Computers and Electronics in Agriculture
27 (2000) 57–70

Computers
and electronics
in agriculture

www.elsevier.com/locate/compag

Knowledge elicitation tools for use in a virtual adaptive environmental management workshop

Alan J. Thomson *

Pacific Forestry Centre, 506 West Burnside Road, Victoria, BC, Canada V8Z 1M5

Abstract

Adaptive environmental management (AEM) deals with the complex interactions of social, environmental, and economic systems, and incorporates the knowledge, values and opinions of many stakeholders and experts. AEM has traditionally been centered on a structured series of workshops to define possible management actions and the indicators used to assess the actions, and generally leads to the construction of a model for exploration of the management options in a consensus-building exercise. There is an optimal group size for the workshop process; however this limits the ideal of including all stakeholders in the process. There are also time and cost constraints on the workshop approach. A new approach to the AEM process has been developed based on the concept of a virtual meeting space, in which stakeholders and experts can interact in a distributed system development process over an extended period of time. The AEM system is based on Java applets, which interact over the world wide web. These applets function as graphical knowledge elicitation tools. A stand-alone version run on a laptop computer by an extension specialist permits use in situations where there is no Internet access, or by individuals or groups who do not have the required computer experience.

Keywords: Knowledge elicitation tools; Adaptive environmental management; Workshop; Round table

1. Introduction

Adaptive environmental management (AEM) is a process which uses management interventions to probe the functioning of ecosystems (Holling, 1978; Walters, 1986; 1993; Gunderson et al., 1994). The choice of interventions and the indicators

* Tel.: + 1-250-3630632; fax: + 1-250-3630775.
E-mail address: athomson@pfc.forestry.ca (A.J. Thomson)

0168-1699/00/$ - see front matter
PII: S0168-1699(00)00097-1

of performance are selected based on their ability to differentiate among hypotheses concerning uncertainties about the systems being managed. The process is generally based on a series of workshops (in other circumstances sometimes referred to as round tables) involving stakeholders, domain experts and managers, and in many cases results in development of a computer model used for synthesis, consensus building, and for exploration of alternative scenarios.

The adaptive management approach underlies the formation of adaptive management areas (AMAs) in the Pacific Northwest of the USA (Stankey and Shindler, 1997), in which it has been concluded that, for the process to work, there is a need for (a) broad public representation, (b) a willingness to honor the legitimacy of the range of concerns identified and the knowledge revealed, and (c) a capacity for interested citizens and communities to have a 'real' ability to participate in, and an influence on, AMAs. Access to knowledge and the capacity to interact with, and contribute to, that knowledge are crucial. These are issues of power: who gets to participate, who has the principal influence, who makes decisions. Stankey and Shindler (1997) suggest that effective adaptive management must explicitly confront the issue of power distribution, and must ensure that equal access to resources is provided, even if this involves designing processes that give a higher profile to stakeholders that are weak. Power issues are fundamental in environmental ethics (Thomson, 1997).

Adaptive management needs to maintain, or even create, an open political process, and consequently must be a social as well as scientific process. The policies that are explored will often be implemented through local institutions. The exercise must seek to transfer knowledge and understanding to local individuals, encouraging the formation of networks of individuals which bridge institutional boundaries.

The idea that computers can be used to mediate the networking process for collaborative knowledge creation — 'socio-media' (Barrett, 1992) — leads to the concept of a 'virtual workshop' or electronic meeting space, in which the knowledge creation task is distributed over time and space. An 'electronic round table' has already been proposed for resolution of environmental conflicts (Lake, 1993). While software products of the groupware category exist to facilitate this type of interaction, these products lack a number of features (Grudin, 1989) that would appear necessary to successfully implement a distributed system for AEM.

In the present study, a system (AEM_Web) for distributed knowledge elicitation and management using Java applets communicating over the world wide web (WWW) is shown to facilitate many of the desired features of the adaptive management process. These features are discussed in relation to (a) providing knowledge acquisition and knowledge-building tools, (b) mimicking the workshop process, and (c) providing linkages between stakeholder knowledge and models of system behavior. The applets described in the paper mimic graphical exercises, using blackboards or flipcharts, experienced by the author in actual AEM workshops. The evaluation of the knowledge is independent of whether it is elicited through this virtual workshop process, or face-to-face in a real workshop, and is beyond the scope of the present paper, which addresses only the knowledge elicitation features of the system; the evaluation, integration and application of the knowledge will be described elsewhere.

2. Java applets

Java applets are programs that are downloaded from a web sever to run in the browser of a client computer. Applets permit manipulation of graphical objects whose properties can be passed to the server for storage in a database, permitting development of graphical knowledge elicitation tools more powerful than the simpler text or numeric knowledge elicitation inherent in HTML-based forms. New approaches to design of web-based systems (Thomson et al., 1998) facilitate deployment of multilingual systems — users can enter knowledge and browse existing knowledge in their own language[1]; the present system is designed for multi-lingual use.

3. Mimicking the workshop process

The first step in the AEM workshop process is the identification of context, objectives and players (including experts, facilitators and stakeholders). This normally is initiated by an individual with a management role in an organization or agency, and involves establishment of a steering committee. A similar process occurs with AEM_Web, but rather than inviting a selected group of stakeholders, a wide range of stakeholders can participate. A registration policy may be adopted to permit active (knowledge entry) as opposed to passive (viewing/browsing) participation. In an electronic meeting environment, with both 'drop-in' and 'concurrent' users, the role of the core group, who manage the process and who may perform modelling and analysis, may change from that described in Holling (1978).

The two major workshop processes that must be mimicked are plenary sessions and sub-group or breakout sessions. The plenary session performs the spatial and temporal scoping of the system, identifying management actions and indicators, and is the primary consensus-building arena. During the plenary session, the major subsystems and their inputs and outputs are identified, and each subsystem becomes the focus of a separate subgroup session. The subgroup sessions are concerned with development of the algorithms to relate outputs to inputs, and involves issues of data collation and data analysis. Competing hypotheses are identified and appropriate test data sets defined. A simulation modelling activity may then be developed to link the subsystems together to permit exploration of scenarios in a gaming process. At this time, major knowledge gaps are identified and decisions for future activities resolved.

[1] A bilingual diagnostic system can be seen at http://www.pfc.cfs.nrcan.gc.ca/health/td_web/. A similar bilingual system (a forestry researchers directory) that includes knowledge-entry and knowledge editing can be seen at http://www.pfc.cfs.nrcan.gc.ca/cfrd/.

4. The virtual workshop

The main interface screen for the virtual adaptive environmental management workshop (Fig. 1) has links to the various activities that are part of the workshop process: goals and questions, spatial scope, temporal scope, actions and indicators, and the simulation model. Items in bold text are available for both browsing and input; items in normal text are closed and are available only for browsing, while grayed-out items are not yet available for interaction.

The web-based workshop functions in a 'drop-in' mode of operation. In the 'drop-in' mode of operation, individuals can access web pages that permit browsing of the current knowledge content of the system, adding new knowledge and possibly modifying knowledge which they had previously entered themselves. To maintain some essential sequencing requirements of the workshop process, there will be periods when sessions are open for browsing and interaction, and other periods when only browsing is permitted. The process begins with an interactive plenary session. This can be followed by a period in which the sub-groups are active, while the material from the preceding plenary session is available only for

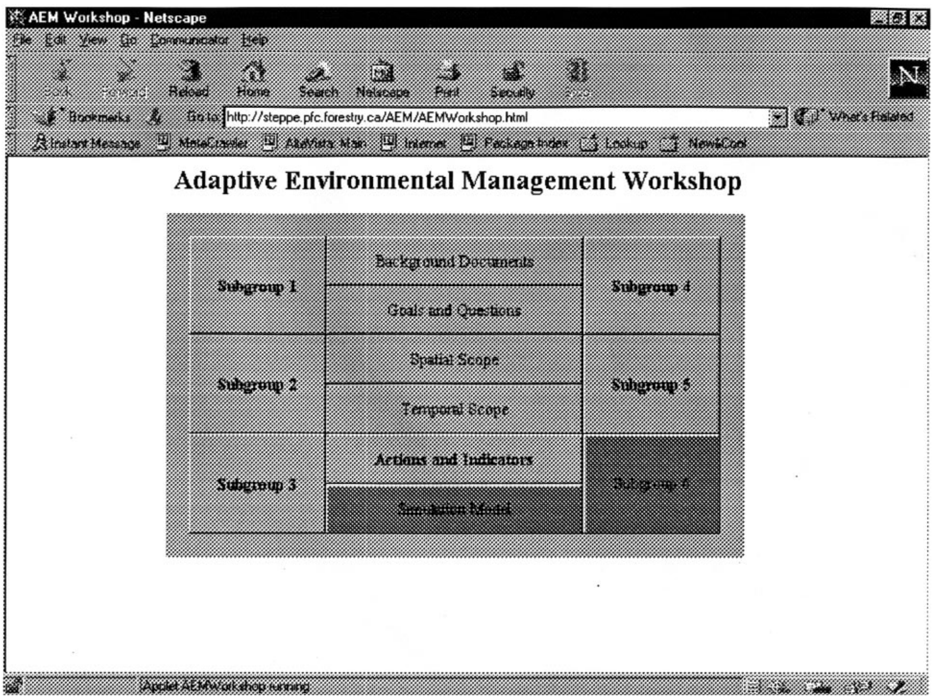

Fig. 1. The electronic workshop applet showing the functions of the plenary session and their status (bold represents open; normal represents closed; grayed out represents pending), as well as the available subgroups. The shading and bolding pattern here represents a workshop in progress. Initially only the background documents and goals and questions may be open.

browsing, and so on. Even within a subgroup session, some parts may be restricted to viewing after some time has elapsed. These sessions will be centered on the use of a range of knowledge elicitation tools. The presentation will continue with a description of these tools, and will conclude with a description of the use of the tools in the AEM_Web environment.

5. Knowledge elicitation tools

5.1. Goals and questions

The opening plenary session is initially concerned with the identification of the range of alternative management goals and questions to be answered. This is accomplished by use of a discussion web, which is easily implemented using the FrontPage web server management software (Jones and Randall, 1997). In a discussion web, as a person participates in a particular thread of discussion, their comments are automatically included as new web pages. A convention is adopted in which the first message of each new discussion thread is a keyword (either 'Goal' or 'Question'), followed by the goal or question itself. This facilitates automated extraction of goals and questions to a database, together with the URL of the discussion thread associated with it. The relational database structures in which this, and all other elicited knowledge, is stored, is beyond the scope of this presentation.

5.2. Spatial scope

Having achieved consensus (or at least closure) on the questions and management goals, the next step is the spatial and temporal scoping. Four aspects of spatial knowledge are elicited: the maximum North-South and East-West extent of the area of interest; the specific themes and areas of interest of the different stakeholders; an indication of landscape features of significance; and flows and linkages among sub-areas.

The extent of the area of interest is identified through the discussion web. Areas of interest for specific themes can be entered as polygons on maps in an applet window (Fig. 2). This provides a rapid but rudimentary GIS function for spatial knowledge elicitation. Flows within the system, such as predominant wind patterns or animal migration routes, are entered as arrow-shaped polygons on a base map in the applet window (Fig. 2). Breadth of the arrow stem can indicate magnitude. These are stored along with a text description, and can be subsequently used to guide the linkages among the geographic units of the system to define processes such as dispersal (Thomson, 1979, 1991).

It must be emphasized that the spatial scoping applet is not intended to supplant a true GIS function; rather, it is intended to augment a GIS capability. A GIS will often be used to generate the background images on which the polygons are digitized in the applet, and in turn, the polygon data may be imported into a GIS for further manipulation and overlay.

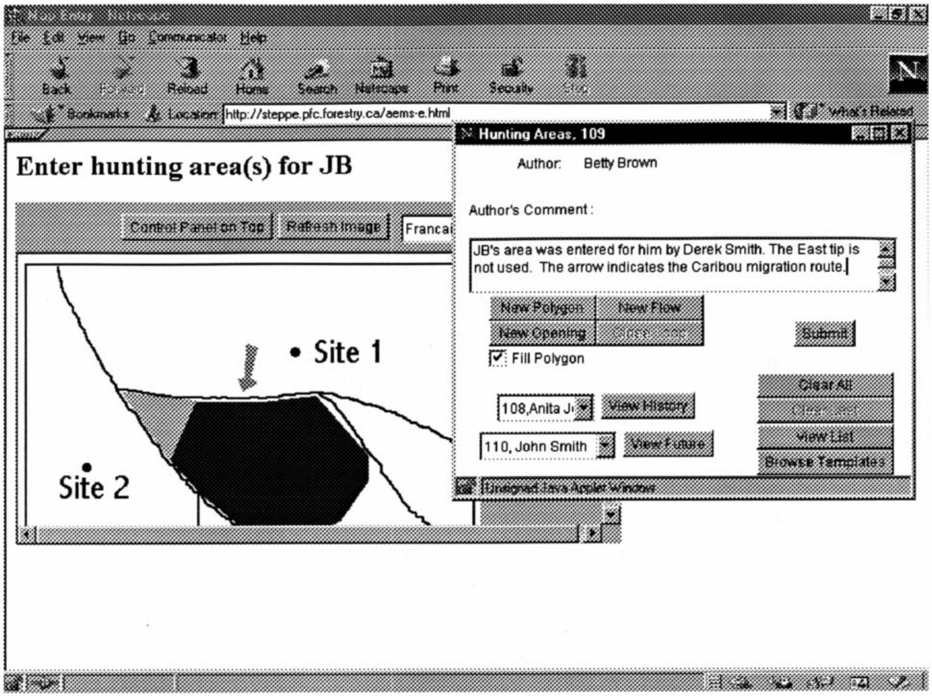

Fig. 2. Entry of thematic information as polygons. Arrow-shaped polygons indicate flows.

5.3. Temporal scope

Opinions on the long-term scoping (duration of the analysis in years) are entered through the discussion web. Knowledge of events falls into a number of categories: the start of an event, the end of an event, a peak year, a trough, or a contributing event (such as spraying of an insecticide). Metaknowledge associated with the event could include details of assessment method; the description of the assessment method helps resolve differences among observations. This information helps in the formulation of appropriate indicators, which is the topic of a subsequent section. All information about long-term and short-term scoping in the knowledge base is available for browsing, so people can enter alternative views of events.

Timings and magnitudes of events happening during a year are entered using an applet (Fig. 3) that adds peaks or troughs by clicking above a particular month. Similar applets are available for events that occur during a day (a 24-h x-axis), or in years over a longer period (up to 100 years).

Both the temporal and spatial applets have a number of common features related to tracking the evolution of knowledge. Each applet has a comment field where the reasoning behind a graph can be described. Supporting data files, which can be archived at a central location, can be indicated. Knowledge previously entered in the system can be used as the starting point for new entries, by modifying the older ones. The old entries are not changed; rather, they are entered in a history list. For each graph, therefore, its past and future can be explored.

In Canada, where there are two official languages, systems developed by the federal government must be bilingual. It is possible to switch between (or among) languages. The underlying data does not change, but the language used for all buttons and labels changes. Entries in the comment fields can also be translated if desired.

5.4. Actions and indicators

Having addressed the spatial and temporal scoping of the system, possible management actions for evaluation and indicators to assess these actions are considered. The actions and indicators are displayed in a Leopold Matrix as discussed by Holling (1978). The initial status of this matrix is based on the purpose of the workshop, with the applet permitting addition of elements (Fig. 4). Both the magnitude and significance of the effect of the action on the indicator are entered. When viewing the matrix, the average magnitude and significance for all entries relating to that action/indicator interaction is displayed. However, by selecting the link from a cell of the table, details of each entry can be examined, as well as entering one's own view. Codes are used to represent the actions and indicators. The initial letter of an indicator code is a reference to the subgroup to which is

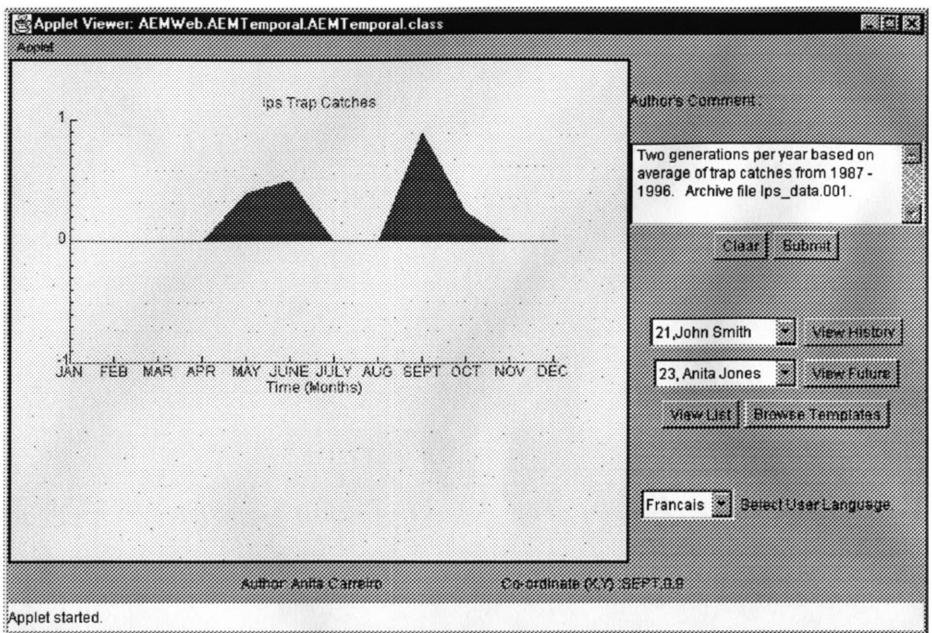

Fig. 3. Example of the temporal scoping applet, showing two generations of an insect population during a year.

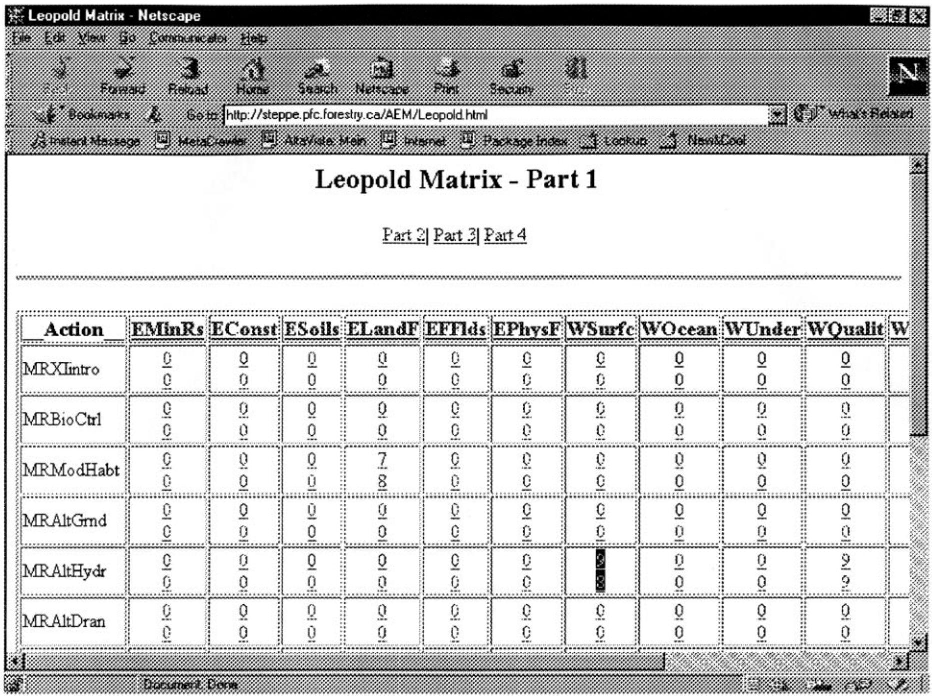

Fig. 4. A hypothetical example of the Leopold Matrix system showing the interactions of actions and indicators. The upper number of each pair (highlighted) is the magnitude of the impact while the lower number is the importance. The actions and indicators for this example are from Appendix A of Holling (1978).

assigned the responsibility for providing that indicator value. Users can enter a dialogue with the workshop facilitators (e.g. by email) regarding indicator groupings, and the facilitators can provide a digest of the rationale. Howells et al. (1998) also describe an electronic version of the Leopold Matrix.

The name of each indicator is actually a link to an overview of all stakeholder values involving that indicator, as described below.

5.5. Specific relationships

The simplest knowledge elicitation tool for particular relationships is provision of the ability to place points on a graph, selecting a symbol, color and size. The information represented by the symbols, like all the information entered into the system, is stored in a relational database on the server and includes the identity of the author of the information. The identity is used to permit subsequent modification of the information by the author. It is possible to click on a symbol and retrieve the associated information, including metaknowledge such as the identity of the author or date of entry (Fig. 5). The distribution of points and their attributes assists the system developers in defining the relationship.

The dynamic capabilities of Java applets permit assigning many graphical attributes to a point through the use of animation, thus points could also be assigned characteristics such as spin, vibration, shrinking and enlarging, or color cycling. Visualization of these added attributes could assist in assigning factors that modify the basic relationship.

Elicitation of complete relationships is facilitated through another applet which permits selection of a basic functional form followed by manipulation of inflection points and asymptotes (Fig. 6). These functional forms capture critical ideas regarding non-linearities, thresholds and time delays. Metaknowledge entered would include a statement of assumptions and an indication of appropriate test data.

The preceding two applets elicit knowledge of the processes in the system. The third applet in this category elicits the values of particular stakeholders, in order to answer the question 'What does this mean to me?'. Construction of a stakeholder value-indicator list (Thomson 1993; Akenhead et al., 1996), which records the reaction of the stakeholder to various levels of the indicators, is accomplished in two stages. First, indicators of interest are selected from a list of all the indicators currently in the system, then these indicators are presented in the form of a pie chart which can be used to indicate the relative importance to the stakeholder (Fig. 7). That stakeholders' values are included in the summary of each indicator

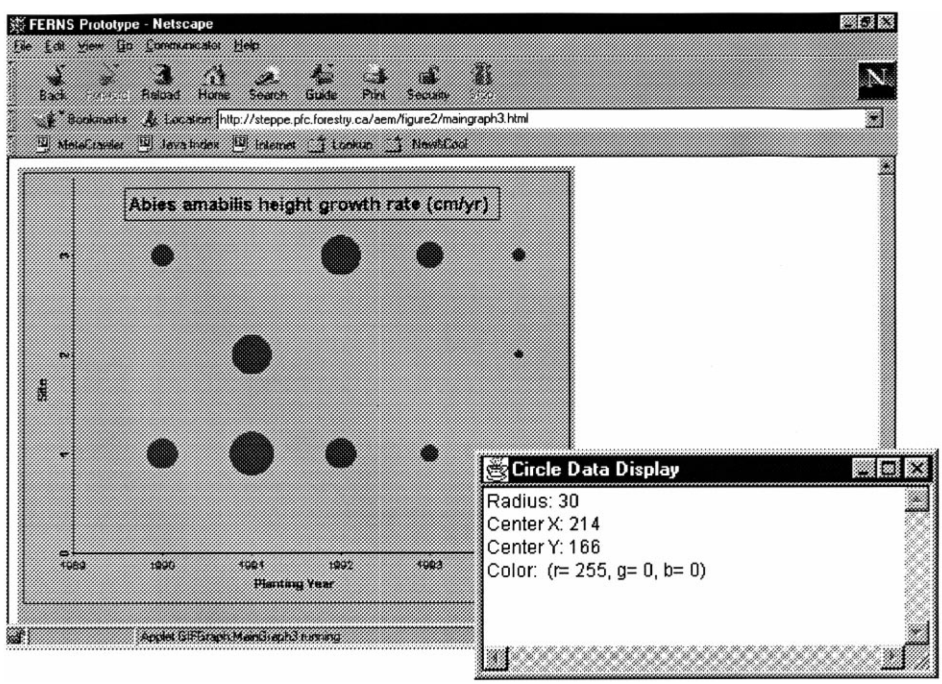

Fig. 5. An applet which permits adding points to help in defining a relationship. The figure also shows the metaknowledge associated with one of the points, viewed by clicking on the point.

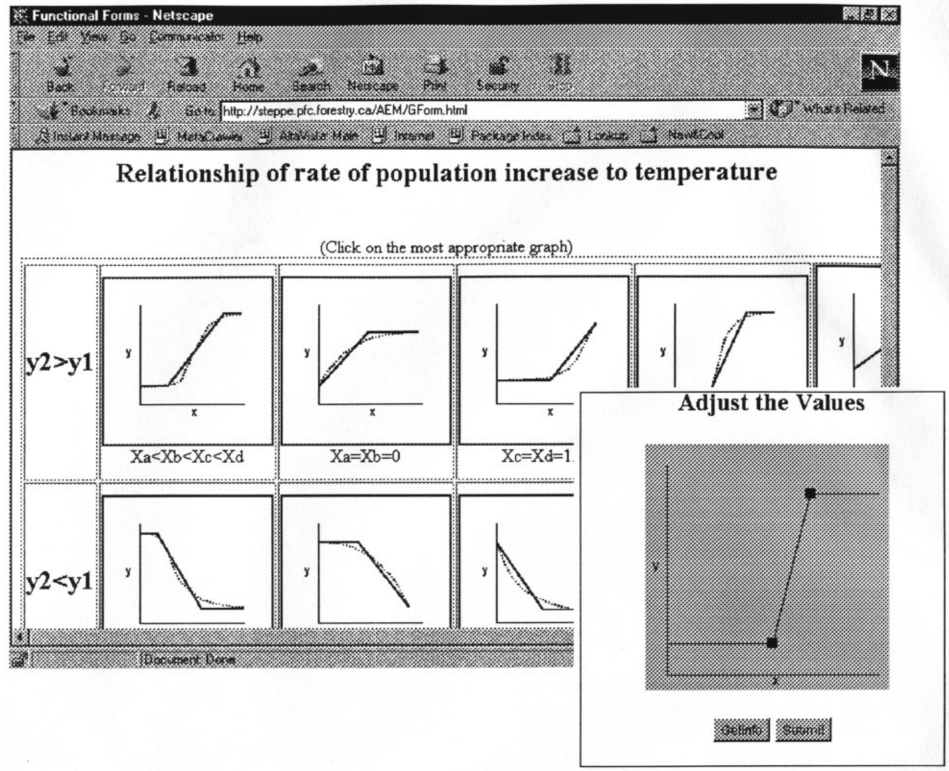

Fig. 6. Elicitation of knowledge regarding functional relationships. Clicking on one of the graphs activates an applet (inset) permitting manipulation of thresholds and inflection points by dragging the boxed handles.

available through the Leopold Matrix described above. The role of the AEM process in conflict resolution is through explicitly considering the specific indicators of all stakeholder groups; the indicators in the figures are an example only, specific indicators are derived for each particular situation. Conflict resolution may also involve contrasting the effects of different hypotheses on indicators evaluated in a simulation model.

6. Subgroups

Buttons link to the available subgroup applets (Fig. 8) from the main workshop applet (Fig. 1). In order to provide predictions of a particular indicator, a subgroup may require information that would appropriately be provided by another subgroup. The set of indicators highlighted (Fig. 8) when one of the indicators in the responsibility list is selected is based on the entries in the Leopold Matrix (Fig. 4).

7. Linking to models

By spreading the workshop process over a longer period of time, there is a reduced time pressure on the model developers. At present, tools to facilitate exploration of the model that is produced have not been developed. Tools that are envisioned include an expert system to assist in scenario design and sensitivity analysis, customized browse paths through a library of model runs, and specific linkages between stakeholder values and model output, expressed in terms of specific indicators. Such tools are not part of the knowledge elicitation suite, which is the focus of the present study.

8. Discussion

Adaptive management is based on several scientific and social processes based on use of computer models for knowledge synthesis and consensus building. Appropriate representation of individuals and groups in the land management process is an issue of environmental ethics (Thomson, 1996). The traditional workshop approach, by virtue of its timing, physical location, or constraints on numbers of

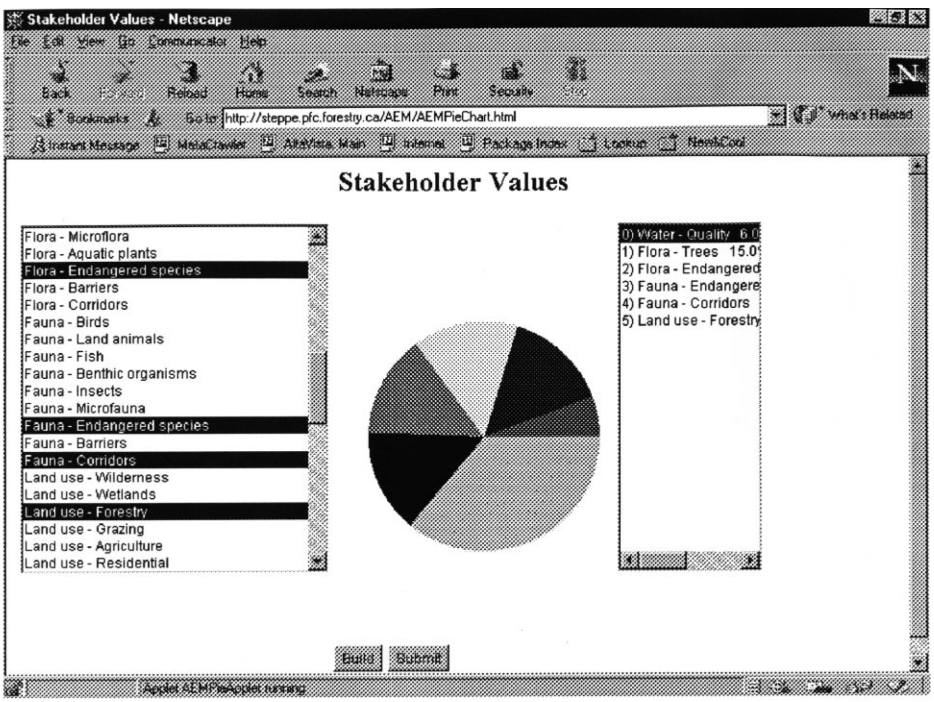

Fig. 7. Elicitation of stakeholder values. First, the indicators of interest are selected, then the relative values are established through manipulation of the pie chart.

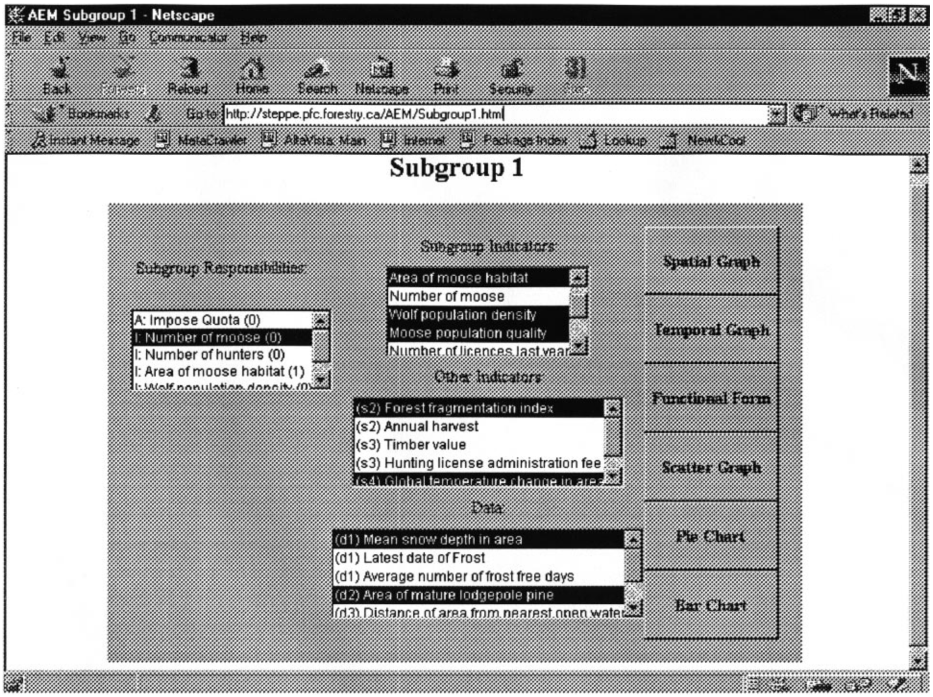

Fig. 8. The subgroup applet showing the set of indicators for which that subgroup is responsible, the set of indicators which it is obtaining from other subgroups, and access to the various knowledge elicitation tools. In the list of responsibilities, actions are indicated by (A) and indicators by (I). Actions or indicators still to be defined are denoted by (0), while those that are defined are denoted by (1).

participants, may limit participation; however, the use of the AEM_Web system, like other multiparticipant decision support systems (DSS) (Holsapple and Whinston, 1996), may widen access to the process. In addition, the system may be of value in settings such as third world countries, where access to a global scientific society in the context of their specific concerns may be achieved.

To be fully effective, however, additional infrastructure may be required, such as training programs for key individuals in affected communities, such as personnel of community, school or First Nations band offices. We have concentrated here on knowledge entry through computers using applet technology, but alternative modes of input to the system must be provided, such as phone, fax, mail, or email. Alternative modes of knowledge entry are especially important for individuals who do not have access to (or comfort with) computers. Such individuals should be able to provide sketch maps or even narrative descriptions of their knowledge, from which the core group/facilitators would enter into the system in a standardized format: this may require use of some form of fuzzy logic to handle terms such as ‘near’ or ‘around’ in narratives.

A key to using this technology to empower the broadest range of individuals is the integration of the software into a specially designed extension process. All the

Java applets can run on a stand-alone computer using the Java appletviewer program in conjunction with a local copy of the database. Extension personnel or technology transfer specialists could therefore take a copy of the system on a laptop computer to work with individuals or groups and assist them to enter their information, which could later be uploaded into a central system. This extension approach could be used in situations where Internet connections are unreliable or non-existent. It could also be used in situations where the required computer skills are lacking.

Hard copy summaries of the knowledge base should be made available at appropriate locations at regular intervals. Such steps would be essential to ensure that the benefits arising from increased access to the process would more than compensate for the various difficulties (Grudin, 1989) encountered in building successful groupware products and the new skills and duties required of facilitators.

If a proposed solution is close to a decision boundary, increasing the accuracy of the estimate is unlikely to reduce contention. The real-life decision process must always be kept in mind. The AEM process does, however, help establish real versus perceived data/knowledge gaps, it establishes an agreed representation of the system, and identifies achievable outcomes, and aids consensus building. In this regard, the most important outcome of the process may be the set of verbal alternative hypotheses.

Systems which include traditional ecological knowledge may require some privacy mechanism to permit input of knowledge essential for First Nations participation while maintaining ownership of the knowledge. Similar mechanisms may be required for proprietary data or knowledge of commercial enterprises. With regard to author identity, permitting anonymous input of questions or knowledge can encourage participation in this type of multi-user system (Holsapple and Whinston, 1996).

As a final thought, 'The most important sources of information about forestry issues tend to be newspaper and television, followed by radio, other printed materials, friends and relatives, and interest groups. Only 16% (of all community residents) overall considered natural resource agencies to be important sources' (Shindler et al., 1996). By participating in this kind of open process, through which their information can be placed in appropriate context, government agencies may improve public perception of their relevance.

References

Akenhead, S.A., Thomson, A.J., Morgan, D., Adams, B., Strome, W.M., 1996. Planning sustainable forestry when there are complicated rules and many stakeholders. In: Proceedings of Eco-Informa, 96: Global Networks for Environmental Information, Lake Buena Vista, Florida, November 4–7 1996. Published by Environmental Research Institute of Michigan and the University of Bayreuth, Germany, pp. 399–404.

Barrett, E. (Ed.), 1992. Sociomedia. Multimedia, Hypermedia, and the Social Construction of Knowledge. MIT Press, Cambridge, MA.

Grudin, J., 1989. Why groupware applications fail: problems in design and evaluation. In Office: Technol. People 4 (3), 245–264.

Gunderson, L.H., Holling, C.S., Light, S.S., 1994. Barriers and Bridges to the Renewal of Ecosystems and Institutions. Columbia University Press, New York.

Holling, C.S., 1978. Adaptive Environmental Assessment and Management. Wiley, London.

Holsapple, C.W., Whinston, A.B., 1996. Decision Support Systems: A Knowledge-Based Approach. West, St Paul, MN.

Howells, O., Edwards-Jones, G., Morgan, O., 1998. Ecozone II: a decision support system for aiding environmental impact assessments in agriculture and rural development projects in developing countries. Comput. Electron. Agric. 20, 145–164.

Jones, D., Randall, N., 1997. Using Microsoft® FrontPage 98, second ed. Que Corporation, Indianapolis, IN.

Lake, R., 1993. Electronic round table: a contribution to co-operative land management. In: Proceedings of the Canadian Conference on GIS-1993, March 23–25, Canadian Institute of Geomatics, Ottawa, Canada, 1993, pp. 163–177.

Shindler, B., Steel, B., List, P., 1996. Public judgments of adaptive management. J. For. 94 (6), 4–12.

Stankey, G.H., Shindler, B., 1997. Adaptive Management Areas: Achieving the Promise, Avoiding the Peril. USDA Forestry Service, Pacific Northwest Research Station General Technical Report PNW-GTR-394, pp. 21.

Thomson, A.J., 1979. Evaluation of Key Biological Relationships of the Western Budworm and its Host Trees. Forestry Canada, Pacific Forestry Centre, Victoria, BC CFS Information Report BC-X-186, pp. 19.

Thomson, A.J., 1991. Simulation of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) spread and control in British Columbia. Forestry Canada, Pacific Forestry Centre, Victoria, BC Information Report BC-X-329, pp. 18.

Thomson, A.J., 1993. Paradigm green: AI approaches to evaluating the economic consequences of changing environmental viewpoints. AI Applications 7 (4), 61–68.

Thomson, A.J., 1996. Asimov's psychohistory: vision of the future or present reality. AI Applications 10 (3), 1–8.

Thomson, A.J., 1997. Artificial intelligence and environmental ethics. AI Applications 11 (1), 69–73.

Thomson, A.J., Allen, E., Morrison, D., 1998. Forest tree diagnosis over the World Wide Web. Comput. Electron. Agric. 21, 19–31.

Walters, C.J., 1986. Adaptive Management of Renewable Resources. Macmillan, New York.

Walters, C.J., 1993. Dynamic models and large scale field experiments in environmental impact assessment and management. Aust. J. Ecol. 18, 53–61.