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Review. Supporting problem structuring with computer-based tools in participatory forest planning

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Abstract

Aim of study: This review presents the state-of-art of using computerized techniques for problem structuring (PS) in participatory forest planning. Frequency and modes of using different computerized tool types and their contribution for planning processes as well as critical observations are described, followed by recommendations on how to better integrate PS with the use of forest decision support systems.

Area of study: The reviewed research cases are from Asia, Europe, North-America, Africa and Australia.

Material and methods: Via Scopus search and screening of abstracts, 32 research articles from years 2002-2011 were selected for review. Explicit and implicit evidence of using computerized tools for PS was recorded and assessed with content-driven qualitative analysis.

Main results: GIS and forest-specific simulation tools were the most prevalent software types whereas cognitive modelling software and spreadsheet and calculation tools were less frequently used, followed by multi-criteria and interactive tools. The typical use type was to provide outputs of simulation–optimization or spatial analysis to negotiation situations or to compile summaries or illustrations afterwards; using software during group negotiation to foster interaction was observed only in a few cases.

Research highlights: Expertise in both decision support systems and group learning is needed to better integrate PS and computerized decision analysis. From the knowledge management perspective, it is recommended to consider how the results of PS —*e.g.* conceptual models— could be stored into a problem perception database, and how PS and decision making could be streamlined by retrievals from such systems.

Key words: facilitated modelling; group negotiation; knowledge management; natural resource management; PSM; soft OR; stakeholders.

Introduction

Challenges in defining and modelling decision problems

Contemporary forest management and wider natural resources management at various geographical and temporal levels of decision-making typically faces the challenge of multiple objectives as well as multiple stakeholders. These decision tasks are messy *i.e.* "wicked" by nature (Churchman, 1967), which means complex interdependencies and no ways to give a simple formulation of the problem. Applying ordinary decision analytic structures (*e.g.* hierarchical decision trees) works with problem situations that are clearly defined, but messy problems require investigating the complex system structures more thoroughly (Ackoff, 1974; Steyaert and Jiggins, 2007). The endeavor of collaboratively constructing a joint understanding about the messy planning problem at hand is called problem structuring (PS), for which various problem structuring methods (PSMs) have been developed in the field of operational research (Woolley and Pidd, 1981; Rosenhead, 1989; Mingers and Rosenhead, 2004; Rosenhead, 2006). Essentially, PS means collecting and systematizing the stakeholders' (or their representatives') perceptions of the decision problem for use in the other phases of the decision analysis with the aid of a systemic view and appreciation of different factual systems and varying internal structures of participants' problem perceptions (Rosenhead, 2006). In the planning-pro-

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cess triangle of problem identification, problem modelling and problem solving, as defined by Martins and Borges (2007), PS mainly falls within the problem modelling part and partly within the problem identification part (see Khadka *et al.*, 2013).

On one hand PS can contribute to the conceptual design of decision support systems (DSS)'s through the interactive discussion of decision analysts, IT-specialists, modellers and decision makers (see *e.g.* Marques *et al.*, 2011). Here the use of PS tools and techniques can facilitate the DSS development process in determination of the different perceptions and requirements of the decision problem. Otherwise well-organized PS may offer several important benefits for the application of forest management DSS, for example: improving the role of local knowledge, stakeholders' feel of control over the problem, and commitment to decisions (Franco, 2007). The computer-based support for PS allows screening the assumptions leading to problem modelling and problem solving, which increases documentation and transparency of the process.

Typically PS involves facilitated group model building and concurrent social learning (Andersen *et al.,* 2007). A sound problem description, which precedes the selection of a decision model, is qualitative by nature: from the perspective of easy participation, decision-makers and/or stakeholders should be granted the power to expose their perception of the decision problem using their own concepts and interpretations. On the other hand, rigorous multi-attribute computational decision support tools utilizing quantitative data may help stakeholder groups to determine inevitable trade-offs between important criteria, and thus help to understand or learn about a decision problem (Andersen *et al.*, 2007; Pykäläinen *et al.*, 2007). Thus PS may well involve the use of computational methods and computerized tools.

However, it has to be acknowledged that the process of PS in forest management involves sharing of knowledge of two kinds: *objective knowledge* based on data and their analysis in a systematic manner, and a type of *implicit knowledge* or understanding derived from personal or organizational experiences, trial and error (Allen *et al.*, 2002) and learning by doing in an adaptive management environment (Khadka and Vacik, 2008). Participatory modelling techniques try to compensate for and respond to a strong tendency to overemphasize authoritative forms of scientific knowledge such as numeric output generated by computer models. This emphasis often occurs at the cost of more tacit and informal forms of knowledge. A mutual learning process for selecting and adapting appropriate models to working with the forest management planning problem at hand is thus proposed to overcome barriers between modellers and stakeholders in the planning process (Siebenhüner and Barth, 2005). In "ideal" PS, the qualitative social process of group negotiation is therefore seamlessly linked with quantitative decision analysis techniques of computerized decision support systems in a way that supports different knowledge types (Kotiadis and Mingers, 2006; Keys, 2007; Montibeller *et al.*, 2006). In other words, PS can be a mixed-methods endeavor with consideration of blended knowledge forms.

Mingers and Rosenhead (2004) group the various PS methods as Strategic Options Development and Analysis SODA (Belton and Stewart, 2002), Soft Systems Methodology SSM (Winter, 2006), Strategic Choice Approach (Friend and Hickling, 2005), Robustness Analysis (Wong, 2007), Drama Theory (Bryant, 2007), Viable Systems Models (Pollalis and Dimitriou, 2008), Systems Dynamics (Assimakopoulos *et al.*, 2006), and Decision Conferencing (Phillips, 2007). In this paper however, we point out that facilitated conceptual modelling (*i.e.* problem structuring) may be conducted either with or without these explicitly named "problem structuring methods" (PSMs). To reach iterative operation and incremental improvements —essential elements of PS according to Mingers and Rosenhead (2004)— computerized tools may be useful because of their ability to store, retrieve, display and modify knowledge produced in group negotiation.

Characteristics and benefits of using computerized tools in problem structuring

This section describes some historical viewpoints as well as aims and benefits of the following six classes of computerized tools that are potentially usable in PS:

i) Spreadsheet tools.
ii) Specific modelling tools.
iii) GIS tools.
iv) Multi-criteria decision making tools.
v) Cognitive modelling tools.
vi) Interactive planning tools.

i) Starting from the early 1950s, electronic data-processing systems have been used to organize, query and store data. Advances in the development of database and management information systems allowed the analysis and reporting of the current state of a system in various forms. Spreadsheet tools provide different functions to answer statistical, engineering and financial needs. In addition they allow displaying data as line graphs, histograms and charts and analyzing relationships between data sets for the needs of a stakeholder group. The user can employ a variety of numerical methods and modify the graphical interface to design custom-made computer programs. Through its common and frequent use in day-to-day business, tools that make use of the basic functionality are often easy to use (Miller *et al*., 1990; Pedersen *et al*., 2007).

ii) Progress in the field of artificial intelligence in the 1960-70s (*e.g.* Zadeh, 1973) fostered the development of expert systems and specific modelling tools. The rise of ecosystem modelling, with a growing number of simulation models available (*e.g.* CAPSIS), allowed predicting possible future states of natural resources under changing environmental conditions (De Coligny *et al*., 2003). Forest growth and ecosystem models are important to investigate and understand key ecosystem processes, and to support forest management decision processes, in particular by providing meaningful background information for group negotiation in which different perspectives, objectives and risk perspectives are contemplated. Experiences with forest simulators for various purposes in different geographical contexts illustrate how forest management problems are addressed through offering spatially explicit approaches at the landscape scale, and integrating empirical and mechanistic models in hybrid simulation approaches (Chertov *et al.*, 1999; Bugmann, 2001).

iii) New demands in participatory planning have led to the further evolution of computer-based tools by addressing spatial issues to meet communication and collaboration needs. A geographic information system (GIS) is designed to capture, store, manipulate, analyze, manage and present all types of geographical and non-geographical data (Burrough and McDonnel, 1998). GIS packages (*e.g.* ArcGIS™, Idrisi™, Quantum GIS) and other visualization tools are increasingly including analytical tools as standard built-in facilities or as optional toolsets for spatial analysis (*e.g.* buffer analysis, overlays, slope and aspect, geostatistics). The growing competition in the GIS market has resulted in lower costs and continuous improvements; currently location-based services (LBS) and web mapping give broad public access to huge amounts of geographic data. The combined use of web-mapping services can also assist with the rapid registration of many opinions directly to computer memory (Kangas and Store, 2003; Tress and Tress, 2003). These developments have influenced the way in which participatory planning processes are designed and implemented. Public participation geographic information systems (PPGIS) are an increasingly important tool for collecting spatial information about the social attributes of place (Brown and Reed, 2012; Pocewicz *et al*., 2012). This information can be viewed, updated and used to direct discussion to essential matters in subsequent stakeholder group meetings focusing on PS.

iv) Different schools of thought have developed a number of tools for addressing multi-criteria decision making (MCDM) problems. These types of computer-based tools mostly support the decomposition of the planning problem, the description and definition of decision criteria and alternatives (*e.g.* Super Decisions, Expert Choice, D-Sight, PROMETHEE-GAIA). Depending on the MCDM, the process of preference elicitation and criteria weighting is supported in various ways. The potential benefits of such tools for PS are linked to the fast calculation of results and the large opportunities for scenario analysis, thus allowing a deeper understanding of the causes for good or bad performance of decision alternatives (Cil *et al*., 2005).

v) Cognitive modelling tools (*e.g.* Decision Explorer, STELLA, CIMAT, Mind Manager, Co-View software) are used to support the process of PS. Cognitive maps represent complex decision problems composed of dynamic entities which are interrelated in complex ways, usually including feedback links (see Harary *et al.*, 1965; Eden, 2004). In some cases, the relationships are described in terms of causalities between connected nodes. Computer tools supporting the process of designing such maps aid the decision analyst in defining the concepts and linkages, and support the analysis of the domain or centrality of such complex items (Wolfslehner and Vacik, 2011). Such approaches help facilitators to articulate and explore a shared vision of the future and to develop a common understanding in natural resource management (Mendoza and Prabhu, 2006).

vi) A collaborative forest planning process may include prioritizing local issues, integrating local knowledge, developing scenarios, and reviewing visualizations in an interactive manner. The level of engagement with local citizens and stakeholders impacts the time and resources required. Several interactive planning tools (*e.g.* multi-agent systems (MAS), role play programs) have been developed to support that effort.

Mostly a MAS application allows representing knowledge and reasoning of several heterogeneous agents when addressing planning problems in a collaborative way. For example, CORMAS (Common-pool Resources and Multi-Agent Systems) has been developed to provide a multi-agent framework that can be used to simulate the interactions between a group of agents and a shared environment holding natural resources (Le Page *et al*., 2000). Other approaches integrate the use of various modelling and visualization tools (*e.g.* CALP visualisation software) with workshops and extensive community planning exercises in order to support discussion among stakeholders, practitioners and decision-makers on sustainability challenges in their communities (Lange and Bishop, 2005).

Objectives

Following the above-described framework of computerized PS, this study reviews the actual use of computerized tools within PS in participatory forest planning research cases from 2002-2011 worldwide. Frequency and modes of using different computerized tool types and their contribution for planning processes as well as critical observations are described. Based on review results, recommendations for integrating PS into forest management decision support systems are addressed.

Material and methods

Data

Via two separate title + keyword searches in Scopus (www.scopus.com) and screening of 245 yielded abstracts, 32 participatory forest planning research cases involving direct stakeholder interaction from years 2002-2011 were selected for review. For details of keyword search terms and article selection procedure, see Appendix 1. Table 1 presents the authors and publication years as well as the case study domains of the reviewed articles. Full references of the study material are presented in the references list.

Analysis

Each article was scanned and explicit and implicit evidence of using computerized tools for the purposes of PS was recorded. Names of computerized tools were noted when applicable, and the tools were classified according to the typology presented in "Characteristics and benefits of using computerized tools in problem structuring" above. Further, the modes of using the tools were identified as before, during, and after the actual stakeholder negotiation. One of the present authors conducted these classification interpretations, and another author verified the results. Finally, the reported benefits and observed critical viewpoints of using the software for supporting PS were distinguished and condensed using a data-driven qualitative analysis approach (Boyatzis, 1998) and a criteria-based spreadsheet analysis.

Results

Software types use modes

The review shows that forest-specific modelling software and GIS were most frequently used in the context of PS (Table 2). The forest-specific modelling software was typically a simulation tool that was used to create scenarios and discuss the results of an analysis in the stakeholder group (*e.g.* Sturtevant *et al*., 2007; Simpson and Gooding, 2008; Sandker *et al*., 2009). GIS software was usually applied in a similar manner, *i.e.* to provide displays to facilitate discussions (Sisk *et al*., 2006; Sapic *et al*., 2009; He *et al*., 2011).

Spreadsheet and calculation tools were used along with other tools to keep record of participants' inputs such as importance scores in workshop tasks (*e.g.* Mendoza *et al*., 2002; Mendoza and Prabhu, 2003). In some cases, the workshop outputs made with manual tools like flipcharts and pens were later digitized and further analyzed with spreadsheets and other software (*e.g.* Purnomo *et al*., 2005a); another use type was to gather information with interviews and use spreadsheets etc. to classify and display information for evaluation in the stakeholder group (Fraser *et al*., 2006). Cognitive modelling tools were used to illustrate the outputs and gather feedback in a more structured way (Hjortsø, 2004) or to foster collaboration when creating cognitive maps (Mendoza and Prabhu, 2006; Salerno *et al*., 2010).

Interactive tools were used mainly in the context of PSMs when PS took place in its pure sense. These occasions applied MAS (Purnomo *et al*., 2005b) to

Table 1. The reviewed articles

ID	Authors	Year	Domain/problem field	ID	Authors	Year	Domain/problem field
1	Mendoza *et al.*	2002	Sustainable forestry	17	Baskent *et al.*	2008b	Multiple-use forest management planning
2	Mendoza and Prabhu	2003	Sustainable forest resource management	18	McIntyre *et al.*	2008	Recreation on Crown lands
3	Purnomo *et al.*	2003	Forest management	19	Simpson and Gooding	2008	Forest planning
4	Hjortsø	2004	Tactical planning of public forests	20	Campo *et al.*	2009	Community forest management
5	Seely *et al.*	2004	Multi-objective forest management	21	Kassa *et al.*	2009	Participatory forest management
6	Mendoza and Prabhu	2005	Community-based forest management	22	Sandker *et al.*	2009	Integrated conservation and development
7	Purnomo *et al.*	2005a	Sustainable forest management	23	Sapic *et al.*	2009	Forest management planning
8	Purnomo *et al.*	2005b	Forest management unit level	24	Suwarno *et al.*	2009	Community based forest management
9	Fraser *et al.*	2006	Forest management, rangeland management and development of sustainability indicators	25	Leys and Vanclay	2010	Plantation forestry expansion
10	Mendoza and Prabhu	2006	Forest management	26	Nordström *et al.*	2010	Forest planning
11	Mutimukuru *et al.*	2006	Joint forest management	27	Ruankaew *et al.*	2010	Integrated renewable resource management
12	Sisk *et al.*	2006	Restoration of ecosystems	28	Salerno *et al.*	2010	National park and buffer zone
13	Lin and Feng	2007	Strategic forest planning	29	Simon and Etienne	2010	Forest management planning
14	Pykäläinen *et al.*	2007	Strategic forest planning	30	He *et al.*	2011	Commercialized wild mushoroom
15	Sturtevant *et al.*	2007	Sustainable forest management planning	31	Mustajoki *et al.*	2011	Sustainable use of forests
16	Baskent *et al.*	2008a	Forest management planning	32	Seidl *et al.*	2011	Sustainable forest management

Table 2. Types of software used in problem structuring

Software type	Number of cases (of 32)
GIS and visualisation	9
Spreadsheet and calculation	7
MCDM	5
Cognitive modelling	7
Interactive	5
Specific modelling	12
No software use reported	2

model the perspectives of the relevant actors, drama-theory-based role plays to take perspectives and experiment with hypothetical scenarios (Campo *et al*., 2009). "Companion modelling", a combination of these two approaches was applied as the third type of interactive tools (Ruankaew *et al*., 2010). Like spreadsheets, MCDM tools were typically not used alone but together with other types of tools such as GIS and cognitive modelling tools (Mendoza and Prabhu, 2005; Nordström *et al*., 2010; He *et al*., 2011). In some cases, some type of sophisticated group modelling was con-

Table 3. Modes of using software in context of problem structuring

Software use mode	Number of cases (of 32)
Before group negotiation	20
During group negotiation	14
After group negotiation	23
Before, during and after group negotiation	8

ducted, but the study reports do not specify in detail whether any software was used to support negotiation (*e.g.* Purnomo *et al*., 2003), although it is rather evident that at least some software must have been used to summarize and digitize the outputs of the workshop for further use in the planning process.

The distribution of the modes of using software in PS reveals that in most of the reviewed forest planning studies software is not used during group negotiation (Table 3) but rather either before or after the workshop activity. Of the 32 reviewed articles, 8 had software for PS before, during, and after stakeholder negotiation. A common feature of these studies was that they all emphasized participants' collaborative or iterative exploration of the decision situation (*e.g.* Mendoza and Prabhu, 2006; Sapic *et al*., 2009; Simon and Etienne, 2010).

Observed alternatives to support problem structuring with software

To further illustrate the various uses and observed potential of different software types in supporting PS, one exemplary case from each of the six software categories presented in Section "Characteristics and benefits of using computerized tools in problem structuring" was selected. The selection was done subjectively for illustrative purposes so that the variety of software uses in forest-planning PS could be explicated. The following section presents the examples and gives short narratives of software usage, including recognized benefits and observed limitations.

i) *GIS and visualisation tools* (Baskent *et al.,* 2008a)

The ecosystem-based multiple use forest management (ETÇAP) approach provided basic socio-cultural information for authorities, created awareness of forest stewardship among local stakeholders, enabled accommodating multiple values in the plans, and allowed a screening of impacts. Both satellite imagery and GIS technologies (Arc/INFO) were heavily used in the case process in northeastern Turkey. The role of GIS software was here to inform a broader audience and frame the discussions, as well as to initialise participatory problem definition and structuring.

Despite the general success of the ETÇAP process, some weaknesses were noted. For instance, the participation process failed to provide follow up meetings and any analytical measure of the performance of the participation process for exploring new possibilities. Although the process was developed in the absence of growth and yield models, various silvicultural options were explored and certain strategic lines of action could be agreed upon between authorities, local villagers and NGOs. The evaluation indicated that trust in the planning process is critical, and learning about the highly technical planning process is vital. Further, responsiveness to local conditions and local stakeholder interactions are pivotal to the cooperation between the agency and the stakeholders (Baskent *et al*., 2008a).

ii) *Spreadsheet and calculation tools* (Pykäläinen *et al.,* 2007)

Interactive utility analysis (IUA) was applied in the negotiation meetings of stakeholder groups for natural resource planning of Finnish state forests. The aim of using spreadsheet and calculation software (Excel) was to sum participants' voting scores of decision criteria, to discuss and modify sub-utility models and thus to learn about each other's objectives, trade-offs between decision criteria as well as the overall production possibilities of the planning region.

The IUA process included reformulating the utility function (weights and sub-utility functions) several times and calculating the corresponding sub-utilities and total utilities produced by the different alternatives. The planning consultant used a computer and the stakeholders and staff asked the consultant to make different kind of analyses. The IUA method, combined with voting methods, effectively promoted the participants' learning process, without excessively violating the participants' preferred iteration styles. This kind of PS process made it easier for participants to write-down their final statements in formulating the decision proposal. The procedure necessitated the use of simulation software to provide alternative forest plans in advance, but the spreadsheet tool adaptively facilitated the group process.

iii) *MCDM tools* (Seidl *et al.,* 2011)

In a vulnerability assessment framework, the study applied ecosystem modelling combined with participatory MCDM in a case concerning Austrian federal forests. The PS phase related on one hand to forming operational stand treatment programs for selected planning units and target species compositions and on the other hand to select vulnerability indicators and analyse their sensitivity. The latter task was done with the aid of PROMETHEE preference functions and input elicited from a stakeholder panel.

In this particular case, the role of stakeholder participants was limited given that the overall frame of analysis was pre-determined. However, from the PS perspective, the workshop and stakeholder panel outputs had an important impact on the outcome of the whole process. It added participatory elements to the modelling framework and helped understand the model structure corresponding to the management problems, which included the use of the PICUS ecosystem model as well as further computerized vulnerability analysis. The procedure enabled the combination and communication of scientific and practical knowledge as well as integration of social and ecological expertise. The MCDM software enabled that in intelligible way.

iv) *Cognitive modelling tools: decision explorer* (Hjortsø, 2004)

One distinguished PSM approach, SODA (Strategic Option Development and Analysis), containing cognitive mapping (Eden, 2004), was used in a tactical planning process of a public forest area in Denmark. Members of a diverse stakeholder group were interviewed individually and in small groups to generate cognitive maps of important aspects within the planning situation. Decision Explorer software was used to develop and display the maps and elicit feedback from the interviewees. A merged map was generated to mediate further discussion in the larger stakeholder group about the planning case.

According to the feedback, the cognitive mapping process led to a richer view of the situation than could have been acquired with individual interviews. Awareness of the complexity increased among the stakeholders, and the planning agency learned about some stakeholders' detailed views. Most of the knowledge generated was already known, but with the aid of cognitive mapping some of the previous implicit knowledge had become explicit.

The stakeholders praised the ability of graphical representations to show relationships between concepts and improve understanding of the problem. Thus, the mapping exercise worked as a PS method and provided a starting point for group negotiations. It stimulated a more active involvement of participants in the planning process. However, some stakeholders perceived difficulties in reading the maps that they had not generated themselves. Thus, it was important that the facilitator paid attention to simplicity and generating a common understanding.

v) *Interactive tools* (Campo *et al.,* 2009)

"Companion modelling" (Barreteau, 2003) enables enquiry into the complex interactions among stakeholders as well as a collaborative model building by stakeholders and researchers. In many ways, the approach represents the most advanced form of PS. It follows the idea of MAS, which recognizes various goals of the stakeholders, their mutual communication and varying representations of each other and the problem situation (Woolridge, 2009). Companion modelling includes the use of drama theory (Bryant, 2007) in the form of role-playing games and, essentially, iterative computer simulations and negotiations to enable learning and model validation.

In this case, the approach was applied within community forest management in the Philippines. Role-playing games, in which the participants competed for a hypothetical geographical natural resource, were visualized with specific computerized illustrations using Chering role-play programme (see Campo *et al.*, 2009, p: 3611). The constructed systemic model about the livelihood activities of the local communities and their impact on the natural resources was illustrated to the workshop participants as UML (universal modelling language) class diagrams (see Campo *et al.*, 2009, p: 3612).

The approach proved promising engagement and learning among the stakeholders. All this made the model validation more reliable compared to ordinary interview and survey techniques. Companion modelling also promoted collaboration between researchers and stakeholders. However, the usability is dependent on the availability of technical facilities, which may be a bottleneck in some contexts, especially in developing countries. Companion modelling also requires time resources and multi-faceted expertise from the researchers and facilitators, which may limit its diffusion.

vi) *Specific modelling tools* (Kassa *et al.,* 2009)

Chilimo forest in Ethiopia was the case area in the study which explored future scenarios of forest management via integrating qualitative insights and quantitative modelling. After gathering interview data from local stakeholders, STELLA software, a tool for modelling, visualizing and communicating complex systems, was used to generate a model for household income, representing the success of the chosen forest-management scenario. Information on forests and livelihoods was summarized and communicated to users both to inform them and to get feedback in workshops, which here represent the PS.

The use of modelling software enabled summarizing gathered information in a systematic way. Provided illustrations helped to facilitate the workshops and contributed to participants' learning as well as their commitment to planning their future and searching for new income opportunities. Thus, the modelling exercise helped to foster a common view on the present situation and future prospects in an activating way.

Discussion

Strengthening the link between problem structuring and decision support systems

The analysis on the use of cognitive modelling software, interactive and group negotiation software indicates that computer support for PS in participatory forest planning domain is not common sense, yet. Alternately, forest planning experts could benefit from greater familiarity with cognitive modelling software, supportive in various participatory planning occasions. The use of interactive software in practical planning processes, in turn, might increase after successful pilot tests in safe environments such as with colleagues or students. There is certainly a need for further research to learn about computerized features that are important to stakeholder group members during workshops (*e.g.* Sheppard and Meitner, 2005). Additionally the limited IT skills of facilitators and the current design of user interfaces might cause some additional barriers for its wider application.

The present results indicate that links between PS and decision support systems are most often realized via forest simulation programs or GIS software. However, the use of forest simulations or GIS is not per se equivalent to PS and decision support *e.g.* in facilitated group negotiation. In a logical framework, DSS would build on GIS data and use it as input for quantitative modelling and evaluation of alternatives. Further, GIS can be seen as visualized information system that helps understand the nature and scale of a problem at the initial stage to PS approaches. To ensure strengthening the link between GIS and PS it would be reasonable to enhance the typical skills of GIS and ecosystem modelling specialists by facilitator trainings, and vice versa, train group-learning specialists to make better use of GIS and simulations software in the facilitation process. Combined skills would presumably lead to joint use of quantitative and qualitative modelling in participatory forest planning processes in future.

A crucial question for future development is how forest management decision support systems could be designed to better utilize the PS results *(e.g.* cognitive maps, preference structures, causal-loop diagrams etc.); and conversely, how the process of PS could be aligned to utilize the benefits of computer-based tools. This would require a pervious and stringent master concept linking the various steps from PS to problem solving. To this end, for example, an exploratory PS task might screen potential objectives and criteria for MCDA workshops, while a descriptive PS task might help to select an appropriate decision model. In turn, a prescriptive PS task could help to set constraints to the optimization task. As many DSS applications do not allow to select criteria, constraints and methods in a flexible and dynamic manner due to the enormous resources needed *(e.g.* in terms of programming, flexible architecture and user interface) the potential of PS is maybe limited here.

In any case, participatory forest-planning processes pose a major dilemma for computer-based tools. While, on one hand, there is an increasing demand for more rigorous and formalized decision-making approaches and to increase transparency and effective communication among participating stakeholders, on the other hand, the use of methods and tools that are too sophisticated usually imposes the risk that people are more likely to accept an unsolved problem than a solution that they do not understand (Reynolds *et al*., 2008). Thus, it needs to be acknowledged that, for land-use planning and resource sharing projects within development cooperation, the potentially available computer support could simply mean technological overkill. In such an environment, technology should not drive the search for optimum solutions in natural resource management, but it is crucial to invest in social acceptance of tools and methods by stakeholders.

Research work and software development with both forest management decision support systems and PS methods thus ought to strive for a balance between simple and intuitive methods that work for the public, and the capability to tackle and deal with complexity and uncertainty, which demands long term research and further international co-operation.

Conclusions

The present findings suggest that the developers and users of decision support systems should i) modify decision support systems to output illustrative material for collaborative problem modelling; ii) enhance problem modelling with stakeholders using specific cognitive modelling software more frequently; iii) make sure that PS activities produce input for decision analysis such as objectives, criteria, weights and constraints in a systematic and coherent way; and iv) consider the use of interactive software tools to facilitate group negotiation in particular, because the present results indicated that computer-aided group facilitation could make the potential benefits of PS appear or grow.

In practice, it is very demanding to integrate and document public interaction, collaborative modelling, multi-criteria analysis, and to simultaneously focus on sustainability as a cornerstone for forestry decision-making. This may be the reason why actors tend to select those planning methods that are easy to handle (*e.g.* Table 2 shows that in half of the cases only simple spreadsheet and generic GIS tools were used) rather than those that would be more engaging, open, transparent, user-friendly, informative and innovative participatory PS methods.

An important final question is how PS could contribute to knowledge management in forest management decision-making (see also Vacik *et al.,* 2013). The organization and sharing of procedural knowledge creates better understanding and leads to more effective problem solving (Heinrichs *et al.,* 2003). Further investigation and development is needed on how the results of PS could be stored in a problem-perception database, or how PS could be streamlined by retrievals from such systems. A "knowledge-base analysis" following the stakeholder analysis could be defined and taken as one optional phase in participatory forest-planning processes.

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Appendix 1. Process of determining the 32 articles for review

Search 1) SCOPUS Advanced search: regular published journal articles from 2002-2011 (17.11.2011)

TITLE-ABS-KEY("participat*") AND TITLE-ABS-KEY("forest management" OR "forest planning") AND TITLE-ABS-KEY("facilitat*" OR "model*") AND PUBYEAR > 2001 AND PUBYEAR < 2012 AND [LIMIT-TO(DOCTYPE,"ar")]

Stepwise result list development: 256 → 194 → 156

Result: 156 articles, which were then judged by reading abstracts; only those were included that *presented an empirical participatory forest planning or forest management decision making case with direct communication between stakeholders,* yielding 29 articles.

Search 2) SCOPUS Advanced search: regular published journal articles from 2002-2011 (17.11.2011)

TITLE-ABS-KEY("forest planning" OR "forest management planning") AND TITLE-ABS-KEY("participa*" OR "collaborat*" OR "stakeholder*" OR "facilitator*" OR "interact*" OR "negotiat*" OR "group") AND TITLE-ABS-KEY("structur*" OR "problem*" OR "concept*" OR "qualitative*" OR "model*" OR "analyst*") AND PUBYEAR > 2001 AND PUBYEAR < 2012 AND [LIMIT-TO(DOCTYPE, "ar")]

Stepwise esult list development: 165 → 123 → 97

Result: 97 articles, which were then judged by reading abstracts; only those were included that *presented an empirical participatory forest planning or forest management decision making case with direct communication between stakeholders/experts*, yielding 22 articles.

→ Combining the two screening results by removing 5 duplicates and 3 with no full paper access: 29 + 22 – 5 – 3 = 43 articles.

→ Looking closer at the 43 articles, and dropping 11 of them because they did not present a real forest planning case or interaction between stakeholders: **final set of 32 articles.**