flexibility from the perspective of the data provider and it enables automatic processing of the data by the tools in the ToolBox.

2.3.3. CMS and knowledge base

The CMS of the AFM ToolBox is the central starting point providing access to the AFM knowledge base and the means to start the tools of the ToolBox (Figure 2). The knowledge base consists of content coded in html and includes (in the prototype version) a description of the forest management planning process (Mintzberg et al. 1973; Walters & Holling 1990; Rauscher 1999), a collection of FAQs from the AFM domain and a set of case studies from the MOTIVE project. The different types of information are interlinked and provide a consistent picture regarding problem type, assessment outcomes for current management practices, and proposed solutions. In addition, information is tagged based on two archetypical user types (manager/analyst). These user types refer to the different information needs and user demands commonly raised by decision makers. The CMS interprets the tags and allows presenting the content of the knowledgebase in user specific form.

The FAQs aim at the most relevant aspects of climate change (e.g. What will the future climate look like? How uncertain are climate projections?), impacts on forests (e.g. What might the tree species distribution look like under an altered climate? How might climate change

Table 1. Data and metadata types for the AFM ToolBox DataBase.

Data type	Description
Site type	Description of site properties such as soil type, nutrient, and water supply.
Climate	Characterization of the used climate scenario including basic climatic averages.
Stand type	Describes initial forest stand condition (species composition, silvicultural system, age, etc.).
Management	Description of the applied management concept including the regeneration phase.
Forest state	Time series of indicators related to the forest state. Examples are the standing timber, biomass, carbon storage in the soil, but also indicators such as species diversity.
Forest flow	Time series of indicators related to the flows from and to the forest stand (e.g. annual increment, timber harvests, tree mortality, carbon sequestration).
Activities	Time series of management activities.

Note: The forest state, flows, and activities are related to actual simulation results of forest models, while the other types are related to context metadata.

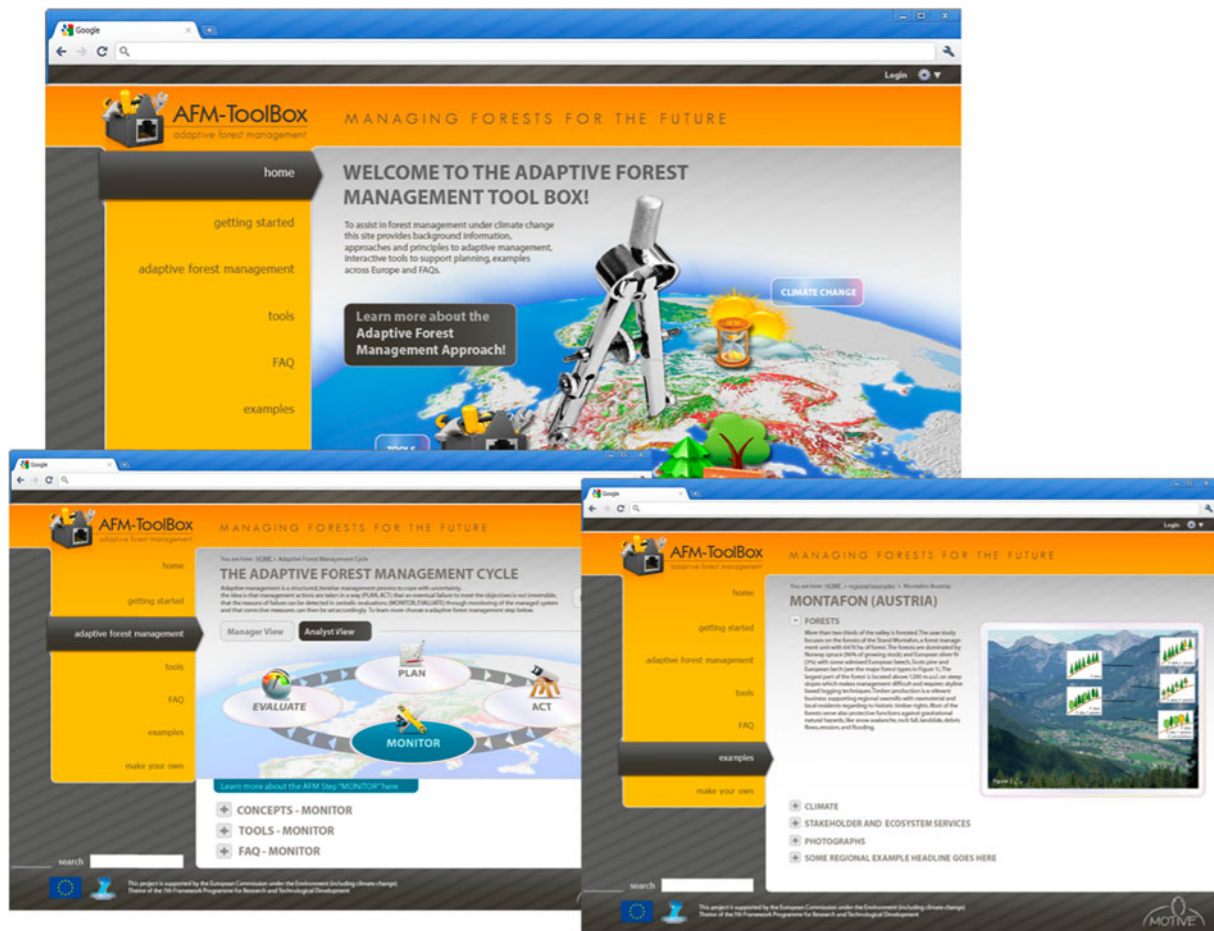


Figure 2. Main page of the AFM ToolBox and access to the knowledge base (here: “Adaptive Management” and “Examples”).

affect the provisioning of ecosystem services?), potential adaptive measures in forest management and silviculture, planning approaches, and how to deal with uncertainty in decision-making. Whenever possible, the content presented in the FAQs is related to contents of the DataBase and recent research findings and networking activities of the involved partners (e.g. MOTIVE project, COST ECHOES on silviculture, and forest management for adaptation and mitigation; <http://echoes.gip-ecofor.org/>).

The set of case studies comprises several detailed, science-based regional examples from all over Europe which have been collected in the context of the MOTIVE project. The examples have been prepared based on a common structure and are thus easy to compare. The contents cover the regional background and its specific challenges, provide options and ultimately recommendations for forest management under climate change, and they give an overview over methodologies and tools that were used in analyzing the case study problem situation.

2.4. Vulnerability assessment tool

2.4.1. Concept

Assessing the vulnerability of ecosystem services under climate change calls, inter alia, for full consideration of climate variability and uncertainty, high degree of stakeholder involvement, integration of ecological and social dimensions, and a focus on adaptation strategies. This is well in line with the holistic systems view advocated by emerging management paradigms such as sustainable forest management. Several conceptual approaches to vulnerability are reported in the literature (e.g. Luers 2005; Fussler & Klein 2006). For the AFM ToolBox, we have used the approach as introduced by Seidl et al. (2011). The vulnerability surface is conceptualized over a rectangular space defined by the dimensions sensitivity and exposure of the system (x -dimension) as well as the systems state regarding adaptive capacity (y -dimension) (Figure 3). Both dimensions are characterized by a set of indicators. The sensitivity indicators represent a set of ecosystem services and are directly retrieved from the DataBase (Section 2.3.1) for

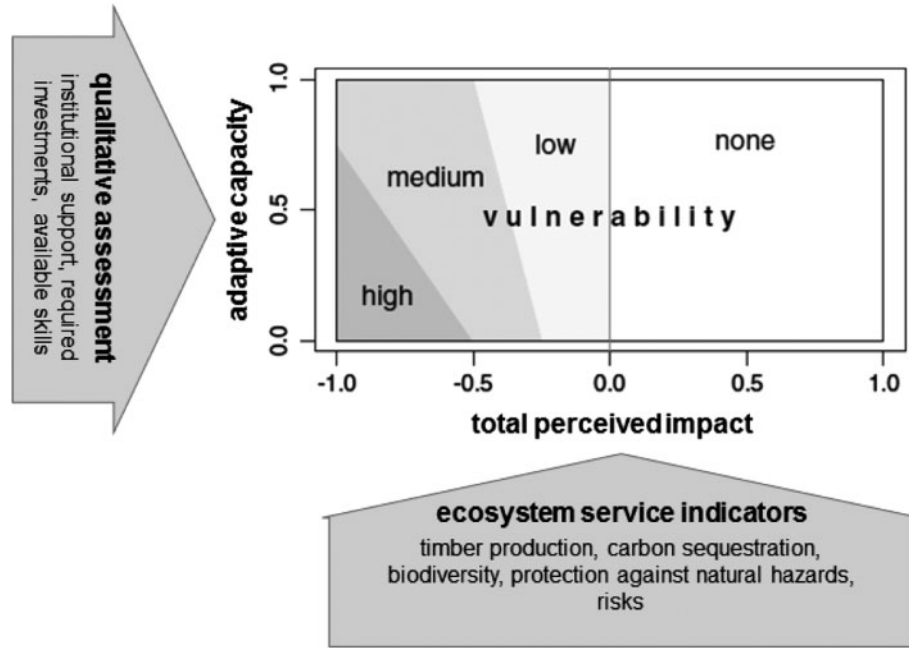


Figure 3. Conceptual representation of the vulnerability surface. The total perceived impact is aggregated from impacts on indicators that are available from forest ecosystem simulations. Values on the y -axis (adaptive capacity) are derived from user input.

each available management alternative. For sensitivity indicators, the difference between indicator value under baseline climate and the respective value under climate change conditions is used to assess the impacts of a changing climate. The indicators for adaptive capacity are qualitative (compare Figure 3). The user has to assess the relevance of each indicator on a scale of three to five predefined qualitative ordinal categories depending on the analyzed problem setting (i.e. none to negligible/moderate/strong for “institutional support”).

The two-dimensional vulnerability surface can be collapsed to a one-dimensional sensitivity index and thus the need to provide user input on adaptive capacity is dropped. To evaluate the sensitivity indicators on a dimensionless scale [0–1], thresholds for recognition and tolerance of an impact must be defined for all indicators. In the manager variant, these thresholds are fixed while the analyst variant of the Vulnerability Assessment Tool (VAT) allows access to advanced features of the tool where thresholds and underlying preference functions which transfer the original measurement scale of the sensitivity indicators into a dimensionless index [0–1] can be adjusted according to specific stakeholder needs. Applying additive value functions from multi-criteria methodology, the indicators can be aggregated at the level of ecosystem services, or across all involved services to yield an overall “multi-functional” vulnerability index. For details, we refer to Seidl et al. (2011) and Lexer and Seidl (2009).

2.4.2. ToolBox implementation

The application of the VAT is split into three general steps (Figure 4): First, the cases for analysis can be selected based on the available metadata in the data-base. For instance, a user may be interested in forest stands that are dominated by beech at sites with a poor water supply. The selection can be further explored in geographical or in biophysical space using an integrated map or via diagrams.

The available indicators in the DataBase are grouped into ecosystem services (e.g. timber production, carbon sequestration, biodiversity) and risks. In the second step, the task of the user is to select relevant ecosystem services and assign weights reflecting the relative importance of the respective indicators.

Step three, the analysis of results, is organized along four predefined questions which respond to typical information needs of forest managers: (1) What is the impact of climate change, when the business-as-usual forest management is continued? (2) What is the impact of climate change, when applying alternative forest management under climate change? (3) What is the effect of switching to alternative (adaptive) management strategies under climate change conditions? (4) What are the risks of shifting to adaptive management when the climate does not change?

The main result is the so-called impact bar displaying the results for the chosen question at the chosen aggregation level (per individual indicator, ecosystem service or full aggregation) of all selected cases on a

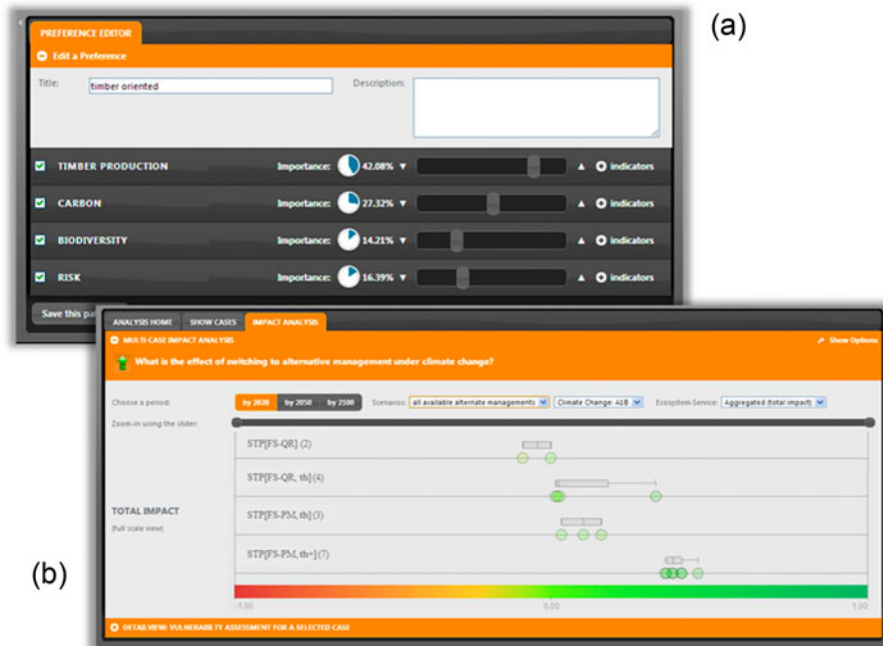


Figure 4. Screens from the main steps of the analysis process with the VAT. The selection of cases (not shown) is followed by the definition of preference patterns (a). The analysis starts with selecting one of four questions (not shown). The impact bars (b) in this example show the expected impact of climate change on ecosystem services under different management scenarios (rows). The green colors of the circles indicate preferable outcome (additional analysis options are not shown here).

scale from -1 (red) to $+1$ (green), where $+1$ indicates fully preferable outcomes. The diagram represents the results for a selected management and climate scenario, and a selected time period. Changing the selection (e.g. switching between the time periods) causes animated transitions of the diagram. Additionally, a vulnerability surface (compare Seidl et al. 2011) contrasting the perceived impact with the adaptive capacity of the forest system is available. Further analysis diagrams for a detailed analysis of single cases are also integrated.

A special feature of the VAT is the “group mode.” Here, a group of users are joined together in a (logical) session working together on an assessment problem. In an iterative Delphi-style approach, the users can express their own preferences for ecosystem services and related indicators, compare them anonymously with the entire group and eventually refine their preferences based on group feedback. The participants in such a session can explore the opinions in the group and how preferences affect the ranking of alternatives. Ultimately, the session ends with the identification of a joint favorite alternative or with the documented contrasting opinions of the participants. Although not required from a technical point of view, our experiences showed that a facilitator providing context information and guidance through the assessment process is key for a successful session. Physical presence of participants also supports the process.

2.5. Optimal management plan

The Optimal Management Plan (OMP) tool has been developed to find an optimal plan for a landscape. This consists of assigning one management option to each stand entity in order to optimize the objective function at landscape scale while meeting the constraints. The set of management options and their outcomes for each stand are stored in the DataBase and have been uploaded by the user.

Generally, forest management models require the generation of mathematical programming matrices to describe the decision problem (e.g. Bettinger et al. 2013). The optimization tool is based on a model generator component (see Falcão & Borges 2005; Garcia-Gonzalo et al. 2013) and a graphical user interface allowing, inter alia, the selection of the eligible management alternatives for each stand type, an easy definition of the objective function as well as the constraints. The model generator component is designed to formulate mixed integer programming (MIP) representations of forest management problems. It is prepared to read outputs from the simulations stored in the database (e.g. harvest volumes) and financial data provided by the user (i.e. interest rate, prices, and costs) to compute the coefficients of all variables in all equations in the model (objective function, the accounting variables, and the constraints). The structure of the files that store the MIP matrices was designed to comply

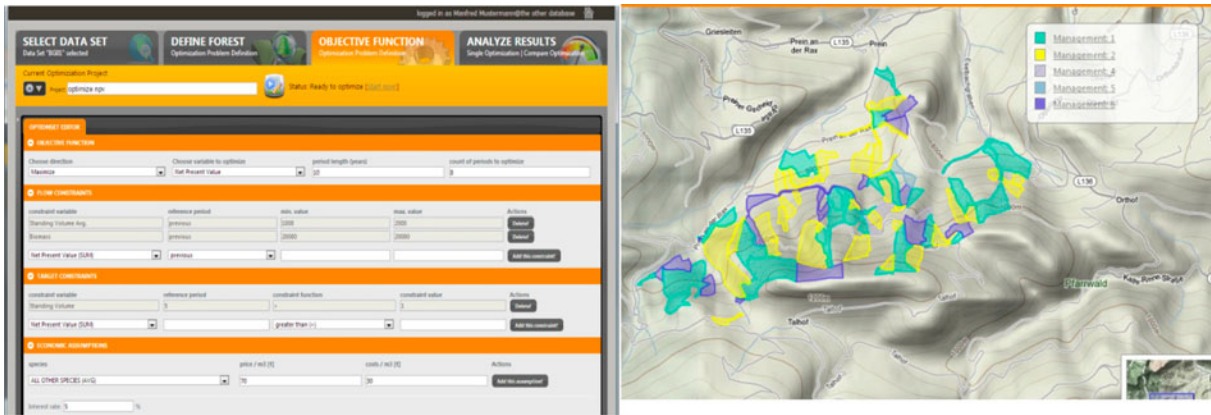


Figure 5. The user can define the objective function, the flow and target constraints as well as several economic parameters for the optimization (left). The optimal assignment of forest management prescriptions can be viewed on a map (right).

with the requirements of the MIP solver. The module is linked to external solvers (the GNU open source MIP solver is used by default but the module is also ready to use Cplex).

In contrast to other tools of the ToolBox, the OMP is considered an expert tool only because the interpretation of the solution proposed by the optimization technique requires some understanding of the methods. Notwithstanding, the graphical user interface of the tool is designed for easy and visually pleasing use (compare Figure 5). The work process is split into four phases: First, the data-set for analysis is selected from a list of available data-sets in the data-base. Typically, a data-set comprises a number of stands which may represent a contiguous region. It further includes all outcomes of forest prescriptions available to manage each stand (previously simulated and uploaded by the user). Second, a specific part of the region (but also the full region) can be specified from a map or a list. Third, the parameters for the optimization process are provided i.e. the tool generates the corresponding MIP model and runs the solver (i.e. performs the optimization). Last, after successfully executing the optimization, the results can be viewed and analyzed.

The parameters for the optimization consist of specifying the objective function as well as flow and target constraints. Additionally, the user can specify the length and number of periods as well as economic parameters such as interest rate or harvesting costs and revenues.

The results of an optimization can be viewed and analyzed as a summary, or in a more detailed table view. The tool also supports the option to visualize results on top of a rendered Google Map (Figure 4). The map view shows the selected prescriptions (for each climate scenario) as colored polygons. The user can also quickly evaluate the effect of different climate-change scenarios on the results of the optimizer: a map shows how many different prescriptions have been selected by the

optimizer for the analyzed climate scenarios, thus highlighting areas with divergent results.

2.6. “Make your own” – customizing the AFM ToolBox

Getting started with the data-driven tools of the AFM ToolBox is simple, because it is web based and comes with ample demonstration data from the MOTIVE project (Figure 6). The AFM ToolBox, however, also supports the use of customized data (i.e. data that is generated by the user or for the user).

Typically, applying up-to-date ecosystem models capable of generating scenario data of forest development under climate change requires high technical skills and an appropriate level of knowledge. Thus, integrating such simulation tools in a DSS which aims at practitioners as end-users would be an inefficient use of limited budget resources. Analysts, on the contrary, are able to handle such complex tools offline. Therefore, it was not an option to integrate forest models directly into the ToolBox. Instead, a harmonized data model (see above) and a DataClient to convert the outputs of different models to the ToolBox data format were developed. The AFM ToolBox client has built-in scripting support, allowing the re-use of custom code for specific forest models.

Full control over all aspects of the AFM ToolBox can be exercised with a local installation of the complete AFM ToolBox either directly on the user’s PC or on a local server. This process is facilitated by a download package of the ToolBox containing all necessary underlying software components and the code for the AFM ToolBox (Figure 6c).

3. Technical implementation

The technical implementation of the AFM ToolBox builds upon on a number of open-source technologies which are frequently used for web development (see

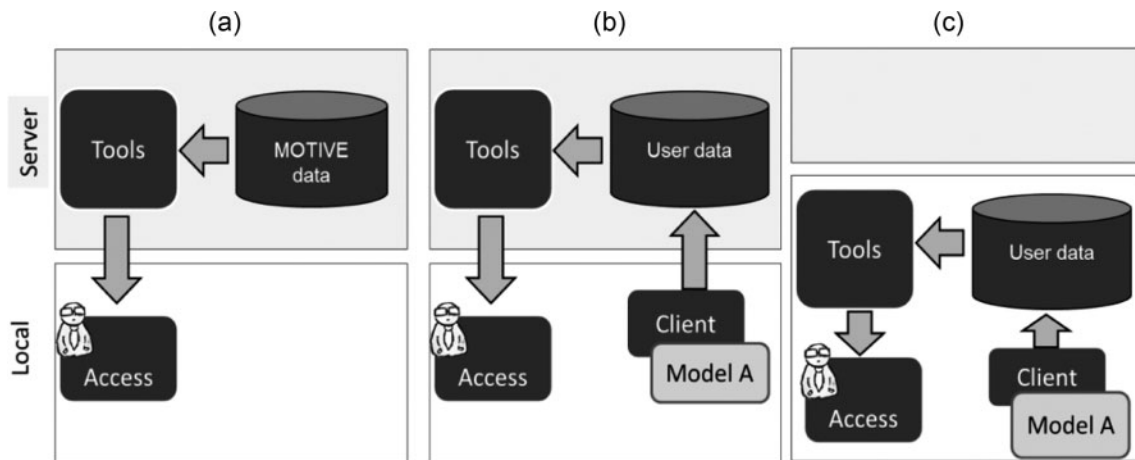


Figure 6. The AFM ToolBox provides three different usage modes with regard to the location and type of the data. In all three cases, the ToolBox is accessed via an Internet browser from the users' local PC. In case (a) ready demonstration data is located on the central server (top panel, gray shaded). Case (b) uses the central AFM ToolBox infrastructure, but with user generated data. Case (c) is a fully local installation with both the data and the tools running locally.

Table 2). Choosing freely available and actually standard technologies has several advantages: (1) development time and costs are low, (2) required technical skills are more wide spread and therefore the barriers for possible adoption by future users are lower, and (3) broadly used technologies tend to have higher life expectancy which is vital for longer lasting projects.

The AFM ToolBox Framework (Figure 1) combines the above-mentioned technologies and provides the technical foundation for the individual tools of the ToolBox. The framework simplifies the process of developing and integrating tools by providing a set of application programming interfaces (API) for database access and database handling, for the administration of user accounts and for persistent storage of tool-specific settings. In addition, the framework comes with a set of user interface controls allowing for a consistent visual appearance across multiple tools of the ToolBox.

The hardware and software requirements for using the MOTIVE AFM ToolBox are modest for just using the ToolBox: here, a typical office PC is sufficient.

Running the server side components requires more processing power and – especially when the optimization tools are used – more memory. Local installation of the AFM ToolBox is currently supported for Microsoft Windows and Linux platforms.

4. Discussion

The MOTIVE ToolBox for AFM under climate change is available as a prototype (<http://afm-toolbox.net/>). No empirical data on user feedback and satisfaction is available yet. So, acceptance of the DSS is still to be proven. However, based on a set of evaluation criteria compiled by the members of the COST Action FORSYS (www.forestDSS.org) in context of the development of guidelines for forest DSSs, the MOTIVE AFM ToolBox approach can be critically assessed (Table 3). Table 4 lists all tools and major functionalities of the current version 1.0 of the AFM ToolBox. It is a balanced set of information, exploration, and analysis components. Knowledge is offered in various forms (background

Table 2. The AFM ToolBox implements numerous open source technologies.

Technology	Description
Webserver (Apache)	Standard web server software on Linux or Windows base operating systems (http://www.apache.org/) (63% of web servers).
MySQL	Server side data base engine (http://www.mysql.com/) used for storing simulation result data and tool specific data.
PHP	Server side programming language (http://php.net/) (80% of websites).
jQuery	Client side Javascript library (http://jquery.com/) used for the user interface (91% market share in Javascript libraries)
processing.js	Javascript library for visual programming (http://processingjs.org/) used for interactive diagrams.
Google Maps API	Mapping technology (https://developers.google.com/maps/) used for maps display.
WordPress	CMS used for the AFM ToolBox website (http://wordpress.org/) (market leader for CMSs).

Note: Statistics on market shares from <http://w3techs.com/> (24.05.2013).

Table 3. Evaluation criteria for decision support tools based on Gray (2001), Menzel et al. (2012), and Vacik et al. (2013).

ID	Criterion	Characterization
(1)	Actively create new knowledge	Allows users to actively create new knowledge if they are aware of a new problem and they are developing novel solutions (e.g. applying the tools, models, and enrich the database with new outcomes...).
(2)	Making knowledge available	Captures and retains knowledge, making it available to users who are seeking solutions to previously solved problems (e.g. using case studies to explore problems, hypertext).
(3)	Increasing transparency	The tool supports the process of increasing transparency (e.g. on the process itself, on the information processed, on the decision-making procedures) on the subject for all stakeholders that are involved in the collaborative planning process (e.g. outsiders interested in the process could benefit, but are not explicitly addressed).
(4)	Gathering interests	The tool has the potential to gather the perceptions and interests of all relevant stakeholders on the subject. It is important to classify whether such information is then stored in the knowledge base or just available during an ongoing session.
(5)	Requires less time in applying	The application of the tool is quick (amount of time needed to apply the tool from users perspective); number of steps to be taken to work with the tool (the less the better).
(6)	Low level of expertise needed	The level of expertise needed to apply the tool is low from user's perspective.
(7)	Flexibility/adapted to different needs	The tool is able to be adjusted to different situations (number of stakeholders, spatial and temporal scale of the study), or changing technologies and management needs; number of parameters to be altered/adapted/specified in problem solving (the more the better).
(8)	Helps to explore/handle uncertainty	The tool allows considering uncertainty (e.g. data, assumptions, and predictions) involved in analyzing/modeling/solving a decision problem.

information, maps, images, documents, examples, FAQs); however, the user cannot customize or enhance the currently available contents of the knowledge base. In designing the functionalities of the ToolBox, no authoring tools have been considered for the online version and no maintenance and quality assurance could be granted. However, it is acknowledged that such interactive functionalities have the potential to increase the acceptance of DSS tools. The VAT has enormous power in the Analyst version, and provides easy-to-use multi-criteria assessment options in the manager's variant. The group decision-making version of the VAT is available in local installation mode only and requires an expert as facilitator to fully utilize its potential. This is an ideal tool to gather preferences of various stakeholders and to create new knowledge by ranking management alternatives according to stakeholder preferences. The

OMP tool provides easy access to advanced MIP methodology with a powerful solver; however, it is actually a tool for analysts and not for practitioners.

Free accessibility via the Internet can definitely be seen as a huge advantage in transferring state-of-the-art knowledge and tools to end-users. The interested user can immediately try the tools and explore the decision space with available data. However, this flexibility and ease of access comes at the cost of not having their own data in the DataBase. To overcome this situation, a user needs to run forest and other models on own data and to upload them to the DataBase, either on the server or after customizing the AFM ToolBox on his/her own desktop computer. Here, it becomes apparent that it is not realistic to assume that all available tools can be operated by a forest manager. For customized toolbox applications very likely, a consultant mode may be the better option.

Table 4. Synthesis of ToolBox tools and major functionalities based on evaluation criteria (see Table 3).

Tool/functionality	Evaluation criteria							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
General information (help, FAQs)	-	-	±	na	+	+	±	±
Case study examples	-	-	±	na	+	+	±	+
VAT (single user)	+	-	+	+	+	+	±	+
VAT (group mode)	+	+	+	+	+	+(*)	+	+
OMP Tool	+	-	-	±	+	-	+	-
DataClient/data generation	na	na	na	na	+	-	±	na
DataViewer	na	na	+	na	+	+	na	na

+: criterion met, -: criterion not met, ±: undecided, na: not applicable, (*): facilitator required.

The way in which facts and scenario analysis output are communicated in textual and graphical form is decisive for the acceptance by the user. For the AFM ToolBox, we have decided to focus on a relatively simple graphical representation in which the user can shift between several graphical variants to explore effects of climate and management on the performance of ecosystem services.

To promote the idea of an adaptive management approach, ample emphasis is on the linkage of the tools and the knowledge base on one hand and the adaptive management cycle on the other. By linking tools and knowledge base to the operational planning and decision-making processes, the AFM ToolBox is promoting the quality of decision-making. Through a better understanding of the pros and cons of different management options, the transparency of the process is increased and a better justification can be given for the performance based on the indicators provided. Optimization is known to be perceived as “black box” by non-expert users. Nevertheless, such tools can generate new alternatives and allow trade-off analysis regarding multiple objectives.

If technical complexity of a decision support process is high (i.e. the use of complex ecosystem models, multi-model simulations, spatial optimization), the cost of technical tool integration and standardization may be prohibitive for a computerized DSS either because the resources and know-how for implementation are not available, or because the use of such advanced tools is too complicated for most potential users. Thus, even if tools are available in the science labs, the transfer into practice via a DSS may be a challenge in itself.

If the procedural complexity of a decision support process is high (e.g. group mode of the VAT), a facilitator may be required to fully utilize the potential of the tool. These two perspectives, technical and procedural complexity, link back to the initial challenge of identifying the DSS user. We strongly believe that several user profiles need to be considered when developing advanced DSS. For the AFM ToolBox, we distinguish the forest manager and the analyst as target users.

Finally, the openness (open source and easy expandability) allows for an extended lifetime of the ToolBox going beyond the development cycles of R&D projects. Any DSS developer can take up the AFM ToolBox and continue, extend, or improve. This can also be seen as a huge advantage for further DSS developments as multi-project time frames required for software production are possible.

The need to focus on targeted audiences for developing successful DSS applications will force decision analysts and researchers to tailor DSSs to end-user needs. The increasing trend toward simple applications and

modularity of tools will support the improved design of new DSS architectures focusing on a collection of loosely coupled tools rather than developing a single highly integrated DSS. Combining various decision support tools that support different phases of the decision-making process and meet different user demands will become therefore an important feature of future DSS projects.

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