26 Information and Knowledge Management in Support of Sustainable Forestry: a Review

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Abstract

For individuals, organizations and nations, success and even survival depend upon making good decisions. Doing so can be extremely difficult when problems are not well structured and situations are complex, as they are for natural resource management. Recent advances in computer technology coupled with the increase in accessibility brought about by the Internet have increased our ability to solve complex problems in natural resources. Scientific disciplines that have evolved to exploit this new computer-based technology include knowledge management and decision science. Impressive computer-based systems have been developed, but their use in natural resource management has been limited. Widespread adoption will require close cooperation among people working in research as well as management, across disciplines, up and down the administrative structure in state and federal agencies and in the private sector.

The objectives of this chapter are: (i) to briefly review the history and recent advances in natural resource information and knowledge management, including decision-support systems and multiple-criteria decision making; (ii) to discuss some of the interrelationships among inventory and monitoring, statistics and modelling, information and knowledge management and policy science; and (iii) to offer some ideas on how to best support sustainability as a forest management paradigm, given the new capabilities afforded by progress in information and knowledge management.

Knowledge Management

Overview

Until fairly recently, many people did not think in terms of 'managing knowledge'. They felt that knowledge was a personal asset accumulated from experiences,

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education and trusted colleagues (Plunkett, 2001). As computer technology improved and became cheaper in the early 1990s, researchers began to explore the gains that could be made by organizing knowledge, codifying it and sharing it more widely. Innovators demonstrated that improving the management of knowledge could: (i) help scientists improve communication of research results to users (Rauscher, 1987); (ii) help government cope with downsized budgets and increased work (Plunkett, 2001); and (iii) help private industry to gain competitive advantages (Heinrichs *et al.,* 2003). The advancement of information management technologies presented new opportunities for business and governmental organizations. In some cases, the implementation of information technologies represented major changes for organizations, as knowledge was now viewed by some as a resource, much like facilities, finances, equipment or workers (Nesbitt *et al.,* 1996; Evans and Wurster, 2000). Some existing applications of information technologies for managing – primarily natural resources – knowledge appear in Table 26.1.

Knowledge exists in either explicit or tacit states. Explicit knowledge is that which has been codified in some way, such as in scientific journal articles, operating procedures, best management practices and simulation models. Tacit knowledge is that which people carry in their minds. It consists of facts, opinions, intuition, feelings and judgements. People seldom fully understand their own knowledge stores. As Polyani (1958) said, 'We know more than we know how to say.'

Knowledge management (KM) can be defined as the systematic strategy of creating, conserving and sharing knowledge to increase performance (Plunkett, 2001; Heinrichs *et al.*, 2003). KM provides methods for managing both explicit and tacit knowledge. Some methods help people to exchange knowledge. Others make existing explicit knowledge more readily accessible (Hansen *et al.*, 1999). But KM also concentrates on methods that help to codify tacit knowledge so that it can be converted to explicit knowledge for general use (Heinrichs *et al.*, 2003). Nonaka and Takeuchi (1995) describe four processes for conversion of knowledge from one form to another:

- Socialization. Tacit knowledge is shared through shared experiences.
- Externalization. Tacit knowledge is articulated into explicit knowledge.
- Combination. Explicit knowledge is organized, systematized and refined.
- Internalization. Explicit knowledge is converted into tacit knowledge.

Knowledge about natural resource management is multifaceted and spans the biological, physical and social sciences (Simard, 2000; Innes, 2003). Such knowledge includes facts, propositions, laws and theories that provide general knowledge about the behaviour and functioning of ecosystems and their interactions with social systems. It also includes knowledge about places, events at specific times and implications for management.

KM uses information technology to identify, create, structure and share knowledge, with the goal of improving decision making (Tyndale, 2002). A number of technologies commonly associated with the term 'knowledge management' have been evaluated for their potential to support management processes (Ruggles, 1997; Plunkett, 2001; Tyndale, 2002). Table 26.1 provides a

Table 26.1. A classification of types of knowledge management tools.

Class of KM tool	Description	Links
Knowledge maps	Establish a classification scheme called a taxonomy of knowledge, provide a frame of reference for many knowledge management products, and serve as a critical first step for identifying available knowledge.	forest.cse.ogi.edu/portal cmap.ihmc.us
Electronic yellow-page directories	Aid in finding hard-to-access tacit knowledge resources by providing access to experts. They also organize existing websites and serve up a variety of explicit knowledge assets in understandable ways.	sref.info/www.forestryguide.de/ www.srs.fs.usda.gov/
Apprenticeship programs	Are typically one-to-one type relationships where an expert coaches a less experienced person in various forms.	www.treeguide.com/forum/
Communities of practice	Support groups of individuals with similar work responsibilities but who are not part of a formally designated work team. Many communities of practice communicate through a web-based system.	groups.yahoo.com/group/ dead_wood/dss.boku.ac.at/
Best practices and lessons learned	Typically present the situation, the options, choices taken and the results for a typical decision problem. They are widely used in natural resource management and can be extensively found on the Internet.	www.kyphilom.com/ www/wood/bmp.html www.forestrybmp.net
Lectures and storytelling	Allow people to gain more understanding and have greater recall then they do from written reports. Stories can be used to capture lectures on a particular topic, to capture after-action reports, to record difficult-to-codify tacit knowledge, and for many other purposes. Web-based software systems exist that support this knowledge management tool.	www.fsl.orst.edu/geowater/ morphology/
Frequently asked questions	In the course of performing a job, people naturally identify questions that their co-workers or their clients ask repeatedly. It is worthwhile to document and develop useful and standardized answers for these types of repetitive questions. Web-based systems also exist that specialize in the management of these questions.	www.answerlink.info

Continued

Table 26.1. *Continued.*

Class of KM tool	Description	Links
Web-based learning	Allows translation of a typical classroom experience to an online media to offer students the opportunity to learn codified knowledge in a structured way at their own pace.	www.forestandrange.org waldbau.boku.ac.at/lehre/
Scientific content management sites	Collects knowledge in some kind of web-based content management system. First, the knowledge has to be found, organized, synthesized, reviewed for quality and uploaded for availability. Secondly, the knowledge content has to be updated and maintained so that it keeps its currency. Software systems exist that support both of these functions.	forestencyclopedia.net www.waterontheweb.org www.cabi.org.compendia.asp
Simulation models	Mathematical models are a popular way to organize specific problem-solving knowledge and provide precise, quantitative answers to guide natural resource managers. Most such models have not yet been converted to be executed over the Internet; however, many simulation models can be downloaded from the Internet and then executed on a stand-alone computer.	www.fs.fed.us/fmsc/fvs/ www.cnr.usu.edu/online/simulation/
Free-content information collaboratories	Create and distribute free information content, e.g. encyclopedia. Articles are edited by volunteers and are subject to change by nearly anyone. They cover a wide range of topics, but lack the authority of traditional materials and lack the opportunity for quality control regarding the content.	wikipedia.org
Time maps	A visual-matrix index of the events, research topics, people and publications,	www.fsl.orst.edu/geowater/

Databases	A common way to organize original source material is a database structure. It is irrelevant whether the data are numerical or graphic or computer files. Web-based methods have been developed to manage databases online. Spatial databases, as in geographic information systems, are included here.	www.archives.gov/aad/
Metadata	Databases make a great deal of information and knowledge readily available, but they don't contain any knowledge about those data, i.e. who, when, how, etc., that indicates their appropriate use.	www.nbii.gov/datainfo/metadata/
Library services	Managing and making accessible published books and scientific journal articles have long been the province of science libraries. These services are also available on the Internet either free of charge or fee-based.	www.srs.fs.usda.gov/pubs/index.htm www.waldwissen.net
Online scientific journals	More and more scientific journals have placed all or part of the content of their original research articles online. Search engines allow the user to find relevant articles and the number of citations referring to them.	www.fbmis.info/ www.scirus.com
Web portals	Provide links to many other sites that can either be accessed directly or be found by following an organized sequence of related categories. The provider of a web portal is responsible for structuring and filtering of web addresses relating to a special theme.	frames.nbii.gov

partial list of some web-based methods that are currently being used for KM in the natural resource field; this list is not intended to be exhaustive.

One example of the application of knowledge management tools has occurred in the area of scientific content management. Other KM tools in Table 26.1 have similar histories but, for brevity, are not reviewed here. Rauscher (1987) introduced the concept of modern knowledge management to the natural resource field in the same year that the first hypertext software programs became available for IBM[1] PC and Apple Macintosh[1] computers. Rauscher (1991) then provided the first electronic hypertext encyclopedia in forestry – 'The encyclopedia of AI applications to forest science'. The purpose of this encyclopedia was to demonstrate the functional difference between electronic hypertext and print-based methods by taking the same content published in the scientific journal *AI Applications* and providing it on a disk as an insert for that issue. Other hypertext products for non-networked personal computers followed in rapid succession: 'Managing the global climate change scientific knowledge base' (Rauscher *et al.*, 1993); 'Computer-assisted diagnosis using expert system-guided hypermedia' (Thomson *et al.*, 1993); 'A hypermedia reference system to the forest ecosystem management assessment team report' (Reynolds *et al.*, 1995); and 'Oak regeneration: a knowledge synthesis' (Rauscher *et al.*, 1997) among others.

As the Internet became more popular, it was obvious to some that KM systems using web-based hypertext had an enormous competitive advantage over stand-alone systems. Saarikko (1994) authored an early comprehensive summary of forestry information resources available on the Internet. He concluded in 1994 that Internet activity had been growing exponentially and that such growth would continue. In a pioneering effort, Thomson *et al.* (1998) combined knowledge-based systems processing and a hypertext user interface (HTML) to provide forest tree disease diagnosis over the Internet. A primary benefit of this approach was that anyone with a web browser could access the diagnostic software from any Internet-connected computer. Universally available access and inexpensive updating appear to be the critical elements for making scientific content management in natural resource management an attractive alternative to traditional, paper-based methods. Examples of scientific content management for natural resources on the Internet can be found at the Forest Encyclopedia Network, which contains a growing number of scientific encyclopedias (Kennard *et al.*, 2005). More and more knowledge management services of different types are appearing at a dizzying rate.

Future directions

Plunkett (2001) observed that 'Knowledge management consists of three fundamental components: people, processes, and the supporting technology.' As extensive web-based KM sites illustrate, we have progressed quite dramatically in our technical capabilities. Within the context of natural resources, it is much less clear that we have advanced equally far in changing our institutional processes and educating our people to use KM efficiently. It is challenging for organizations to properly value and use both tacit and explicit knowledge in the management of environmental problems while promoting a climate of learning that encourages the recognition and sharing of employees' experiences (Boiral, 2002). While we know of no study to objectively document the low level of use of KM tools in the natural resource field, anecdotal evidence suggests that many workers are very reluctant to use them. This may be a more serious problem for the public sector than the private sector, where organizational policies can be enforced more rigorously. In any case, a thorough evaluation of how natural resource management and science institutions support KM processes and how workers in this field use the available KM tools does not currently exist.

An effective KM strategy for an organization might have the following goals:

- All new employees are introduced to the KM strategy and their roles as consumers and contributors of knowledge.
- All employees are part of an explicit KM system for their entire professional life and are rewarded appropriately for how well they share their tacit as well as explicit knowledge.
- Processes for KM exist and are strongly supported at all levels of an organization. Among these processes are periodic stocktaking assessments, after-action reporting, mentoring and apprenticeship programmes, storytelling opportunities, effective and active communities of practice, periodic assessments of both internal and external client groups, and visible and vocal leadership endorsement of all effective KM processes.
- KM support technologies (see Table 26.1) are available and effective. They are used routinely by all members of an organization.
- Mission-critical knowledge has been identified, structured and codified. It is readily available. A system exists to monitor the availability and quality of this mission-critical knowledge, either tacit or explicit.
- Security of confidential and proprietary information is high where necessary. Knowledge is routinely re-evaluated to make sure that those people who should have access do have access.

KM is a young discipline, so 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). Knowledge gains economic value when it is used to solve problems, explore opportunities and make decisions that improve performance. Hence, the problem-solving process is the vehicle for connecting knowledge and performance (Gray, 2001). Ways must be sought to enhance and promote KM in organizations (Girad and Hubert, 1999), because KM increases efficiency and generates value. These are important whether the organization is a commercial enterprise trying to reduce costs or a government agency competing for shared funding resources.

> We must remember that knowledge is only in the past tense. Learning is only in the present tense, and prediction is only in the future tense. To manage sustainable forests, we need to be able to know, to learn, and to predict.
>
> Chris Maser, 1994

Decision-support Systems

Overview

For the purposes of this discussion, we adopt the definition of decision-support systems (DSSs) from Holsapple (2003, p. 551): 'A computer-based system composed of a language system, a presentation system, a knowledge system, and a problem-processing system whose collective purpose is the support of decision-making activities.' Two key attributes in Holsapple's definition are a problem-processing system and purposeful support of a decision-making process. A decision-making process is a method that guides an individual or group through a series of tasks from problem identification and analysis to design of alternatives and selection of an alternative (Mintzberg *et al.*, 1976).

> Systems that generally fulfil the Mintzberg and Holsapple definitions include multi-criteria analysis techniques like the analytic hierarchy process, Electre, and Promethee; knowledge-based systems that provide a framework for applying procedural or reasoning knowledge to decision problems; and, perhaps somewhat more arguably, optimization systems including linear or goal programming. While geographic information, spreadsheet, and database systems may be critical components of a DSS, it stretches the definition of a DSS beyond usefulness to classify these types of applications as DSSs.
>
> (Reynolds, 2005)

Numerous simulation systems have been developed to support many aspects of forest planning (Schuster *et al.*, 1993; Mowrer *et al.*, 1997), but most should be considered as potential tools in a DSS framework as opposed to DSS *per se* (Reynolds, 2005). In most cases, these systems aid in the analysis phase of the decision process, but fail to directly support the other decision steps.

The adaptive management process provides the theoretical framework for most modern DSSs (Rauscher, 1999; Reynolds, 2005). Adaptive management consists of four components (Walters, 2002):

- Planning. The planning and decision-making process of Mintzberg *et al.* (1976) is a useful supplement to the adaptive management model, the end point of which is a set of goals and constraints that guide the action phase of the process. This phase prescribes how, when and where to implement activities to achieve the identified goals within the constraints. Identifying suitable hypotheses concerning expected outcomes of actions is critical at this stage to support the experimental nature of management actions and promote efficient learning. KM tools may support the identification of possible treatments and likely outcomes.
- Implementation. This phase puts the plan into action. Each activity implemented on the landscape must be adequately documented so that it is clear what the conditions prior to action were and how the management activity changed those prior conditions.
- Monitoring. This phase requires periodically examining the implemented management activities and recording current conditions over time. Adequate documentation must be developed because different people may need to

use this information over many years in order to learn whether goals were achieved by a treatment or not. KM tools may be used here to convert tacit knowledge to explicit knowledge.

- Evaluation. Hypotheses are tested in the evaluation phase by comparing actual and expected outcomes. The learning part of adaptive management comes from the differences found between the actual and expected outcomes and what changes these differences require in the next cycle. Results from this phase provide a starting point for the next iteration of planning (e.g. lessons learned, storytelling).

Future directions

Reynolds (2005) concludes that recent versions of DSSs designed to support ecosystems and sustainable forest management represent great improvements. He writes:

> The task posed to the DSS development community, to deliver effective, integrated decision support for sustainable forest management, was too large and complex to be achieved in a single development cycle. It has required, instead, an incremental and adaptive approach to system design.

In retrospect, it is difficult to understand that we did not anticipate this result. Not surprisingly, much work still needs to be done especially in the following areas.

Improve DSS niche identification

Even analysing only three out of possibly a dozen candidate DSSs, Reynolds (2005) found that each one occupies a different niche based on scale (landscape, forest level, operational level), support for all or only some parts of the four components of adaptive management listed above, access to different decision-analysis methods and an ability to make the entire planning process understandable to the user. There is a great need for all DSSs to be accessible to users and well documented and supported. In addition, there is a need to classify many popular software products such as spreadsheets, GIS and growth-and-yield models to clarify their supporting role within larger DSSs (Rauscher, 1999). Right now, these products reside in a poorly organized 'grab bag' of tools. Many, if not most, supporting resources used by DSSs were not designed to be a part of a DSS. As DSSs proliferate, the problem of clarifying the role of various supporting resources is compounded and logistically, technologically and administratively challenging.

Improve communications between DSSs operating at different scales

Multiple DSSs have been designed to function at the landscape, forest and project scales. Most DSSs embrace a hierarchical approach to planning (e.g. Martell *et al.*, 1998). Only a few definitive examples of integrated, multi-scale forest-resource planning have been described (Rose *et al.*, 1992; Reynolds and Peets, 2001; Vacik and Lexer, 2001). DSSs are rarely able to provide information either up the scale to the next higher level or down the scale to the next lower level (Mowrer *et al.*, 1997; Reynolds, 2005). This issue has been identified, and in some cases explicitly addressed (Camenson, 1998), but these examples are the exception rather than the rule.

Uniformly good support for biophysical, social and economic goals

Most DSSs still do a better job of accounting for biophysical goals than social and economic goals (Mowrer *et al.*, 1997). European approaches to decision support appear to focus primarily on the forest stand or forest enterprise level, with heavy emphasis on timber management support (Rauscher *et al.*, 2005). Due to the heterogeneity of European ecosystems, the landscape level has not been a frequent focus of DSSs so far. The concept of forest sustainability has a long tradition in Europe, and the paradigm is shifting from sustained yield and constant forest cover towards sustainability of an increasing diversity of values, goods and services. Researchers and forest managers in the USA and Canada have had a longer tradition in the development and application of DSSs. So current North American approaches have focused more heavily on non-timber forest products, such as clean water, wildlife and aesthetics, than their European counterparts (Rauscher *et al.*, 2005). More emphasis needs to be placed on improving support for non-timber goals in most DSSs.

Improve group consensus tools within DSSs

Mowrer *et al.* (1997) reported that tools for building group consensus were entirely missing from all DSSs examined. This deficiency is no longer as pronounced as it once was, as we review several recent developments in the section on multiple-criteria decision making below. Wide-scale acceptance and use of DSSs by the forest management community will depend to a great extent on how well these applications permit group participation in decision making. Successful group consensus tools will require designing the software with a human behaviour focus rather than a technical focus.

Improve use of DSSs by the management community

Capabilities of DSSs are expanding, and the systems are being used more frequently. Nevertheless, DSSs have not yet been widely adopted as standard tools for forest management in most areas of the world (Lexer *et al.*, 2005). We sense, however, that we are approaching a turning point – existing DSSs may soon be mature enough for forest managers to routinely use for complex decisions. More evaluations and case studies need to be conducted with management participation in order to gain widespread acceptance.

Improve support for implementation and monitoring

Evaluation and planning are typically performed over short time spans and in close temporal proximity to each other. However, implementation and monitoring are recurring activities that may be spread over many years in a typical adaptive management cycle. Speculating a little, one might imagine a collection of new system components, such as task-scheduler and task-management agents, helping to assure that implementation plans are staying on track and that data are updated and summarized. They could even be helping to spot evidence that might trigger initiation of a new management cycle. It is difficult to overstate the significance of decision-support implementations for these phases of the process. When we have learned how to provide practical support for the implementation and monitoring phases of the decision process, forest managers will be able to provide convincing demonstrations of successful adaptive management (Reynolds, 2005). Currently such efforts are extremely limited by time, money and support tools.

Provide greater flexibility for choosing alternatives

Simon (2003) observed that:

> In decision theory, the discussion of choice criteria has largely focused on two polar opposite alternatives: optimizing, that is, selecting the best alternative according to some criterion; and satisficing, that is, selecting an alternative (not necessarily unique) that meets some specified standard of adequacy.

Optimization methods have been criticized primarily because: it is difficult to incorporate real-world complexities into the mathematical approaches; solution mechanics have made it extremely difficult to explain to users why the solution came out as it did; and it takes a great deal of formal education and mathematical expertise to properly formulate a problem (Gigerenzer and Todd, 1999; Simon, 2003). The satisficing methods have been criticized primarily because solutions are not optimal. Despite a few dissenting voices (Howard, 1991), forest scientists are found overwhelmingly in the optimization camp. Many modern DSSs designed to address ecosystem and sustainable forest management problems use the satisficing method (Andersson *et al.*, 2005; Lexer *et al.*, 2005; Twery *et al.*, 2005). We believe that both satisficing and optimizing methods are legitimate strategies for choosing among alternatives. DSSs should routinely offer a wider range of alternative selection tools than they typically provide today.

Multi-criteria Decision Making and Satisficing

Overview

A traditional decision analysis has three elements: (i) a decision maker; (ii) a set of feasible alternatives; and (iii) a well-defined criterion (or objective) by which each alternative can be mathematically evaluated (Romero and Rehman, 2003). This objective function is commonly augmented with a set of mathematically defined constraints. One of many optimization algorithms can then be applied (depending on the form of the problem) to find the optimal value for the objective function within the feasible space.

The early successes of operations research methods resulted primarily from their focus on well-constrained problems in tactical planning. These methods were developed to address needs in industrial and business operations, where inputs, outputs, resources, actors, flows and other problem components could be described with completeness and certainty. Gradually these operations research methods were applied to planning in forest and natural resources management. In an era of forest management that was focused primarily on timber harvesting – with its real similarities to industrial operations – direct application of these optimization methods seemed to work well.

Traditional optimization-based decision analysis depends, however, upon some critical fundamental assumptions. One of these assumptions is that the decision maker is seeking to optimize a well-defined single objective (Klein and Methlie, 1990). A second assumption is that not only is there one best 'right answer' but it can be discovered through an objective technical process (Smith, 1997, p. 420). A third assumption is that the natural world is both predictable and knowable in a mechanistic and deterministic way (Smith, 1997, p. 420). All that is needed is to collect enough data. Finally, it is assumed that the values provided for mathematical expression are known quantities with no uncertainties. In situations where any one of these assumptions cannot be reasonably justified, any selected solutions, while possibly good ones, are no longer optimal. Given these constraining preconditions, then, some would ask why we use such exacting methods. In fact, optimization analyses have been quite successful in many situations. They have excelled in addressing mathematically well-defined problems and in addressing the quantitative components of larger problems.

However, Romero and Rehman (2003) posit that it is equally true that there exists considerable evidence that undermines the validity of the assumptions behind optimization. The primary argument is that, while traditional optimization processes are mathematically and logically sound, such formulations simply do not reflect real-life problems faithfully enough (Mendoza and Martins, 2005). As Levy *et al.* (2000) noted, ill-defined and messy problems create a decision environment containing imprecision and conflicting performance indicators. The previously applied optimization methods were difficult to fit reliably and effectively into this framework. In many situations, problem complexity prevents formulation of an adequately representative utility function (Gigerenzer and Todd, 1999; Romero and Rehman, 2003; Simon, 2003). Natural systems 'can be surprisingly simple and still be too complex for us to predict exact conditions only moderately far into the future' (Smith, 1997, p. 421). Furthermore, considerable uncertainty often exists in the data used to formulate the problem. Even multiple-objective programming (Mendoza *et al.*, 1987) and multiple-objective fuzzy linear programming (Gupta *et al.*, 2000) are essentially extensions of the linear programming model to several well-defined objectives. To address this new class of decision problems, multiple-criteria decision-making (MCDM) techniques were developed, beginning in the 1970s. Stewart (1992) reviewed those approaches, and Mendoza and Prabhu (2000) identified several important features of MCDM, including:

- Accommodation of multiple criteria (or attributes) in the analysis.
- Allowing direct involvement of multiple experts, interest groups or stakeholders.
- Not data-intensive: expert opinion can be used in place of data.
- Effective for both quantitative and qualitative data.
- Transparent analyses so that participants could understand what was happening and why.

In reality, the decision maker is frequently looking for an optimal compromise among several objectives. That situation may call for MCDM or for satisficing a set of goals. We first discuss MCDM in more detail, followed by a very brief overview of satisficing.

Multiple-criteria decision-making theory

One of the earliest MCDM methods is multi-attribute utility theory (MAUT) or value theory (Keeney and Raiffa, 1976; von Winterfeldt and Edwards, 1986). In its simplest form, MAUT provides a set of utility functions (one function for each attribute, or performance indicator), and then scores each decision alternative on each attribute. Scores across all attributes are combined for each alternative (often using an additive model), with individual attribute scores being appropriately scaled for comparability and weighted according to importance. The decision alternative with the highest aggregate utility (or value) score is then preferred. This general MAUT framework has spawned a large number of variants. Each variant modifies one or more aspects of the traditional implementation: to assign weighting values, to scale attribute scores, to combine scores across attributes (e.g. non-additive models), to elicit utility functions, etc. As a result, MAUT has been modified in a wide variety of ways. Furthermore, MAUT has been augmented by other multiple-criteria decision methods and other decision aids to make it more complete in some cases and to improve its applicability in other cases.

Another MCDM approach that was developed about the same time as MAUT and has all its components is the analytical hierarchy process (AHP). The AHP provides for: decomposition of the decision problem into a multi-level hierarchy of criteria, direct pairwise comparisons of the decision alternatives (or, alternatively, rating them individually) and rigorous mathematics to generate a preference structure for the alternatives. Schmoldt *et al.* (2001) describe many applications of AHP to environmental and natural resources decision making. While many have used the AHP as an MCDM technique by itself, others have used it in combination with other MCDM methods (e.g. Prato, 1999; Lexer, 2000; Hill *et al.*, 2005). In other MCDM developments, Leskinen *et al.* (2003) have used statistical methods to estimate ecological values and to account for interactions among the decision variables. Drechsler (2004) demonstrated the integration of quantitative population models with MCDM to evaluate decision conflicts. Recently, the network structure of the analytical network process has been used to model the complexity of forest decision problems in evaluating sustainable forest management strategies by using a criterion and indicator approach (Wolfslehner *et al.*, 2005). These several examples, and many others not cited, attest to the versatility and extensibility of MCDM methods in general.

Future directions for MCDM

Research in MCDM methodologies continues at a rapid pace to improve their problem-solving power. The following R & D areas represent several of the most active.

Integrating geographic information systems

Given the geo-spatial context of most forestry decision problems, it is not surprising that considerable recent effort has gone into integrating geographic information systems (GISs) and MCDM (Jankowski and Nyerges, 2001; Jankowski *et al.*, 2001; Feick and Hall, 2004; Sakamoto and Fukui, 2004; Hill *et al.*, 2005). Map-based displays enable better elicitation of utility functions and present decision results in ways that encourage understanding and iterative analysis.

Support for group decision making

Because single individuals rarely make natural resource management decisions, group decision making has become a priority topic in MCDM. Empirically, we have come to understand that group decisions are typically better than average individual performance, but rarely as good as the best individual. Hence, while there are many other reasons to engage groups in decision processes, making the best decision choices is not one of them (Schmoldt and Peterson, 2000). These include broad ownership in the decisions and their implications, support for implementation of decisions, more complete coverage of all pertinent issues and viewpoints during the decision process, and the appearance of an open and inclusive decision process. Examples from this rapidly expanding MCDM focus area include Mendoza and Prabhu (2000), Schmoldt and Peterson (2000), Jankowski and Nyerges (2001), Jankowski *et al.* (2001), Feick and Hall (2004) and Thomson (2005). Given the growing importance of inclusive and open decision processes in forestry, it is reasonable to assume that participatory decision making will continue to generate new developments in and variants of MCDM. Some efforts have already gone into adding MCDM to virtual meeting environments, which currently include such things as group whiteboards, shared documents, audio/video connectivity, voting and Delphi processes (Kangas and Store, 2003). As with many other technologies, MCDM will need to become network-accessible so that decision-making processes and/or results can be shared among geographically dispersed participants and stakeholders.

Expanding the suite of tools compatible with MCDM methods

Opportunities exist for expanding the repertoire of techniques available for MCDM. For example, the above applications of the AHP and GIS, in combination with other MCDM methods, have proved to be very effective. Traditional optimization or simulation techniques can also be used to generate biologically possible or economically feasible alternatives for evaluation within MCDM approaches (Kangas *et al.*, 2000; Kangas and Store, 2002). There exists a large toolkit of quantitative methods that can be very useful as part of a broader MCDM framework.

Incorporating risk and uncertainty into MCDM methods

Because all decisions occur in an uncertain environment and decision results can have uncertain consequences, greater effort is needed in measuring the uncertainty and risk associated with alternatives. While a decision alternative may be chosen precisely because it is expected to lead to a desired future condition, there may also be considerable risk associated with that alternative. The likelihood of attaining the future condition may be low or the potential for undesirable side effects may be high. Currently much of this type of risk assessment needs to be considered by the decision maker outside the formal MCDM process, where it is exogenous, rather than integral, to the decision analysis process.

Satisficing solutions

As a decision-making method, satisficing differs markedly from optimization or MCDM. The originator of the satisficing concept, Herbert Simon, argues that a large body of evidence shows that people rarely actually engage in optimization (Simon, 2003). Even knowledgeable experts in the fields of optimization and decision analysis readily admit that they rarely apply formal decision methods in their personal lives (von Winterfeldt and Edwards, 1986), even when a high-stakes decision is involved. Why? Because obtaining detailed data and trying to predict future behaviour of complex natural systems is a time-consuming and expensive proposition (Smith, 1997). People are inclined naturally towards the satisficing approach. They limit their input data to the most important and available information. They limit their alternative courses of action to a small set of possibilities. They choose the most acceptable option from that limited set rather than attempting to seek an optimal solution (Smith, 1997; Simon, 2003). In addition, wise satisficers make sure to monitor results of decisions to detect failure as soon as possible and then decide on corrective actions, which may lead to choosing another alternative.

Satisficing implemented as a decision process in DSSs depends upon the existence of goals, also called objectives or targets. Each goal must have one or more measurement criteria, which can be determined by measuring the current state of affairs or estimated for some simulated future state (Nute *et al.*, 2000; Rauscher *et al.*, 2000). Once these goals and their measurement criteria exist, decision makers: (i) generate possible courses of action in numerous ways; (ii) measure or predict the goal criteria; and (iii) evaluate how well the goals as a set, and individually, have been achieved. This process of alternative generation and simulation is repeated until: (i) the goal criteria are satisfied; (ii) the satisficing criteria for unachievable goals are adjusted downward so that they can be achieved (reality adjusts perceived values); or (iii) satisficing criteria for easily achievable goals are adjusted upward to obtain and maintain goal achievement at a higher level than originally thought possible.

Satisficing has numerous attractive characteristics (Simon, 2003):

- The decision process is relatively cheap because all possible alternatives need not be addressed.
- Since measurement criteria for goals are commonly defined as some threshold value, e.g. grassy openings must occupy at least 5% of the area of the property, the requirement for precision in simulating the future is significantly reduced.
- There is no requirement to create and agree upon a single utility function from multidimensional goals.

- Because the computational task is relatively small and the mathematical formulation of the problem is very simple, a high educational level is not required to implement the process.
- The causal relationships among the goals, the measurement criteria and the simulated state of forest ecosystems are relatively easy to explain to decision makers and stakeholders.

Future directions for satisficing

The satisficing method of alternative selection and goal satisfaction is currently underutilized in the natural resource field. More research is needed to compare and contrast satisficing with the various MCDM methods. It may be entirely possible to combine the two approaches in a very effective way.

Alternative selection and goal satisfaction methods differ significantly in effort and cost. Research to better match the risk of arriving at a poor solution with the total effort expended can be expected to yield effective guidance to managers. Most problem situations require forecasting the consequences of actions taken today on the forest landscape at some point in the future. The further out into the future the forecast, the more unknowable and uncertain the predictions are likely to be, until a point is reached where even pretending to predict the future is absurd. We need to scientifically examine when and whether it makes sense to invest large amounts of effort and money on choosing alternatives based on forecasting changes in the forest landscape unrealistically far into the future. The proponents of satisficing would argue that it is better to spend less effort and money on the front-end of the decision problem and more on inventory and monitoring to detect failure as soon as possible. It is this failure detection that is at the heart of the adaptive management idea. Coupled with the rather low-cost satisficing decision approach, increased inventory and monitoring would allow early detection of problems based on reality rather than overextended theory and potentially untrustworthy forecasts.

Conclusions: How Can We Best Support Sustainability?

The scientific community is slowly coming to grips with the concept of sustainability. An inherent difficulty with this concept has been that, unlike traditional scientific investigations that seek to explain how things currently function or how previous events led to current phenomena, sustainability research is forward-looking, with the goal of understanding how both current and future societal needs can be met (Schmoldt, 2004). This goal is further complicated by an imperative for maintaining ecological and environmental integrity as well as staying within the parameters set by what is socially acceptable and economically feasible. The function of a decision-support system is to organize the decision process and provide flexible, on-demand access to the full array of methods and tools applicable to a particular problem situation (Rauscher and Reynolds, 2003). In this context a 'good' decision is one that is made based on a thorough understanding and analysis of the problem (Holloway, 1979). There is no guarantee that a good decision will always achieve a good outcome in terms of sustainability. The consequences of a 'good' outcome are favourable with respect to the preferences of the decision maker. A decision resulting in a bad outcome could still be considered a good decision as long as the decision-making process indicated the possibility of a bad outcome. The presented methods and tools provide a proper documentation of the decision-making process. Thus, rationales and information used in arriving at a decision can be compared with the achieved outcome, which enables better decisions in the future.

As the new sustainability sciences, such as ecological economics, industrial ecology, environmental geology and ecological engineering, organize themselves and advance, we can cooperate with scientists in these new fields to help them reorganize what we currently know, using our full KM toolkit. Much progress can be made relatively rapidly by drawing new boundaries of knowledge or by connecting existing data, information and knowledge in new ways (e.g. Vacik *et al.*, Chapter 23, this volume). As new data, information and knowledge are created, we can use our KM tools to rapidly integrate that new content into the existing body of knowledge. We can also share that content cheaply, widely and immediately. There is no doubt that such integration is technologically feasible; what is missing now is a shared vision and the political will to implement it. The KM sites of Table 26.1 provide excellent support tools for this objective.

We need to be concerned with how to make available both tacit and explicit knowledge. There is a temptation to concentrate primarily on explicit knowledge because it is tangible; we can readily organize it, check it and build taxonomies for it. Tacit knowledge, on the other hand, is messy. It moves from person to person and group to group. It grows and changes as it moves. KM professionals will have to continue to facilitate this movement of tacit knowledge (Dixon, 2000). The inexplicit nature of our understanding regarding sustainability concepts (their definitions) and practice implies that our knowledge management skills and tools will be severely challenged. This problem is further exacerbated by varied and inexplicit value systems (national, local and organizational), which must enter into any sustainability discussion. The struggle to implement the concept of sustainable forest management can be supported by many of the more tacit knowledge-oriented tools of Table 26.1: communities of practice, free-content information collaborations and best practices and lessons learned sites.

We can use our existing DSSs to define new goals and measurement criteria that better address forest sustainability. The use of MCDM and satisficing techniques and their various combinations will allow us to model the trade-offs between conflicting resource goals and will help us to identify compromise solutions. From there, we can identify in very precise terms what data, information and knowledge are needed to make the kinds of decisions we are looking for. On the other hand, a tension exists between the application of DSSs and the present use of inventory data. It may not even be possible to inventory a measurement criterion in a real forest or forecast the future value of that measurement criterion by using currently available prediction systems. Such examples are numerous and provide great opportunity to focus new research efforts to fill these major knowledge gaps.

Some people have advocated models designed to signal ecological problems before they occur – *anticipatory* research. Most ecological models are not constructed with this intent in mind, and few researchers place sufficient confidence in their models to extrapolate to unrecognized problems. However, with proper attention to ecological scale combined with a system science approach to investigation, we may have the tools in place to conduct anticipatory research. Given a sufficiently sound understanding of a system's dynamics and modelling those dynamics at the appropriate scale(s), we may be positioned to make informed predictions about system behaviour within an ecologically meaningful context. Armed with this knowledge, we will be positioned to direct policy discussions – if not policy itself – towards sustainable practices. As our environmental problems become more complex and far-reaching, the ability to anticipate impacts (or understand them shortly after they are uncovered) will greatly improve our reaction time and inform our alternatives.

Policy science must play an important role in the effort to define sustainable forest management and design implementation strategies. There is great opportunity to better understand the nature of the environmentally based conflicts that have energized a broad spectrum of the world's public. Policy scientists must take the forefront in analysing and communicating results from such studies. Another important focus area for policy science is the area of group decision-making dynamics and methods. There is an urgent need to analyse and summarize the experience of the last 20 years and communicate the results as lessons learned and best practices for group decision making. Finally, policy scientists should increase their focus on examining the environmentally based conflicts from a global perspective with a view to crystallizing the descriptive, factual knowledge. Who produces what kind of forest product and who consumes it in what quantities? Which forest regions in the world are best suited to sustainably produce what kind of product and in what quantity? What are the social, economic and ethical consequences for a country to reduce its forest product production while at the same time increasing the quantity of forest products it imports from other regions of the world? Such questions and their answers need to be widely known and commonly agreed upon before a truly sustainable regional and national forest management policy can be successfully implemented. The many powerful tools of KM can help us achieve these goals.

Note

1. Trade names are used for informational purposes only. No endorsement by the US Department of Agriculture is implied.

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SUSTAINABLE FORESTRY: FROM MONITORING AND MODELLING TO KNOWLEDGE MANAGEMENT AND POLICY SCIENCE

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