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The role of knowledge management tools in supporting sustainable forest management

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Abstract

Aim of study: Knowledge Management (KM) tools facilitate the implementation of knowledge processes by identifying, creating, structuring, and sharing knowledge through use of information technology in order to improve decision-making. In this contribution, we review the way in which KM tools and techniques are used in forest management, and categorize a selected set of them according to their contribution to support decision makers in the phases of problem identification, problem modelling, and problem solving.

Material and methods: Existing examples of cognitive mapping tools, web portals, workflow systems, best practices, and expert systems as well as intelligent agents are screened for their applicability and use in the context of decision support for sustainable forest management. Evidence from scientific literature and case studies is utilized to evaluate the contribution of the different KM tools to support problem identification, problem modelling, and problem solving.

Main results: Intelligent agents, expert systems and cognitive maps support all phases of the forest planning process strongly. Web based tools have good potential to support participatory forest planning. Based on the needs of forest management decision support and the thus-far underutilized capabilities of KM tools it becomes evident that future decision analysis will have to consider the use of KM more intensively.

Research highlights: As the problem-solving process is the vehicle for connecting both knowledge and decision making performance, the next generation of DSS will need to better encapsulate practices that enhance and promote knowledge management. Web based tools will substitute desktop applications by utilizing various model libraries on the internet.

Key words: best practices; cognitive mapping; expert systems; intelligent agents; web portals; workflow systems; Decision Support Systems.

Introduction

Access to information and the ability to put it to productive use (knowledge) have always been the hallmark of successful individuals, companies, and even nations. Thus, the recognition that knowledge has great value has been with us for a long time. But until fairly recently, most people did not think in terms of "managing knowledge"; rather, they regarded knowledge as a personal asset, being the sum of our experiences, education, and our informal community of friends and colleagues that can be trusted to help perform better in our complex world. In the early 1990s approaches of modern knowledge management (*e.g.* libraries, encyclopedia) indicated a shift from knowledge as a personal asset to knowledge gaining additional value for organisations by computer based support. As computer technology improved and became cheaper, researchers in academia, government, and private industry began to explore the gains that could be made by organizing knowledge (Hjerland, 2003), codifying it, and sharing it (Neches *et al.*, 1991) more widely. Early innovators demonstrated that actively improving the management of knowledge could help scientists get their research results into the hands of users. The idea of augmenting human intelligence appeared as early as the 1960s (Engelbart, 1962). Recent theore-

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tical discourse about the trialogical approach to learning (Paavola and Hakkarainen, 2009) views electronic resources as mediating tools, *i.e.*, as a third essential component in contemporary knowledge management (KM)

However, in computer science literature concerning decision support systems (Burstein and Holsapple, 2008), a knowledge system is composed of data, models and methods without an explicit reference to managing knowledge. An actual KM perspective becomes evident when looking at the contemporary challenges of forest management decision support systems: *e.g.* informational complexity, adaptive design cycles, and program collaboration (Eriksson *et al.*, 2012). Indeed, a wider concept of KM contains various types of knowledge and also various subprocesses of action. This broad concept is crucially important to recognize when dealing with complex forest management problems via decision support systems and participatory planning methods.

Knowledge may be either explicit or tacit. Explicit knowledge is knowledge that has been codified in some way, such as scientific journal articles, operating procedures, databases, etc. Tacit knowledge in contrast refers to the knowledge that people carry in their minds. It consists of subjective opinions, intuition, feelings, understanding, or judgments. People often are not explicitly aware of their own knowledge stores ("we know more than we know how to say", Polanyi, 1958). However, there is a bigger gap between knowing and doing than between ignorance and knowledge (Pfeffer and Sutton, 1999). Additionally, it is not easy to turn information into knowledge, or to turn individual learning into organizational learning (Smith and McKeen, 2003). Moreover, there is knowledge pertaining to the different activity domains of actors that not only draws on different scientific disciplines (*e.g.*, social science, economy, physics, engineering), but that also emerges from the combined use of experiential, tacit, lay, expert, and theoretical knowledge (Kain and Söderberg, 2008).

Knowledge about natural resource management is multifaceted and spans a broad spectrum of spatial, temporal, and process scales. Various forms and types of knowledge can be found. Its domains are biological, physical, and social (Simard, 2000; Innes, 2003). Declarative knowledge like facts, propositions, or schemas provides general knowledge about the behaviour and functioning of ecosystems. It includes episodic knowledge (specific time and place events) and semantic knowledge (about entity relations of facts and general information). Procedural knowledge is about how to do things. Individuals, companies, organizations, universities, and nations provide a rich mixture of ideas, contextually relevant facts, and expertise for declarative and procedural knowledge. With reference to natural resources or sustainable forest management in particular, all these knowledge types are either explicitly or implicitly present when contemplating information for identifying, defining, structuring, and solving today's messy forest management problems with the aid of decision-support systems (DSS) and related software. It is therefore evident that developing and utilizing forest-management DSS will benefit from versatile and systematic management of the various kinds of knowledge that are relevant in this context.

KM represents a systematic strategy of creating, conserving, and sharing knowledge to increase the performance of individuals, companies, or nations (Heinrichs *et al.*, 2003). KM attempts to provide methods for managing both explicit and tacit knowledge. Sometimes this means primarily socially-based methods that help person-to-person knowledge exchanges. Other methods can take advantage of existing explicit knowledge that has already been codified for other purposes to make it more readily accessible (Hansen *et al.*, 1999). But KM also concentrates on methods that help the process of moving from tacit knowledge to explicit knowledge, thus expanding the amount of codified knowledge available for use (Heinrichs *et al.*, 2003). Nonaka and Takeuchi (1995) describe a typology of knowledge practices based on the conversion of knowledge from one form to another. In the process of socialization, tacit knowledge is shared through shared experiences by individuals. Through externalization, tacit knowledge is articulated into explicit knowledge with the help of metaphors and analogies. By utilizing information and communication technologies and existing databases explicit knowledge is systemized and refined. In the internalization phase, explicit knowledge is converted into tacit knowledge, *e.g.*, through learning by doing.

KM approaches, methods, and tools can be utilized in multiple ways in the context of forest management decision-making. However, the opportunities provided by advanced KM may not yet be sufficiently well articulated and communicated to scholars and professionals involved in forest management decision support. Therefore, the extant KM information may seem fragmentary, and the gaps between opportunities and present applications in forest management may have thus far remained unrecognized. For example, the recent book "Computer-based tools for supporting forest management" (Borges *et al.*, 2013) presents the most comprehensive compilation of forest management decision support systems mainly from Europe, Russia, Brazil and the US, but in many country report chapters, sections addressing KM remain slim. This may partly be because the respective authors are not particularly KM experts, but perhaps also because KM may have been considered as an embedded part of forest management software development that it has not been given distinct attention. Good examples do exist, *e.g.* KM in the cases of Austria (Vacik *et al.*, 2013), Germany (Felbermeier, 2013), the Netherlands (Boerboom, 2013), Finland (Kurttila *et al.*, 2013) and the US (Gordon and Reynolds, 2013), but in any case, it seems obvious that KM approaches, tools, and techniques deserve to be better explicated and analyzed for the purposes of the design and use of forest management decision support systems.

In this contribution, we (i) review the way in which KM tools and techniques are used to support forest management, (ii) categorize a selected set of them according to their contribution to support decision makers in the phases of problem identification, problem modelling, and problem solving, and (iii) address some key development issues based on the recognized gaps between the needs of forest-management decision support and the thus far underutilized capabilities of KM.

Material and methods

Managing knowledge in the field of natural resources management

KM tools do not manage knowledge by themselves, but rather facilitate the implementation of knowledge processes. They promote and enable knowledge processing by identifying, creating, structuring, and sharing knowledge through the use of information technology in order to improve decision-making (Tyndale, 1992).

The natural resource field has been the subject of several early attempts to demonstrate the value of applying KM principles focusing on explicit knowledge. Rauscher (1987) introduced the concept of modern KM to the natural resource field in the same year that the first hypertext software programs became available. As the Internet became more popular, it became obvious that KM systems using web-based hypertext had an enormous competitive edge over standalone systems. Saarikko (1994) reported on an early comprehensive summary of forestry information resources on the Internet.

A current comprehensive portal to such information is the Global Forest Information Service (GFIS, http://www.gfis.net/gfis/), coordinated by IUFRO. Examples of modern natural resource management KM systems on the Internet can be found at the Forest Encyclopedia Network (http://forestencyclopedia.net/indexes), where a growing number of scientific encyclopaedias can be found (Kennard *et al.*, 2005).

The various models describing ecosystem processes (*e.g.*, growth models) can be viewed as KM systems that help to retrieve and re-use the knowledge that was created and stored (with the aid of extensive field research, statistical analysis, and process-based modelling) for new and emerging decision-support purposes. Model libraries, in turn, can be seen as higher-level KM systems of lower-level KM systems, providing more opportunities for simulation and optimization software users, for example, to select appropriate models for the problem at hand. This kind of hierarchical structure of KM has evoked the need to enhance metadata management, which essentially aids utilization of the stored knowledge, and contributes to the quality of derived knowledge by explicating its origin and reliability.

Because KM is still a young discipline, a generally accepted framework for it has not yet been established. Instead a variety of approaches to KM have been implemented across a variety of organizations (Rubenstein-Montano *et al.*, 2001). Apostolou and Mentzas (1998) proposed a classification of Information and Communication Technology (ICT) tools based on Nonaka and Takeuchi's (1995) modes of knowledge conversion. Borghoff and Pareschi (1998) classified KM approaches according to knowledge workers, knowledge repositories, knowledge cartography, and the flow of knowledge. A number of technologies commonly associated with the term "knowledge management" have been evaluated for their potential to support management processes (Ruggles, 1997; Tyndale, 2002). Consequently, various classification schemes for KM techniques (sets of procedures and tools used to achieve a specific purpose in KM) can be identified (Rubenstein-Montano *et al.*, 2001; Metaxiotis, *et al.*, 2005). The classifications aim to structure the tools and methods available according to their purpose and needs, mostly in organisations. Plunkett (2001) observed that

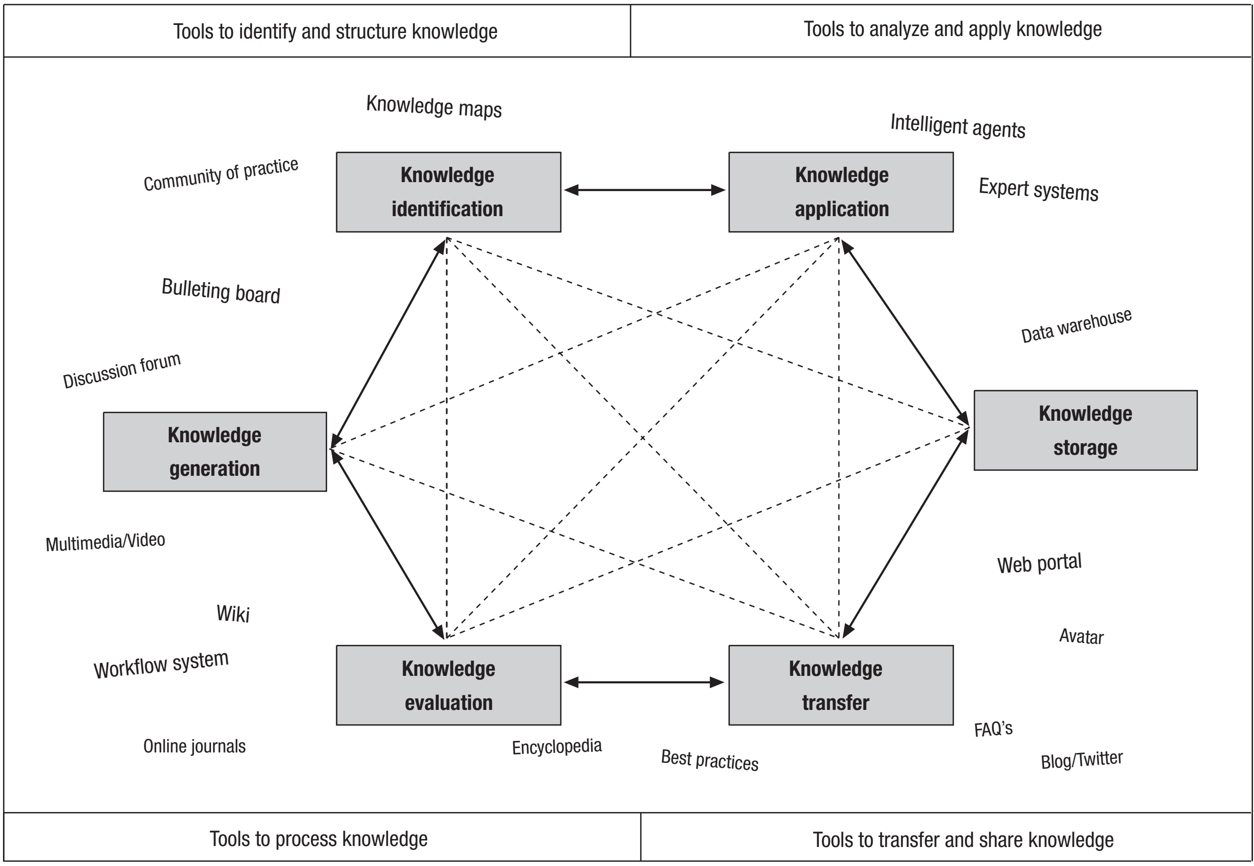

Figure 1. Classification of Knowledge Management (KM) tools and techniques according to their potential to support knowledge management processes.

"Knowledge management consists of three fundamental components: people, processes, and the supporting technology." Therefore, in our contribution, we mainly focus on KM processes (cf. Heinrichs *et al.,* 2003) that can be supported by various tools and techniques applied by the user. However, because each KM tool and technique can support various processes, any proposed clustering will always be only one possible way of categorisation (Fig. 1).

Classification of KM tools

Based on the review of the scientific literature, the experiences of the authors, and lessons learned in the FORSYS Cost Action FP0804, a comprehensive description and classification of KM tools was developed. By the term, tool, we refer to technologies that support the performance of activities or actions (Ruggles, 1997) to acquire, share, and utilize knowledge. For tools described in the scientific literature, their main characteristics, the application to forest management, and the potential to support the forest planning process were provided. This material was utilized to summarize the main findings in this contribution. Various KM approaches are often used to develop DSS components and are partly integrated in DSS where information, data, and conceptual knowledge are captured. The manner in which KM approaches, communication tools, and methods in general are integrated in DSS depends on their potential to support decision makers in the decision making phases of problem identification, problem modelling, and problem solving. Therefore each tool was classified according to its strength of evidence in supporting decision making and how relevant its use is as a KM tool within organisations, in supporting participatory planning or as an integrated component of a DSS. For the qualitative assessment of each tool a four-level Likert-scale was used, in which the actual relevance was classified as strongly relevant (3), partly relevant (2), relevant to a minor extend (1), no evidence found (0). When there was no empirical evidence found for the use of a particular tool in supporting forest management, it was tried to estimate the potential of the tool with reference to other domains outside forest management. The potential use of a KM tool is described in a narrative way in the text. In the following, an evaluation of the different KM approaches is presented in order to provide evidence for this assessment.

Description of KM tools

Tools to identify and structure knowledge

Descriptive KM tools (*e.g.*, knowledge mapping) in natural resource management in general focus on the management of declarative data, information, and knowledge. The focus here is on what we know (Thomson *et al.*, 2007). The purpose is to create a shared, explicit, and accessible understanding of concepts, ideas, relationships, and categories that enables effective communication and understanding of a common societal knowledge base (Heinrichs *et al.*, 2003). It is important that all stakeholders of a particular issue be able to agree on a common descriptive set of knowledge. Such a common understanding of the descriptive, factual knowledge provides a sound basis for reasonable disagreement and discussion concerning interpretations, courses of action, and values.

Cognitive mapping is a process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in their everyday environment (Downs and Stea, 1973). The act of cognitive mapping can be described as "the mental structuring process leading to the creation of a cognitive map" (Arthur and Passini, 1992). Cognitive (or mind) maps are a graphical representation of the knowledge mapping procedure used to represent words, ideas, tasks, or other items linked to, and arranged around, a central concept. They are used to generate, visualize, structure, and classify ideas, and are a tool for studying and organizing information and structuring problems.

Many examples confirm the use of knowledge mapping to support forest participatory planning within organisations. Tikkanen *et al.* (2006) used cognitive mapping as a tool to explore the objective-structure of forest owners in a Northern Finnish case study. Due to their experiences, it can be argued that cognitive mapping is a promising means of merging qualitative and quantitative approaches in an objective analysis in forest planning. Hjortsø (2004) applied a modified version of Strategic Option Development and Analysis (SODA), which integrates cognitive mapping, to enhance the level of citizen participation in a strategic forest-management planning process managed by the Danish Forest and Nature Agency. The approach was used to communicate current understanding of the nature of the decision problem. Fuzzy cognitive mapping was used to develop a participatory ecosystem management plan for Uluabat Lake, in Turkey (Özesmi and Özesmi, 2003). To assess participants' perspectives on an appropriate forest management strategy, Kearney *et al.* (1999) used a Conceptual Content Cognitive map (3CM) technique to identify differences in stakeholders' conceptualisations in the Pacific Northwest USA. The same technique was used during an elicitation of forest values and perceptions of forest stakeholders in northwestern Ontario (Kant *et al*., 2003). However, cognitive mapping also has been used for assessing sustainable forest resource management (Mendoza and Prabhu, 2003) or a rapid stakeholder and conflict assessment (Hjortsø *et al.*, 2005), but no examples of cognitive mapping as an integral DSS component were identified in the literature.

Tools for processing knowledge

A workflow is a formal description of a process, consisting of a set of connected tasks (elementary or complex activities), possibly iterative or not, to obtain a specific result. Workflow tools (*e.g.*, Windows Workflow Workbench) are, in a sense, descriptive, but more importantly they encapsulate procedural knowledge about how to process information. A workflow can usually be described using formal or informal flow diagramming techniques, showing directed flows between processing steps. Components can only be plugged together if the output of one previous (set of) component(s) is equal to the mandatory input requirements of the following component. Thus, the essential description of a component actually comprises only inputs and outputs which are fully described in terms of data types and their meaning (semantics). Workflow systems are used to describe and support standardized processes by a formal flow diagramming. Perhaps one of the more notable contemporary examples of a system implementing workflows is the Trident Project, a scientific workflow workbench built on the Windows Workflow Foundation of Microsoft Research (Barga *et al.,* 2008). Álvarez Taboada *et al.* (2004) developed a workflow to locate eucalyptus (*Eucalyptus globulus*) plantations in Galicia (Spain) affected by eucalyptus snout beetle (*Gonipterus scutellatus*), and to determinate the basic spatial patterns, in order to predict future hot spots and develop more integrated pest management. The workflow includes six basic phases: goals establishment, data collection, data management, processing, outputs, and feedback. Lei *et al.* (2006) designed a workflow-based infrastructure for forestry grid (WIFG) that supports data-flow driven applications. The WIFG has been used for planning the conversion of cropland to forest. A workflow was also designed to assess sustainability impacts of changes in the Forest-Wood-Chains (FWCs) due to deliberate actions (*e.g.* in policies or business activities) or due to external forces (*e.g.* climate change, global markets) within the ToSIA software tool (Lindner *et al.*, 2010). The FWCs are defined as chain-of-production processes by which forest resources are converted into products and services. The Quebec Wood Supply Game is a KM approach which explores possible solutions for logistical problems in the forest products industry and to enhance the value chain and related workflows (Van Horne *et al.*, 2010).

Tools to transfer and share knowledge

Predictive KM tools focus on the management of procedural knowledge. The focus is on how activities occur, how things are changing in the real world, how specific problems are solved, and how we predict the results of alternative courses of action (Heinrichs *et al.,* 2003). The organization, transfer, and sharing of such pieces of procedural knowledge (*e.g.*, focusing on forest-management practices) is made possible via web sites, web portals, online encyclopaedias, wikis, or communities of practice. These tools can be combined with models of all kinds that provide users with a structured, problem-solving environment.

A web portal is a website designed as an entry point to other websites: in fact, it typically provides links to many other sites that can either be accessed directly or can be found by following an organized sequence of related categories from diverse sources in a unified way. Apart from the standard search engine feature, web portals offer other services such as e-mail, news, web feeds, databases, or even entertainment features. The provider of a web portal is responsible for structuring and filtering web addresses relating to a special theme. There are many applications available in the forest field, aiming to share scientific and market information. Internet-based service delivery through portals can be a valuable tool, in particular for information dissemination and business transactions (Costopoulou and Tambouris, 2003). They developed a simple prototype portal for increasing the efficiency and quality of current commercial practices of producers of natural Christmas trees in Greece. The European Forest Institute (EFI) has launched the EUROFOREST Portal as a free and non-commercial service for forest and forestry information users (Vesa *et al.*, 2007). The portal WALDWISSEN.NET can serve as an example for providing an overview about forest related information and research findings in Germany, Austria and Switzerland by four languages (Lässig *et al.,* 2007). The Italian Agricultural Research Council together with the National Union for the Forest Scientific Innovation Forest created a portal for providing access to news, databases, utilities, and state of the art in scientific research and practical forestry (Fior and Notarangelo, 2008). Researchers at Swedish University of Växjö developed a web portal for forest owners in a structured and reliable way (Flensburg, 2000) and the German portal DSS-WuK offers the user the opportunity to screen the impact of climate change on tree species suitability (Jansen *et al.,* 2008). According to the growing number of web portal applications, it seems that this type of tool is strongly used within organizations and as a means for transferring relevant findings to practioners. Potentially, this type of tool could be used to at least partially support participatory planning in forestry as well. No examples of web portals were found that are an integral DSS component.

A best practice is in general the most significant technique, method, process, or activity that allows better results with the least amount of effort in relation to a specific context. Depending on the scope, therefore, best management practices (BMPs) are a collection of examples or repeatable procedures that have proven themselves over time for a large number of people, and which are formalized into rules that can be followed to improve results in some problem domain. A given best practice is only applicable to a particular condition or circumstance, and may have to be modified or adapted for similar, but slightly different, circumstances. In addition, best practices can evolve over time as improvements are discovered through actions and learning from their application. There are many examples for BMPs and lessons learned within organizations and for supporting participatory forest planning. Pimbert (1997) describes lessons learned from an experience in participatory planning for forest management in the Central Rhodope Mountains of Bulgaria, and the American National Forest Foundation (NFF) documents creative approaches used by community-based collaborative planning (NFF, 2007). Another example of computer-based BMPs is the application designed and implemented by the Northeastern Forest Experiment Station of USDA Forest Service, which describes the relationships between forests and streamwater quantity and quality, based on four decades of forest hydrology and meteorology research (Hornbeck and Smith, 1997). The model is implemented in a user-friendly format, and allows the user to choose combinations from five management objectives related to water quality and quantity. Regardless of goals selected, all users are informed about BMPs required to control nonpoint source-pollution of aquatic ecosystems. Based upon the options selected, taking into account forest stand and precipitation data, possible silvicultural systems are recommended to meet the management objectives. The most recent and perhaps the most comprehensive example of best practices in the field of forest management decision support systems are the guidelines that are being finalized as a result of COST Action FORSYS. These guidelines gather the recommendations for the developers and users of forest management DSS to be able to tackle the challenges that today's multiple complex forest management problems contain. The guidelines will include aspects of DSS architecture and quality control, integration of models and methods, knowledge management as well as solutions for participatory planning tasks.

Tools to analyze and apply knowledge

Prescriptive tools (*e.g.*, intelligent agents, expert systems or other artificial intelligence tools) deal with causality, judgment, values, and choices. Causal knowledge, and the prescriptive tools that manage it, create the assumptions and drive the actions that directly affect the lives of individuals, ecosystems, and their interrelated processes (Rauscher *et al.,* 2007; Vacik and Lexer, 2007).

An expert system is a computer-based application that performs a task or series of tasks, supports decision-making or solves problems in a particular field by using knowledge and analytical rules defined by experts of that field. Expert systems are considered as well known techniques for knowledge management that can aid in solving problems in specific domains (Baeshen, 2008) and have been adopted early by forest sciences as well (*e.g.* Suda *et al*., 1988). A wide variety of methods can be used to simulate the performance of the expert: i) the creation of a knowledge base which uses some knowledge representation structure to capture the knowledge of a subject-matter expert (SME); ii) a process of gathering that knowledge from the SME and codifying it according to the structure, which is called knowledge engineering; and iii) once the system is developed, it is placed in the same real world problem-solving situations as the human SME, typically as an aid to human workers, or as a supplement to some information system. Expert systems may or may not have learning components.

There are many examples of expert systems found in the literature that are integral DSS components, a few of which are mentioned here. Saint-Joan and Desachy (1996) have implemented the GEODES (GEOgraphic Decision Expert System) system that allows users to specify knowledge of a problem domain through a graphic user interface. A problem specification and geographic data are used to provide a problem-solution map showing favourable and less favourable areas for the evolution of forest in a region. Kaloudis *et al.* (2005) designed an expert system that identifies forest insects and proposes relevant treatment. Once an insect is identified, the system can recommend an appropriate treatment, aiming at reducing spread of insects and minimizing possible forest damage. Kaloudis *et al.* (2010) implemented an Expert System for Forest Management Planning (FMP-ES) of lowland pine forests in order to reduce wildfire damage. Chen *et al.* (2010) designed an expert system applying basic principles on sustainable management of rural forests for farmers in a web environment. Wu *et al.* (2007) designed a web-based Forestation Planning Expert Decision Advisory System (FPEDAS) to provide support for operational planning of tree species selection for planting. Zhao (1998) used artificial intelligence (AI) technologies to design an expert system for expressing the relationship between wood properties and its merchantable classification to classify wood and provide volume, price and value of logs or sawn timber. Zukki *et al.* (2010) designed an expert system prototype utilizing the Analytical Hierarchy Process (Saaty, 1992) to evaluate and select the best use of forest resources with regard to sustainable forest management for selected forest areas in Malaysia. Wang *et al.* (2009) and Wu *et al.* (2011) developed a WebGIS-based information service platform for forest pests that supports forecasting (*e.g.* occurrence period, tendency), diagnosis (*e.g.* amount of pest), prevention and control of forest pests in cultivated rapid-growing and high-yield forests. Finally, one of the most widely used expert systems in resource-management DSS applications is NetWeaver (Miller and Saunders, 2002), an object-oriented logic-based processing system in which complex problem representation is facilitated by a graphic design environment. NetWeaver is a primary component of the spatially enabled Ecosystem Management Decision Support (EMDS, Reynolds *et al.*, 2003). In the EMDS context, Netweaver has been used in a wide variety of DSS applications for natural resource management around the world since about 1998, because the parent EMDS system provides a very general solution framework, adaptable to numerous natural resource problems and spatial scales.

Intelligent agents (IA) exhibit some form of artificial intelligence that assists a user, and will act on their behalf, performing repetitive computer-related tasks. While the working of software agents used for operator assistance or data mining (sometimes referred to as bots) is often based on fixed pre-programmed rules, "intelligent" here implies the ability to adapt and learn.

According to Kasabov (1998), IA systems should exhibit the following characteristics: accommodate new problem-solving rules incrementally; adapt online and in real time; be able to analyse itself in terms of behaviour, error and success; learn and improve through interaction with the environment (embodiment); learn quickly from large amounts of data; have memory-based exemplar storage and retrieval capacities; have parameters to represent short- and long-term memory. In this context, various agents can be defined: for example, decision agents geared to decision making, input agents that process and make sense of sensor inputs, processing agents that solve a problem like speech recognition, or believable agents that exhibit a personality via the use of an artificial character for the interaction.

To improve the mechanism of problem solving, multi-agent systems (MAS) are being applied in the exploitation of DSS (Liu and Wang, 2000; Mao and Tan, 2001; Badjonski and Ivanovic, 2000). In fact, intelligent agents today are normally gathered in a hierarchical structure containing many sub-agents. Intelligent sub-agents process and perform lower level functions. Taken together, the intelligent agent and sub-agents create a complete system that can accomplish difficult tasks or goals with behaviours and responses that display a form of intelligence. The USDA Forest Service has designed an agent based software system that integrates a suite of the decision-support tools that are most useful to forest managers into a complete goal-driven decision-support process within the Northeast Decision Model project NED-2 (Nute *et al.*, 2004). NED-2 uses a set of semi-autonomous agents to manage these tools for the user. A graphical user interface provides powerful inventory analysis tools, dialogs for selecting timber, water, ecological, wildlife, and visual goals, and dialogs for defining treatments and building prescriptive management plans. Prolog agents use growth and yield models to simulate management plans, perform goal analyses on user-specified views of the management unit, display results of plan simulation using GIS tools, and generate hypertext documents containing the results of such analysis. Each agent in NED-2 possesses both the procedural and the declarative knowledge to perform a particular step in the NED decision process (Nute *et al.,* 2004). A group of Chinese researchers designed and implemented an agricultural and forestry economy decision-support system (AFEDSS) based on agents (Yeping *et al.*, 2007). The AFEDSS is composed of an interface agent, management agent, model agent, forecast agent, assistant decision agent, and data-management agent. It allows simulating and modelling the complex processes of agricultural and forestry economies in reasonably short computational times and with less subjective uncertainty.

Evaluation of KM tools

Knowledge mapping supports the phase of information gathering and problem identification. Fuzzy cognitive mapping offers many advantages for ecological modelling, including the ability to include abstract and aggregate variables in models, the ability to model relationships which are not known with certainty, the ability to model complex relationships which are full of feedback loops, and the ease and speed of obtaining and combining different knowledge sources

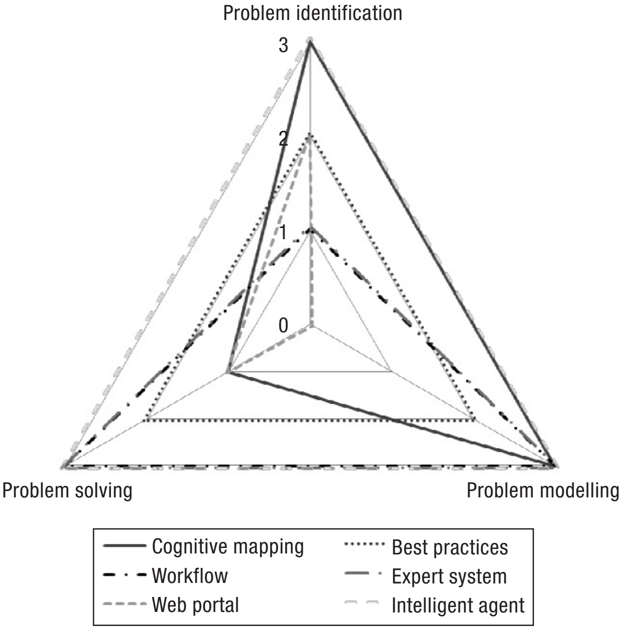

Figure 2. Assessment of Knowledge Management (KM) tools in supporting problem identification, problem modelling and problem solving.

and of running different policy options (Özesmi and Özesmi, 2003). Knowledge mapping tools partly support the decision-making and problem-solving phases of the forest planning process (Fig. 2). Workflows strongly support the phases of decision making and problem solving. In fact, the approach can capture and retain knowledge, making it available to decision makers who are seeking solutions from previously solved problems, facilitating decisions that are reproducible, supporting the decision-making phases in identifying or analyzing alternatives, and in giving advice about which alternative to choose.

Web portals are not used directly in forest planning, although a web portal could partly support the phase of information gathering and problem identification. It appears that web portals are currently not used in the phase of problem modelling. Because web portals provide links to many other sites, they have the potential to support decision making by capturing and retaining knowledge, making it available to decision makers, who are seeking solutions from previously solved problems by sharing similar experiences. These developments may influence the way in which participatory planning processes are implemented as well. The use of web-mapping services are becoming increasingly important for collecting spatial information about social attributes (Pocewicz *et al*., 2012).

Both best practices and lessons learned support all phases of the forest planning process. In fact, if best practices are derived from a team that learned during problem structuring, problem modelling, or problem solving, the experiences gained could be used by others working in a similar problem context. However, it is difficult for people to collaborate and share experiences face to face in the problem modelling phase. Therefore, best practices strongly support the phase of decision making and problem solving, but they have to be adapted to specific conditions or circumstances.

Expert systems support the phase of problem modelling. In fact, they help to:

— Identify expert knowledge, facts, and experiences in relation to a decision problem.

— Codify available knowledge for machine processing.

— Reduce complexity.

— Support the involvement of subject-matter experts.

— Combine various forms of qualitative and quantitative information.

In addition to strongly supporting decision making, expert systems allow for the capture and retention of knowledge, making it available to decision makers who are seeking solutions from previously solved problems, thus facilitating decisions that are reproducible and improving decision-making ability.

Internet-based, distributed systems have become essential in modern organizations. When combined with artificial intelligence (AI) techniques such as intelligent agents, such systems can be powerful aids to decision makers. Agents can be used for intelligence gathering and problem identification. For example, data management agents can manage, control, and classify local and distributed information, and search and dispatch information that may be critical to decision making. These agents can not only search in a local database according to the task, but they can also visit network information resources, and send relevant data and information to function agents (Yeping *et al.*, 2007). For problem modelling and problem solving, model agents are used to produce a concrete problem-solving model with the support of a data agent.

KM tools:

— Are used to develop DSS.

— Used in participatory planning approaches.

— Support decision-making processes within organizations.

— Are sometimes integrated in DSS applications.

In the latter context, KM techniques can support the

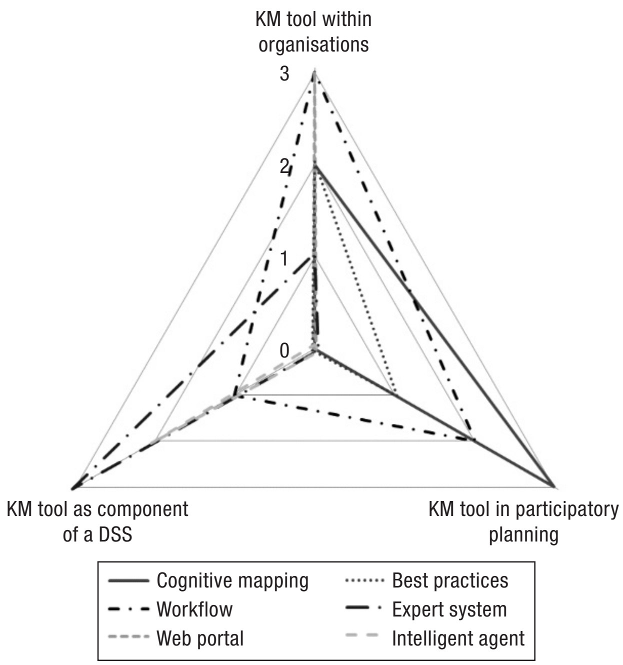

Figure 3. Assessment of Knowledge Management (KM) tools to be used in participatory planning, within organisations and as integral component of decision support systems (DSS).

identification, generation, evaluation, storage, transfer, and application of information, data, and conceptual knowledge in its various forms. In general, the various forms of knowledge are made explicit in models and methods, but often it is not easy to identify the knowledge component in describing a computerized DSS. Overall, KM tools can be used in many different contexts. Fig. 3 indicates the potential of KM tools to be used in participatory planning, within organisations and as a component of DSS.

A web portal can support the process of identifying a decision problem within an organization. Such portals aim at providing knowledge for users within a consistent environment (mostly the Intranet within an organization). The integration of different knowledge sources (*e.g.*, document management systems and project databases) is an integral part of every portal. Such a tool can be used to search, store, and share relevant information (Best practices-lessons learned) in the context of a forest decision problem. The objective of collecting, organizing, and presenting experiences and best practices is to improve the efficiency and effectiveness of processes, and to adapt the knowledge of an organization to contemporary organizational knowledge (compare Fig. 2). A group of subject-matter experts might use KM tools such as cognitive mapping (or mind mapping) to support the process of structuring/modeling a problem. In the context of workshops, brainstorming could be supported by a computerized tool to facilitate the structuring of a decision problem. However, as the character of each problem is different, the potential contribution of any KM tool and technique is generally context specific.

AI techniques, database management systems and workflows are commonly used as integral components of DSS. Databases store raw data, and there is a need to retrieve data and information (*e.g.*, data mining). In DSS for forest management, some model libraries may be used, and metadata (about growth models or optimization algorithms, for example) may be stored and retrieved in DSS processes. When data need to be transformed into knowledge, data mining may be a significant step in this process. As workflows are used to describe the directed flows between processing steps in the context of a decision process they are often used as integral parts of existing DSS. Additionally, an agent can be used for retrieving information from databases, for finding out and identifying knowledge, or for monitoring the environment, and reacting to certain trigger conditions. An expert system may support the process of solving a decision problem. Through the analytical capabilities of an expert system, it might be possible to identify appropriate strategies to manage forest diseases, for example. Expert systems use an inference engine to process a rule base, thereby simulating the reasoning process that a human expert pursues in analyzing a problem, and arriving at a conclusion.

Problem structuring methods (such as cognitive mapping) are applied in participatory planning (Hujala *et al.,* 2013) but online applications and computer based software tools that may help to support KM within organizations are mostly rare in forestry. In that context, it strongly depends on the nature of the decision problem, whether a KM tool can be successfully integrated into a DSS environment.

Conclusions

From our review and the recent FORSYS publication (Borges *et al*., 2013) it becomes evident that KM tools are very seldom used in the process of DSS development, or as integral components in DSS, prompting the question, why are there so few examples of successful KM implementations in DSS in forest and natural resources management? Is it only because developers and users of DSS are not sufficiently familiar with the concepts and ideas of KM, even though they manage knowledge? Or is there a bottleneck of transferring KM implementations from one successful process to others due to the high level of effort and resources required to do so? Considering these questions, what approach or approaches might be promising for the future development of DSS? In the currently evolving cyberspace era, re-usable knowledge objects, with open access and well-managed metadata, are central issues requiring attention for more advanced use of KM in DSS development. For forest-management DSS in particular, this suggests the need for more general DSS that would be able to access various model libraries on the internet. The latter point, in turn, suggests the need for a trend away from desktop applications towards international online tools and cloud computing. In this context, intelligent agents and other AI solutions could prove useful to aid the metadata management, knowledge optimization, and knowledge quality management.

Practical recommendations for developers and users of forest-management DSS can be divided into short and longer term guidelines. In the near future, it will be essential for KM practitioners to promote a better understanding among disciplinary scholars and system developers concerning the concepts, methods, and tools of advanced KM. It will be important not only to raise awareness, but to make at least small improvements in managing knowledge in forest management. The tools can be used to identify, structure, create, and share knowledge assets, but it is still difficult to locate the relevant information to support collaboration in forest planning with respect to problem identification, problem modelling, and problem solving. It is quite demanding to identify and apply the right tools and methods for knowledge sharing from a user perspective. Some benchmarking across national borders and, more importantly, across disciplinary boundaries may be beneficial as a social application of lessons learned. Knowledge about natural resource management gains economic value when it is used to solve problems, explore opportunities, and make decisions that improve overall performance. Because the problem-solving process is the vehicle for connecting both knowledge and performance, the next generation of DSS will need to better encapsulate practices that enhance and promote knowledge management in an adaptive management environment. Because DSSs are based on formalized knowledge, their application in decision making facilitates decisions that are reproducible and as rational as possible. The way a decision maker arrives at a decision is automatically documented; thus, by the use of DSS, the process of decision making can be evaluated *post hoc,* thus supporting the opportunity to learn under which assumptions, what actions have been implemented. The decision-making process itself results in improved understanding of the problem and the process, and generates new knowledge. When solutions are evaluated and found effective, the acquired knowledge can be externalized in the form of best practices, and might be documented in model libraries, or shared among experts via information networks. Although decision making and processes for knowledge creation are interdependent, research has not adequately considered the integration of decision-support and knowledge-management systems.

Taking a longer perspective, a more ambitious research agenda for KM within forest and natural resources management could be established. This endeavour would seek to develop and test a new generation of KM solutions, particularly designed to respond to the needs of forest management operating under the combined pressures of climate change, collaborative governance, and ecosystem services. A special emphasis should be put on transferring the good examples to other regions and contexts. The Community of Practice on Forest Management Decision Support Systems (www.forestdss.org) can serve as a platform for a continuous exchange of the latest developments in the integration of decision-support and knowledge-management systems.

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PEFC promotes sustainable forest management through independent third-party certification. It assesses and endorses national land management standards that align with its principles. In the United States, both SFIÂ® and ATFS discussed below are endorsed by PEFC.Â SFI guides the forest management of the majority of industrial forestland in the United States as well as some privately and publically held lands. SFI Program Participants demonstrate their SFI commitment by improving forestry practices on their forestland and by promoting sustainable forestry practices with private forest landowners, foresters and loggers.Â â€¢ Determining the risk to your forestland by using tools found at www.southernwildfirerisk.com. â€¢ Using gates, etc. to control access to your property. The efficient and sustainable management of such complex forest ecosystems is difficult and requires a solid and comprehensive information basis to support well informed management decisions. Until recently, however , the cost for forest inventory data has been very high. Huge amounts of forest data like geographical tree position, wood type, timber volume as well as quality information, needed to be recorded literally by hand. Keywords: forest policy, forest resources, sustainable forest management, sustainability assessment, Elgedaref State. 1. Introduction.Â A distinct separation was made between the roles of the Provincial Forests Administration in supplying the needs of rural areas and protecting rural lands; and that of the Central Forest Administration in managing the central forest reserves and supplying the urban areas with their wood supplies and the supply of railway sleepers [4]. The second forest policy was issued in 1986.Â In this research, calculation of the percentages was used as a tool of analysis for interpretingÂ In this regard, the policy emphasized the role of community forestry and popular participation in forest management and rehabilitation. Strategy for forest-based industries. Sustainable forest management. Wood and other products. Woodworking.Â Unsustainable management in many tropical countries has led to forest degradation and deforestation, and has contributed 17.5% of all greenhouse gas emissions. The EU and its countries seek to address these impacts through the EU FLEGT Action Plan and the United Nations' Reduction of Emissions from Deforestation and Degradation (REDD). See more on wood and other forest products in the EU.Â Together, and with the support of bilateral donors, these organisations were responsible for the Tropical Forestry Action Plan (TFAP). Action plan - more recently, the United Nations Forum on Forests (UNFF) has addressed the "3-Ds" in a broader context. Sustainable forest management (SFM) is the management of forests according to the principles of sustainable development. Sustainable forest management has to keep the balance between three main pillars: ecological, economic and socio-cultural. Successfully achieving sustainable forest management will provide integrated benefits to all, ranging from safeguarding local livelihoods to protecting biodiversity and ecosystems provided by forests, reducing rural poverty and mitigating some of the effects of