

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

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Introduction

The identification and design, selection and implementation of adaptive measures in forest management requires a sound knowledge base as well as tools to support the forest manager. Decision support systems (DSS) are considered as particularly useful for unstructured, ill- and semi-structured decision making problems. Thanks to the recent huge advances in information technology, DSS are nowadays usually computer-based tools that help decision makers through direct interaction with data and analysis models. They are, however, usually built for a specific context and specific decision making procedures, making a broader adoption of DSS into practice difficult.

A typical setting in forest resource management combines one responsible decision maker and a heterogeneous group of stakeholders having a diversity of partly contrasting interests and expectations towards forest management and who are usually not involved formally in decision making processes about forest management. Forest resource planning and decision making deals 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 as inherent uncertainty in planning outcomes increases.

Therefore it is likely that a highly pre-determined decision making process (i.e. the decision model) will not be accepted in this area. 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 any kind of decision makers and stakeholders. However, considering that context specificity and flexibility is a key requirement for acceptance of decision support tools by end users calls for a tool box approach where a diverse set of tools is made available to potential users. A tool box approach was also found to be more suitable for addressing different user and problem types simultaneously.

In the context of the MOTIVE project we set out to design and implement a decision support tool box for adaptive forest management which is based on a thorough analysis of contemporary DSS development activities. The objectives of this contribution are to introduce the conceptual frame of the MOTIVE ToolBox decision support system, and to outline the technical implementation of the ToolBox.

Conceptual frame for DSS development

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 MOTIVE AFM ToolBox.

- (i) **Modularity.** The metaphor of a “tool box” hints 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).
- (ii) **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 adequacy for decision support in a group setting.
- (iii) **Different types of knowledge and information.** The ToolBox should support both interactive, data driven tools and “softer” types of information such as demonstration examples and FAQs. The data for the interactive tools are produced externally using various types of models (e.g., forest ecosystem models, optimization tools).
- (iv) **Different data sources.** The AFM ToolBox offers easy try-out of tools with ready-to-use data from the 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 their problem domain can then invest in preparing own customized data for use with AFM ToolBox tools.
- (v) **Problem types.** The AFM ToolBox in its current version is designed for (a) 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, (b) 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 of the ecosystem service indicators depends on the forest model used.

ToolBox components

ToolBox overview and data flow

The implementation of the AFM ToolBox consists of a “ToolBox Framework” acting as the “shell” for the data driven tools and the ToolBox website with the knowledge base (see Figure 1). The input data for the tools are stored in the ToolBox database.

External forest models are required to simulate forest development in response to management and climate scenarios and to provide performance indicators of different alternatives either directly as model output, via linker functions establishing a relationship between model output and a suitable ecosystem service indicator, or to feed other specialized models of ecosystem services with forest structure and composition. Such raw data are transferred to the database by a special tool, the AFM ToolBox client (see Figure 1). The client is highly customizable and has the ability to handle the outputs of a diverse set of forest models (e.g., LandClim or PICUS).

ToolBox database

The data format of the AFM ToolBox database contains two types of data: on the one hand, 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). On the other hand, it includes metadata providing context information to the numerical simulation data (see Table 1). As an example, the “site type” is defined using seven attributes (soil type, soil texture, water influence, stoniness, water holding

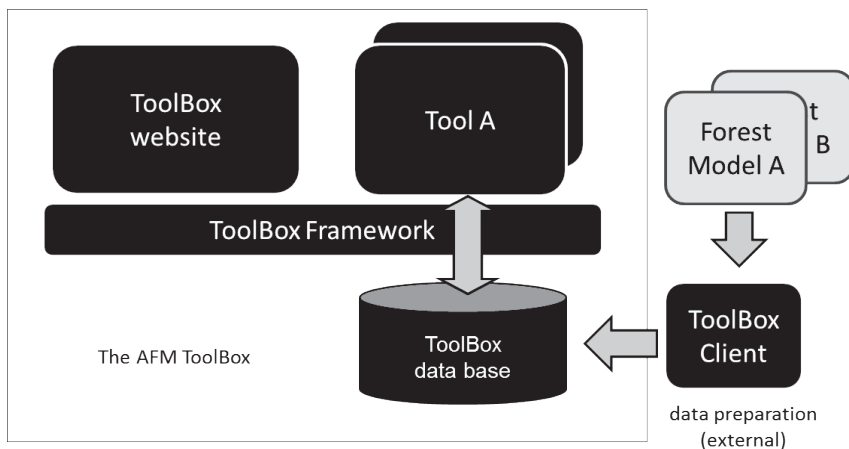


Figure 1. Conceptual scheme of the AFM ToolBox. Arrows indicate the flow of data.

Table 1. Several data and metadata types for the AFM ToolBox database. The forest state, flows and activities are related to actual simulation results, while the other types are related to context metadata.

Data type	Description
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.
Site type	Description of site properties such as soil type, nutrient and water supply
Stand type	Describes initial forest stand condition (species composition, silvicultural system, age, ...).
Climate	Characterization of the used climate scenario including basic climatic averages.
Management	Description of the applied management concept including the regeneration phase.

capacity, water supply rating, nutrient supply rating). Attributes are either numerical (e.g., water holding capacity) or use a pre-defined classification scheme (e.g., soil texture is either “sandy”, “loamy”, or “clay”). Subsequently, simulation output data is linked to these 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.

Knowledge base

The AFM ToolBox website is the central start page providing access to the AFM knowledge base and the means to start the tools of the ToolBox (Figure 2). The main elements of the knowledge base are a conceptual description of the forest management planning process (Rauscher 1999), a collection of FAQs from the adaptive forest management domain and a set of case study examples from the MOTIVE project. The different types of information are intensively interlinked. In addition, information is tagged based on two archetypic user types (manager/analyst).

The FAQs aim at the most relevant aspects of climate change (How will the future climate look like?), impacts on forests (How may tree species distribution look like under an altered climate?), potential adaptive measures in forest management and silviculture, planning approaches, and how to deal with uncertainty in climate projections. Whenever possible, the knowledge base integrates data from recent research and networking activities (e.g. COST ECHOES on silviculture and forest management for adaptation and mitigation).

The case study examples comprise of several detailed, science-based regional examples from all over Europe which were collected in the MOTIVE project. The examples have been prepared so as to share a common structure and are thus easily comparable. The contents cover the regional background and its specific challenges, provide options and 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.



Figure 2. Main page of the AFM ToolBox and access to “Adaptive Management” and “Examples”.

Vulnerability assessment tool

For the AFM ToolBox we have used the vulnerability approach as introduced by Seidl et al. (2011). Sensitivity to impacts and adaptive capacity of forests are placed on a two dimensional surface and are characterized by a set of indicators. The sensitivity indicators represent a set of ecosystem services and are stored in the database for each available management alternative. The indicators for adaptive capacity are qualitative and need to be provided by the user of the tool. For sensitivity indicators the difference between indicator value under baseline climate and the respective value under a climate change scenario is employed in the vulnerability assessment.

The application of the vulnerability assessment tool is split into three general steps: First, the cases for analysis are selected. Secondly, the value-based preferences of the user or user group are defined, and the third step is the interactive analysis of the results.

The cases for analysis can be selected based on the available metadata in the database. 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 using an integrated map or via diagrams. In the second step, the task of the user is to select relevant ecosystem services and assign weights reflecting the relative subjective importance of the indicator/ ecosystem service.

Finally, the results can be visually analyzed using interactive diagrams that provide insight into the perceived impacts of management and climate scenarios and their relation to the adaptive capacity of the forests. Additional analysis diagrams for a detailed analysis of single cases are available.

A special feature of the vulnerability assessment tool is the “group mode”. Here, a facilitator works together with a group of stakeholders on an assessment problem.

Optimal Management Plan

The Optimal Management Plan tool (OMP) tool assigns one of the available management options to each stand entity to optimize the objective function at landscape level while meeting constraints (e.g. even flow constraints). This tool is designed to formulate forest management problems in mixed integer programming (MIP) (see Falcão and Borges (2005), Garcia-Gonzalo et al. (2013)). Further it presents a graphical user interface allowing an easy definition of the objective function as well as the constraints.

In contrast to other tools of the ToolBox, the OMP is considered as an expert tool only, because the application of optimization technique per se requires some profound knowledge of the methods. Notwithstanding, the graphical user interface of the tool is designed for easy and visually pleasing use.

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 database. Typically, a data set is a region comprising of forest stands. 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. They consist of an objective function (the variable to maximize or to minimize) as well as flow and target constraints. Additionally, the user can specifies economic parameters such as interest rate or harvesting costs and revenues.

And fourth, the results of an optimization can be viewed and analyzed as a summary, or as more detailed table view. The tool also contains an option to visualize results on top of a Google Maps rendered map.

”Make your own” – Customizing the AFMToolBox

Getting started with the data driven tools of the AFM ToolBox is simple, since it is web based and comes with ample demonstration data from the MOTIVE project. The AFM ToolBox, however, supports also the use of customized data (i.e., data that is generated by the user or for the user). Full control over all aspects of the AFM ToolBox can be exercised

Table 2. Synthesis of AFM ToolBox tools and major functionalities.

Tool/ functionality	Type	Data source	Manager/Analyst	Participatory
General information, FAQs	Info	Scientific literature, experts	M/A	No
Case study examples	Info	MOTIVE case study reports	M/A	No
Vulnerability Assessment tool (single user)	interactive	MOTIVE data; user data	M/A	No
Vulnerability Assessment tool (group mode)	Interactive	MOTIVE data; user data	M/A	Yes
MIP optimizer tool	Interactive	MOTIVE data; user data	A	No
Data client / data generation	Data	NA	A	No
Data viewer	Data	NA	A	No

with a local installation of the complete AFM ToolBox either directly to 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.

Technically, the AFM ToolBox builds upon on a number of open source technologies which are frequently used for web development. Since the ToolBox components are open source itself, it can easily be extended or modified by interested parties. Currently, the AFM ToolBox is can be locally installed on Microsoft Windows or Linux platforms.

Discussion and Outlook

Table 2 lists all tools and major functionalities of the MOTIVE AFM ToolBox. It is a balanced set of information, exploration and analysis components. For the AFM ToolBox we have decided to focus on relatively simple graphical representation where the user can shift between several graphical variants to explore effects of climate and management on ecosystem service performance. To promote the idea of an adaptive management approach and to improve the quality of decision making, ample emphasis is on the interlinkage of the tools and the knowledge base.

What are the limitations and the benefits of the current version? Free accessibility via the internet can definitely be seen as a huge advantage in transferring state of the art knowledge and tools to endusers.

However, this flexibility easily masks the fact, that the users have not per se access to analyze their own data. The provisioning of own data is technically challenging (operating simulation models and other tools) and very likely beyond the scope of the typical forest manager. In this case, consultancy is indicated to overcome the technical complexity. If, on the other hand, the procedural complexity of a decision support process is high (e.g. group mode of the Vulnerability Assessment tool) a facilitator may be required to fully utilize the potential of the tool.

These two perspectives link back to the initial challenge of implementing decision support systems. 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 (use of open source and easy extensibility) allows for an extended life time of the ToolBox. Any DSS developer can take up the AFM ToolBox and continue, extend or improve. Future planned developments include new tools (spatially explicit analysis).

References

- Falcão, A. and Borges, J.G. 2005. Designing decision support tools for Mediterranean forest ecosystems management: a case study in Portugal. *Annals of Forest Science* 62: 751–760.
- Garcia-Gonzalo, J., Palma, J., Freire, J., Tomé, M., Mateus, R., Luiz Carlos, E. R., Bushenkov, V. and Borges, J.G. 2013. A decision support system for a multi stakeholder's decision process in a Portuguese National Forest. *Forest Systems*. (In print).
- Rauscher, H.M. 1999. Ecosystem management decision support for federal forests of the United States: a review. *Forest Ecology and Management* 114: 173–197.
- Seid, R., Rammer, W. and Lexer, M.J. 2010. Climate change vulnerability of sustainable forest management in the Eastern Alps. *Climatic Change* 106: 225–254.