Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Forest Policy and Economics 5 (2003) 433–446
Forest Policy and Economics
www.elsevier.com/locate/forpol

The science/policy interface in logic-based evaluation of forest ecosystem sustainability

Keith M. Reynolds[a,*], K. Norman Johnson[b], Sean N. Gordon[b]

[a]USDA Forest Service, Pacific Northwest Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, USA
[b]Department of Forest Resources, College of Forestry, Oregon State University, Corvallis, OR, USA

Received 10 April 2002; received in revised form 8 May 2003; accepted 8 May 2003

Abstract

Numerous efforts around the world are underway to apply the Montreal criteria and indicators to assess the sustainability of temperate and boreal forests. In this paper, we describe a logic-based system for evaluating the sustainability of forests at regional and national levels. We believe that such a system can make evaluation of sustainability more consistent and transparent. This effort also makes two points abundantly clear: (1) a systematic way to organize expert judgment about ecological, economic, social and institutional relationships (here, using 'fuzzy logic') is crucial to building such a system and (2) that the structure of this logic-based system reflects a policy framework and a series of decisions about values and what is meant by 'sustainability'.
© 2003 Elsevier B.V. All rights reserved.

Keywords: Montreal Process; Forest; Ecosystem; Sustainability; Criteria and indicators; Logic; Model; Knowledge base; Decision support

1. Introduction

The 1992 Earth Summit enunciated principles for sustainable development of the world's forest resources (United Nations, 1992). Subsequently, the 11 signatory nations to the 1995 Santiago Declaration, representing approximately 90% of the world's boreal and temperate forest cover, affirmed the recommendations of the Montreal Process (WGCICSMTBF, 1995) that prescribed a set of seven criteria and 67 indicators for evaluating sustainable forest management (SFM).

*Corresponding author. Tel.: +1-541-750-7434; fax: +1-208-979-5355.
E-mail address: kreynolds@fs.fed.us (K.M. Reynolds).

1.1. Criteria, indicators and measurement endpoints

Prabhu et al. (2001) describe criteria and indicators (C&I) as 'information tools in the service of forest management' in the sense that they 'can be used to conceptualize, evaluate, implement and communicate SFM.' For the purposes of this paper, we follow the definitions of C&I given by Prabhu et al. (1999a).

In addition to C&I, it is also necessary for subsequent discussion to define measurement endpoints. Some Montreal indicators are simple; their definition suggests an obvious one-to-one correspondence between an indicator and a metric for

1389-9341/03/$ - see front matter © 2003 Elsevier B.V. All rights reserved.
doi:10.1016/S1389-9341(03)00041-8

that indicator. However, definitions of some Montreal indicators are more complex in the sense that they represent a synthesis of two or more data elements, which we refer to as measurement endpoints.

1.2. Differences in scale of application

The purposes of C&I for SFM vary with geographic scale of application (Castañeda, 2001). At national or regional scales such as FEMAT (1993) and ICBEMP (USDA Forest Service, 1996), C&I are used as policy instruments to evaluate and adjust laws, policies and regulations. At the scale of forest management units evaluated by CIFOR (1999), the USDA Forest Service Inventory and Monitoring Institute, or forest certification initiatives (e.g. FSC, 2000), C&I are used primarily for evaluating and adjusting management practices.

Federal scientists and managers have shifted their scale of analysis from the national forest to the 'bioregion', with the bioregion defined in terms of the range of species of interest. Thus, assessments and plans were developed for the federal forests of the region of the northern spotted owl (FEMAT, 1993) and the region of salmon that utilize the Columbia River system (ICEBMP, USDA Forest Service, 1996). Assessment of sustainability at the regional scale has became the dominant focus of numerous efforts in the Northwest, including the CLAMS effort on the Oregon Coast and the INLAS effort in the Blue Mountains of northeast Oregon.

In addition, some organizations and governments have now begun to directly utilize the Montreal C&I in assessment of sustainability. The Oregon Department of Forestry, in perhaps the best-known example, has utilized these C&I to begin a conversation about the sustainability of Oregon's forests (ODF, 2000).

1.3. Objectives

In this paper, we have two objectives: (1) to illustrate the usefulness of a logic-based approach to utilizing the Montreal C&I in evaluating the sustainability of forests and their benefits and (2) to identify the roles of science and policy in this effort. To accomplish these objectives, we will construct a prototype framework for utilizing C&I in assessing sustainability, highlight the policy choices that must be made in this construction, and discuss some of the lessons we learned from this effort.

Any indicator or criterion implies a model and set of assumptions that relates the indicator to more complex phenomena and comes with an obligation to make explicit both the metric and the underlying model (Hammond et al., 1995; Adriaanse, 1993). Relatively little research to date has focused on developing formal representations of indicators and their interrelations as a basis for actually evaluating SFM despite recent widespread interest in developing and applying C&I for evaluating SFM (Prabhu et al., 2001). However, a few efforts, primarily associated with the Center for International Forest Research (CIFOR), have been experimenting with use of semantic networks and similar types of representation (Colfer et al., 1996; Haggith et al., 1998; Prabhu et al., 1999b). In this paper, we consider the use of fuzzy-logic based network representation for evaluation of the Montreal C&I at national and regional scales as a way to accommodate lexical uncertainty inherent in natural language descriptions (Zadeh, 1976). Our primary objective is to show how formal knowledge representations can help reveal the myriad of decisions involved at the science/policy interface of SFM, as well as bring transparency and consistency to the evaluation process.

2. Analysis

2.1. Montreal criteria and indicators

The Montreal specifications provide relatively clear definitions of biophysical, socioeconomic and framework attributes requiring evaluation (WGCICSMTBF, 1995). However, design of evaluation procedures that allow interpretation of the Montreal C&I is one of the major technical issues that remain to be resolved (Raison et al., 2001). The design of any model that purports to evaluate sustainability with respect to a set of C&I must necessarily incorporate value judgments and other subjective elements (Prabhu et al., 2001), and this is no less an issue for biophysical aspects as it is for socioeconomic ones (Lélé and Norgaard, 1996). We discuss several specific aspects of subjective design elements in the context of logic models in Section 2.4.

2.2. Conceptual frameworks

Sustainability is fundamentally a human construct (Franklin, 1993). Hence, any discussion of resource sustainability is strongly conditioned by human values and objectives. Following the approach of Davis et al. (2000), we need at least six elements to assess the sustainability of some value or values in which we are interested:

(1) *Specified conditions or outcomes to be sustained* (*the indicators*) (ability to produce timber, old growth habitat).

(2) *A measure for each condition or outcome* (i.e. cubic feet of growth of merchantable timber, acres of old growth).

(3) *Calculation of the level of the indicator over some time period using the selected measure* (i.e. current condition, future condition under some plan or policy, etc.)

(4) *A frame of reference for gauging sustainability.* A frame of reference enables us to assess the risk to sustaining the value being analyzed. As an example, this frame of reference might be the historic range of variability for the condition or outcome of interest (such as the historic range of variability of old growth in the coast range). By comparing the level of the indicator to the frame of reference, we can assess the amount of risk relative to providing sustainable levels of the condition or outcome of interest.

(5) *Methods for assessing sustainability* (*sustainability check*) for each specified condition and outcome (a non-declining harvest volume over time, a level of old forest within the historical range of variability). This check may require the development of reference conditions, such as the historic range of variability, for the condition or outcome of interest.

(6) *A monitoring program* to collect data on the actual amount or qualities of the conditions and outcomes to be sustained. This is the reality check for determining if an implemented plan or policy is in fact meeting sustainability standards.

Both science and policy are needed to utilize this framework. Policy decisions are needed to select the values of interest and the methods for assessing sustainability. Science is needed to specify indicators and measures of the values of interest, developing reference conditions, and specifying a monitoring plan. Successfully completing all these tasks will require the joint effort of policy makers and scientists with significant interaction between the two groups.

Representation of what we think we know about ecosystems often is problematic and, while scientific frameworks are valuable organizing tools (Johnson et al., 1999), a basic difficulty is that the framework concept itself is ill-defined. What constitutes a valid framework? Too often, the term connotes a conceptual model with no well-defined, underlying syntax so the problem specification is semantically vague at best, and unintelligible at worst. One way to address this lack of specificity is through the construction of logic models with well-defined syntax and semantics. Interpretation of data by a logic engine can then provide a consistent evaluation of system states and processes represented in the model.

2.3. Using logic models as design frameworks

Logic models (or knowledge bases) provide a formal specification for organizing and interpreting information, and are a form of meta database. In our design of a specification for evaluating SFM, we are using the NetWeaver Developer system (Rules of Thumb, North East, PA) that represents a problem in terms of propositions about topics of interest and their logical interrelations. In design of a NetWeaver model, a topic for analysis is translated into a testable proposition. For example, if the topic is forest sustainability, the associated proposition might be as simple as ‘The forest ecosystem is sustainable.’ The statement of the proposition by itself is inherently ambiguous because sustainability is an abstract concept. However, the full formal logic specification underlying a proposition makes the semantic content of the proposition clear and precise (Figs. 1 and 2). The

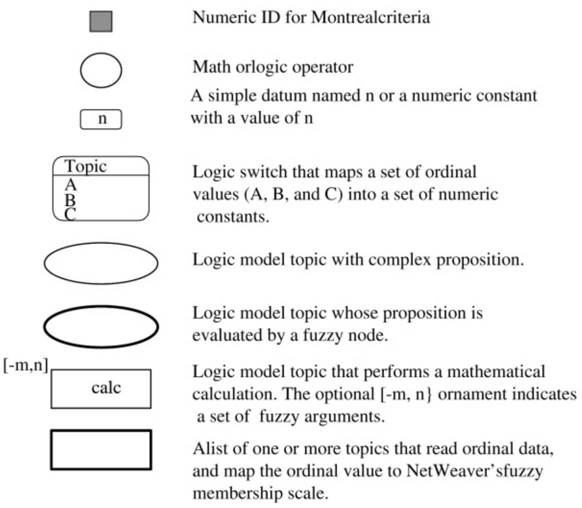

Fig. 1. Key to logic symbols used in subsequent figures.

biophysical, socioeconomic and framework topics (Fig. 2) are logical premises of forest sustainability. The proposition about forest ecosystem sustainability evaluates as *true to the degree that* integrity of the biophysical environment, suitable socioeconomic conditions, and a suitable framework exist.

The phrase, 'true to the degree that,' in the previous sentence is intended to emphasize that strength of support for propositions in NetWeaver models is evaluated by what might be termed 'evidence-based reasoning.' This form of reasoning is implemented in NetWeaver with fuzzy math (Reynolds, 1999), a branch of applied mathematics that implements qualitative reasoning as a method for modeling lexical, as opposed to stochastic, uncertainty (FuzzyTech, 1999).

The logical discourse on forest ecosystem sustainability is extended by providing a logic specification for each premise. Each iteration of discourse extends the logic structure another level deeper by defining a logic specification for each topic in the level above. The pattern of discourse generally proceeds from abstract to concrete propositions, with a tendency for premises of a particular proposition to be less abstract than that proposition. Eventually, each logic pathway terminates in a premise, or set of premises, each of which can be evaluated by reference to data. Logic pathways in a knowledge base can thus be construed as a cognitive map of the problem that provides a formal data specification. The specification not only describes what data are to be evaluated, but how the data are to be interpreted to arrive at conclusions.

The graphic form of logic representation is significant because, based on extensive experience, the semantics of any particular model are easily conveyed to broad audiences in this form. Consequently, a group of specialists, representing diverse disciplines, can easily collaborate in the design of a complex model because the architecture and its graphic representation provide an effective basis for organizing discussion and for continuing evolution of a design.

Perhaps more importantly, during model evaluation, conclusions and explanations of their derivation are easily and intuitively traced through the evaluated state of a logic model, to communicate effectively with both policy makers and the other interested parties. Effective communication between model designers and policy makers is especially important in the context of designing a logic model for evaluating SFM, because, as we discuss below, it turns out that many aspects of the model design reflect important policy decisions concerning how sustainability is to be evaluated.

As a meta database, a logic model helps ensure consistency in interpretation of data across time and space. Such models can be designed for broad geographic application, taking some care in their design. In the next section, we discuss evaluation of indicators against reference conditions by use of dynamically defined fuzzy membership functions.

Prabhu et al. (2001) emphasize the need for transparency in models that evaluate C&I for SFM because any such model (1) embodies important policy decisions in its specification and (2) depends on value judgments and critical assumptions that require documentation. For example, the specific arrangement of C&I within some evaluative framework reflects value judgments concerning the relative importance of components being evaluated, and thus constitutes an important policy decision. We have already mentioned how the

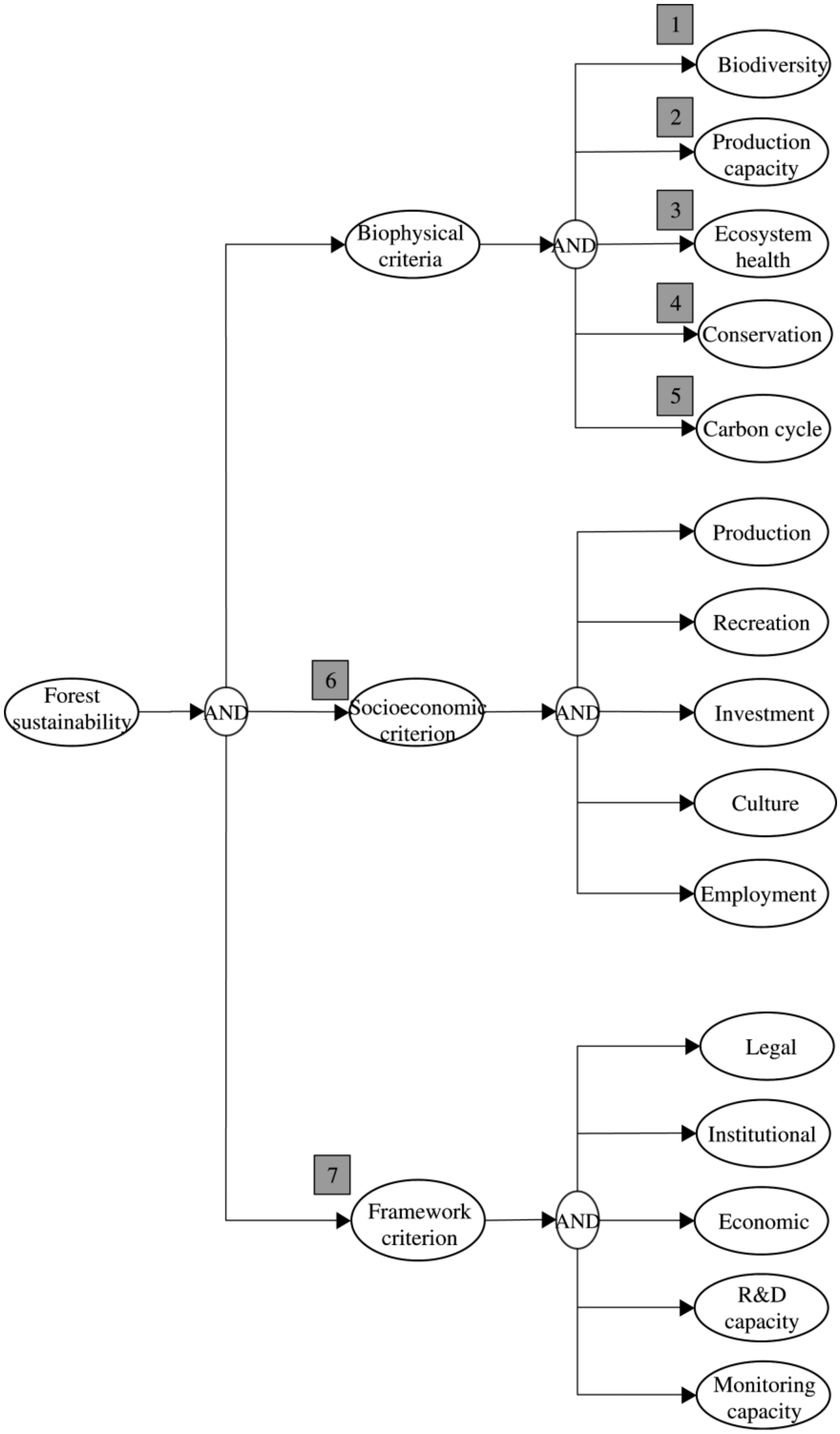

Fig. 2. Partial logic specification for evaluating sustainability of a forest ecosystem. Each premise has its own logic specification that may extend many more levels. NetWeaver knowledge bases are graphically built from modular components like this, simplifying incremental development of complex models. Only the first three levels of network structure are illustrated.

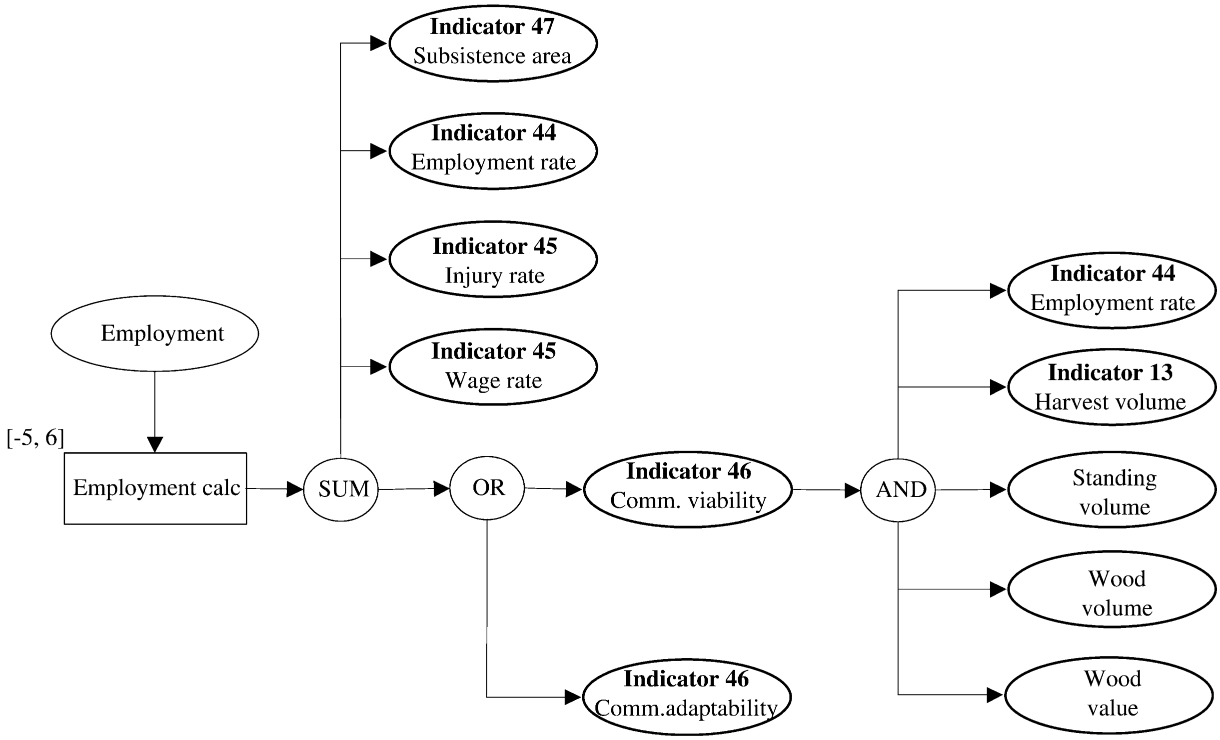

Fig. 3. Logic specification for evaluation of the employment topic under the socioeconomic criterion (criterion 6). Community viability depends on (e.g. is cross-linked to) indicators 13 and 44 as well as data elements of other biophysical indicators related to wood production (indicators 29 and 31) and production capacity (indicators 11 and 12).

graphical representation used in NetWeaver logic models facilitates discussion on the design of models and the derivation of conclusions. Equally important, however, the NetWeaver framework provides an extensive set of documentation attributes for each topic in a model, including description of the proposition, explanation of the proposition, technical authorities, literature citations and assumptions.

2.4. Model design issues

2.4.1. Implications of model organization

Most representations of C&I for evaluating SFM are arranged hierarchically (Prabhu et al., 2001), and this is true in the case of the Montreal C&I (WGCICSMTBF, 1995). However, Prabhu et al. (2001) emphasize the value of a more general network representation such as that used in NetWeaver, which allows cross-linkage among indicators and perhaps other intermediate topics. In our current prototype of the Montreal C&I logic, for example, evaluation of community viability (indicator 46) depends on indicators 13 and 44 as well as data elements related to other indicators (Fig. 3). Although, the logic specification for community viability is the only significant example of networked relations in our prototype model, it is very likely that additional networked relations within and between the biophysical and socioeconomic criteria will emerge in the continuing evolution of the design.

Organization of topics within the current Montreal design specification has important policy implications. For example, most science colleagues have found the highest-level organization (Fig. 2) quite acceptable, but an alternative representation is quite possible (Fig. 4), and these two represen-

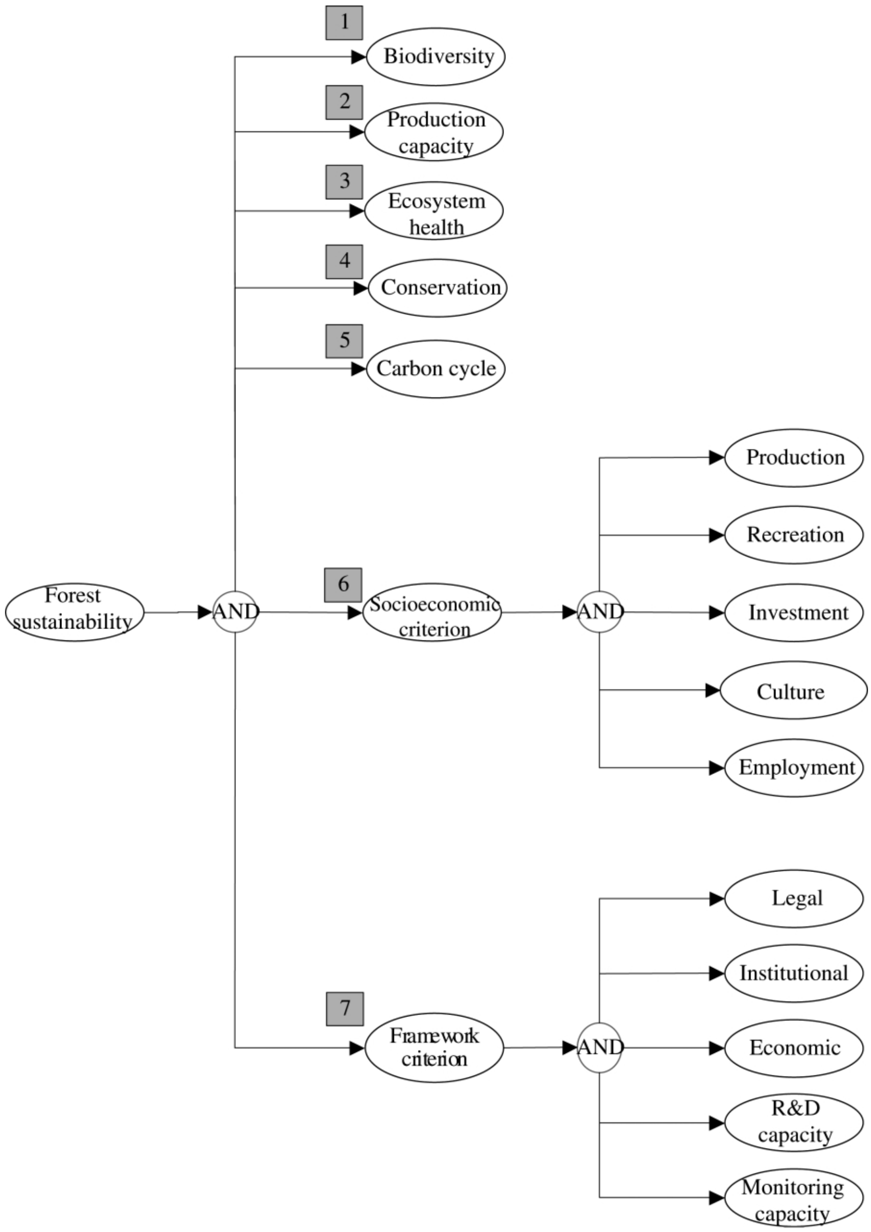

Fig. 4. An alternative (partial) logic specification for evaluating sustainability of a forest ecosystem. In this representation, biophysical criteria assume more importance compared to Fig. 2.

tations of sustainability would produce very different evaluations. The five biophysical criteria in the current specification are subsumed under the biophysical topic (Fig. 2). Assuming for the moment that all topics in the model carry default weights of 1 (see the next section), the current specification effectively asserts that the collective evidence from all biophysical criteria is equal, in terms of strength of evidence for sustainability, to the collective evidence from criterion 6 or criterion 7. The

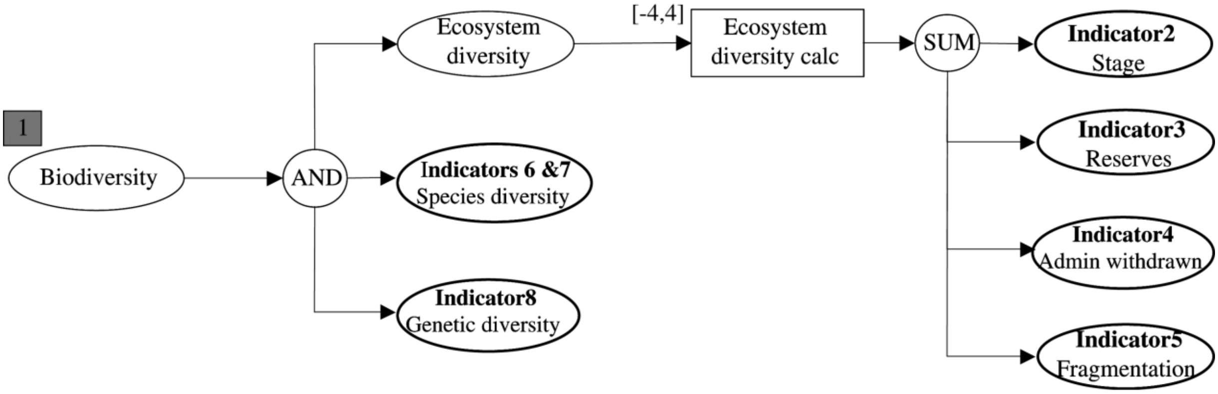

Fig. 5. Additional level of detail of the logic specification for the biodiversity criterion, illustrating the AND and SUM operators which represent different philosophies about how information combines.

alternative representation (Fig. 4) puts much greater emphasis on the biophysical criteria, asserting that the collective evidence of each biophysical criterion (1–5) is equal to that for criterion 6 or criterion 7.

2.4.2. *Synthesis of information*

Evaluation of any criterion for SFM involves multiple indicators. Therefore, the definition of a criterion (Prabhu et al., 1999a) stresses the need for integration of information in evaluating any SFM criterion. In the case of the Montreal C&I, integration of information may, in fact, extend many levels deep (e.g. Figs. 2 and 4). The specifications of the employment topic (Fig. 3) and biodiversity (criterion 1, Fig. 5) illustrate another design issue with significant policy implications: the choice of how to integrate information. The most commonly used logical operators for combining elements in NetWeaver are AND, OR and SUM. The fact that the logic model requires us to explicitly assign an operator to each synthesis reveals critical information that is often undefined in less rigorous descriptions.

The computation implemented by the NetWeaver AND operator effectively evaluates the set of topics that are arguments to the operator as limiting factors. That is, the result of the AND operation is constrained by the least favorable component. A three-legged stool is a useful visual analogy to the AND operator: if one leg is removed (a line of evidence evaluates as fully false), the stool topples.

The SUM operator, commonly associated with calculations in the Montreal logic model, effectively asserts that the topics in the set of arguments to the SUM operator can compensate for one another. For example, in the evaluation of the ecosystem diversity topic (Fig. 5), if the proposition for indicator 2 evaluates as fully false, but propositions for indicators 3, 4 and 5 evaluate as fully true, then the proposition of suitable ecosystem diversity evaluates to 75% true.

The OR operator is the functional opposite of AND. In this case, the three-legged stool is magical and will continue to support weight as long as any one of the legs is functional. Fig. 4 uses an OR operator to combine community viability with community adaptability: socioeconomic goals are likely to be met if either the community can continue sustainably as it is or it can successfully adapt to new conditions.

2.4.3. *Relative weights on topics*

Each topic in a NetWeaver logic model has an intrinsic weight attribute in addition to its set of documentation attributes. Intrinsic weights are always assigned with an initial default value of 1 during model design. Among other uses of the intrinsic weight attribute, model designers can set the weight attribute on any topic to adjust its contribution of evidence to a proposition. However, we strongly recommend against use of weights for this purpose because they become an integral part of logic model but they do not appear in the standard model display formats. Space for documenting weights is available within each topic, but it is not obvious to the casual observer. If weighting of topics is deemed necessary in model design, then setting weights explicitly with data input is preferable to preserve transparency and flexibility.

Use of the SUM operator in evaluating lines of evidence related to biodiversity (Fig. 5) illustrates the simplest method of implementing a model of compensatory effects in NetWeaver. A slightly more complex representation could, for example, have modeled the influence of indicators 2, 3, 4 and 5 on biodiversity with a sum of products in which each product included an explicit weight term for an indicator.

We have avoided both the use of intrinsic weights and use of the weighted sum of products formulation in the current prototype of the Montreal logic model on the grounds that both representations complicate interpretation of an evaluation and introduce an additional layer of subjectivity to the model. Nonetheless, it is important to recognize that even use of default intrinsic weights carries with it the implicit assumption that all topics contributing to evaluation of a proposition have equal weight.

2.4.4. Reference conditions for quantitative measures

'Possibly one of the biggest challenges facing researchers currently is the identification and quantification of…thresholds' for SFM indicators or more specific measurement endpoints (Prabhu et al., 2001). In the context of endpoint evaluation, thresholds refer to critical values that distinguish between, for example, fully acceptable, fully unacceptable, or partially acceptable values. Perhaps more often than not, definitions of thresholds for endpoints used in evaluation of SFM will require scientifically-based judgments in lieu of more precise calculations. Fuzzy membership functions provide an effective approach to representing such qualitative or semi-quantitative relations (Zadeh, 1976). Fig. 6 demonstrates a fuzzy membership function that compares old-growth forest cover to its probable historical extent. Scenarios evaluated that are clearly outside the historical range of less than 20 or greater than 80% receive values of zero in the model, while those in the 40–60% range receive full credit (+1), and remaining intermediate values partial credit.

NetWeaver has two basic methods for implementing fuzzy membership functions. The simpler, more limited, method specifies a function with arguments that define up to four threshold values. Although, this method is easy and fast, it has the disadvantage that arguments are constants in the logic model specification. In the current prototype logic model for the Montreal C&I, fuzzy arguments are commonly used in junction with topics performing calculations. For example, the biodiversity calculation (Fig. 5) uses a fuzzy argument indicated by [0, 4], in which the threshold values, 0 and 4, indicate results that are completely unacceptable and completely acceptable, respectively, with respect to biodiversity (each of the four topics, representing the premises of biodiversity, return a value in the closed interval [0, 1]).

Fuzzy nodes provide a more general solution for representing fuzzy membership functions, and have the advantage over the fuzzy argument approach that arguments used to define the function can be read as data inputs or calculated from data, so functions can be built dynamically. Fuzzy nodes are used extensively in the Montreal C&I logic model to evaluate endpoints (for example, Figs. 2, 3 and 5). The most compelling reason for use of fuzzy nodes in model design is the potential to design very general models with broad geographic application because the function is defined by data inputs rather than arguments defined in the logic model.

2.4.5. Qualitative measures

Most measurement endpoints of Montreal criteria 1–6 (Fig. 2) are well defined and can be evaluated quantitatively with fuzzy membership functions as described above. However, most indicators and nominal measurement endpoints of criterion 7 are defined in relatively vague terms (WGCICSMTBF, 1995), and, in almost all cases, it was not immediately obvious to us what would constitute suitable metrics for the measurement

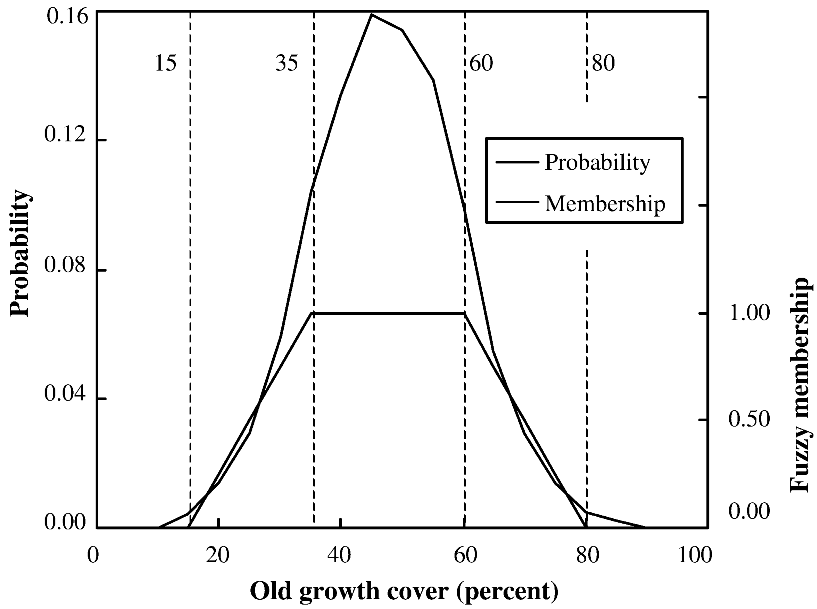

Fig. 6. Deriving a fuzzy membership function for suitability of old-growth forest cover from statistical information. The probability curve shows the estimated probability density for old-growth forest in the Oregon coast range for the past 3000 years (adapted from Wimberley and Spies in Davis et al., 2000, p. 12). The superimposed fuzzy membership function maps percent cover values into a measure of suitability. Dashed reference lines indicate thresholds used to define reference conditions for the fuzzy membership function.

endpoints for these indicators. Consequently, in the current prototype, all indicators (or more specific endpoints) of criterion 7 are evaluated by mapping values from a subjective ordinal response scale (none, weak, moderate, strong evidence) for each nominal measurement endpoint onto a fuzzy membership scale of [0, 1]. The specification for evaluation of the adequacy of the legal framework (Fig. 7) is presented as a typical example of logic specifications under criterion 7 (Fig. 2). We consider these qualitative specifications for evaluations to be temporary placeholders for more quantitative ones that hopefully will be forthcoming as appropriate technical authorities develop suitable measurement endpoints.

2.4.6. Reliability of data

Reliability of data for evaluation of SFM relates to stochastic uncertainty rather than lexical uncertainty. Formal representation of stochastic uncertainty is problematic in the context of a logic model. We have not addressed this issue in the current Montreal C&I prototype, but one conceivable strategy that deserves further investigation would adjust weights on topics based on a normalized metric such as the standard error of the mean of the associated measurement endpoint. There are at least two difficulties with the latter strategy: (1) error estimation may be difficult or impossible for many measurement endpoints and (2) even if error estimates were generally available, knowledge of correlations between errors is likely to be poor or completely lacking for most logically interrelated measurement endpoints, in which case the default assumption of independent errors would bias strength of combined evidence toward overestimation of total error.

2.4.7. Precision of available knowledge and availability of data

In NetWeaver, the logic specification of a topic may include two or more alternative pathways by

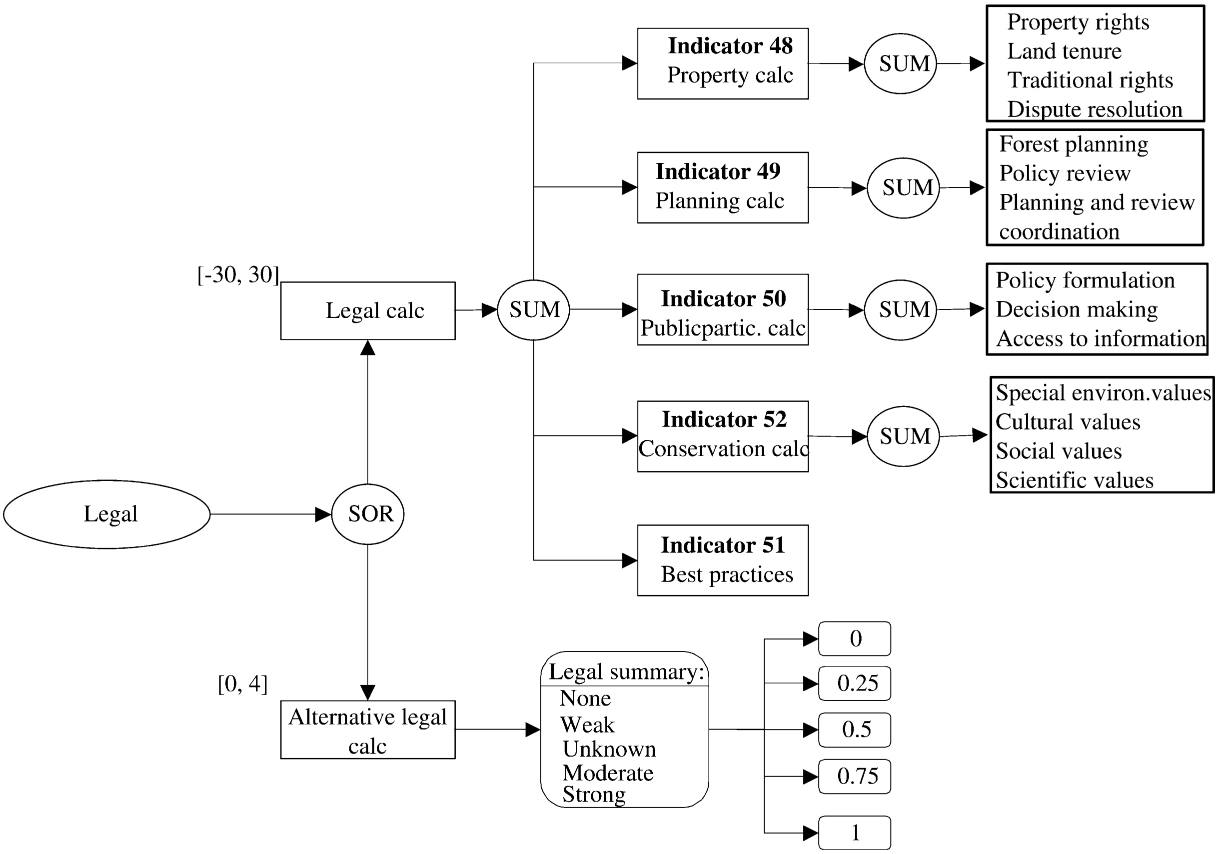

Fig. 7. Logic specification for evaluation of the legal framework topic under the framework criterion (criterion 7). The SOR operator specifies a set of two or more logic pathways in order of preference (top to bottom in this figure). The most preferred pathway is selected if sufficient data are available for the path. Otherwise, the next most preferred pathway is tried. SOR evaluates to undetermined if no pathway has sufficient data.

which the topic can be evaluated. In the current prototype model for the Montreal C&I, all premises of the framework criterion (Fig. 2) include a sequential OR (SOR) operator that specifies a preferred ordering of alternative pathways for evaluation. For example, the specification of the legal framework (Fig. 7) may evaluate evidence for legal support based on 30 specific nominal measurement endpoints (the preferred path), or it may evaluate a very simple and highly generalized observation on the state of the legal system. Switch operators may also perform a function similar to the SOR node, but use context information read by the switch to select among pathways.

3. Lessons learned

3.1. Lexical uncertainty is an important issue in evaluation of C&I for SFM

Natural language is useful for conveying broad ideas but finer points are always open to interpretation. Our administrative and legal systems refine and operationalize policy statements via quantification of regulations and restatement and contextualization of meaning. Logic frameworks are helpful for identifying and storing the multitude of decisions that need to be made to operationalize broad policies. In particular, the concept of fuzzy logic allows us to define an acceptable range of interpretation for lexical uncertainty in the C&I.

3.2. The set of topics and the manner in which they are evaluated depend on geographic scale

Quite simply, scale matters. The prototype logic model we have described was designed for regional-scale application. The regional model can easily be adapted to finer geographic scales such as forest management units, but, in doing so, it is important to recognize that evaluation of some topics may not be appropriate at the finer scale (e.g. topics related to global carbon cycling). Other topics, such as species and genetic diversity, may still be appropriate to evaluate at a finer scale, but the measurement endpoints of an indicator, and the manner in which they are evaluated, may require adaptation. For example, the forest management unit is most likely not a suitable scale to evaluate the status of a threatened species with a geographic range much broader than the management unit. In fact, considering assessment of sustainability integrated over a range of scales, evaluation of the status of threatened species specifically at the level of the forest management unit might best be limited to species that are endemic, or nearly so, to the management unit.

3.3. Many aspects of evaluating sustainability cannot be answered by science alone

Design of a logic model for evaluating SFM is a scientific enterprise in its own right insofar as it is an attempt to synthesize problem-solving knowledge in a formal analytical framework, and is fundamentally concerned with the representation of that knowledge. Science also has a clear and unequivocal role with respect to selecting reference conditions against which Montreal indicators are to be evaluated. However, as we have pointed, many decisions about logic structure are either clearly policy decisions or at least reflect the need for a dialogue at the science/policy interface. A specific example of a decision that is at least primarily policy-based concerns the basic hierarchical organization of the seven Montreal criteria. Specific choices of AND vs. SUM operators are examples of decisions requiring additional dialog between science and policy perspectives. Finally, interpretation of the relationship between indicator values and reference conditions to make the crucial calls on sustainability of each indicator is fundamentally a policy decision.

3.4. Acquiring data on SFM is necessary but not sufficient for setting policy

The Montreal Process (1997) provides a partial specification for evaluating SFM to the extent that it defines a set of C&I for an evaluation. Clearly, though, the Montreal Process is not a complete specification, because it does not provide a basis for drawing any conclusions about the state of sustainability, given the data. The data need to be interpreted if they are to provide a basis for policy decisions related to sustainability.

3.5. Evaluating sustainability is not the same as defining desired future conditions

Evaluating sustainability and defining desired future conditions are fundamentally different actions. Comparing indicator values to reference conditions (evaluating sustainability) enables us to understand where we are at and where we are headed—to assess the risks to sustaining the values in which we are interested. Defining desired future conditions (setting ‘targets’), on the other hand, states where we would like to go. While evaluating sustainability can inform our thinking on what we would like to achieve, reference conditions and desired future conditions need to be kept separate so that people do not mix what ‘is’ with what we would like to be.

3.6. Evaluating the state of SFM and deciding how to respond are separate but interdependent decision processes

We have developed a system for evaluating the state of SFM. It should help us understand the degree to which any statement of current conditions or trends seem likely to sustain the values of interest. It can highlight problems and special risks, given the information on indicators and reference conditions and policy decisions about how to organize that information to assess sustainability. This approach, though, does not explicitly state what might be done to overcome problems that are detected. Understanding the problems in achieving sustainability is a precursor to improving the likelihood of sustaining the values of interest, but deciding how to respond is beyond the scope of our effort here. Rather, we are interested in building a platform that enables people to understand and discuss the elements of sustainability, where we may be headed for trouble, and where we seem on a path toward sustaining the values in which we are interested.

4. Recommendations

4.1. Assess the policy role in sustainability evaluation and undertake a policy review of model organization and strategies for integrating sustainability information

Assessment of sustainability cannot proceed without policy decisions to build the framework for evaluation. Whether scientists, technicians, or policy makers make the calls, a number of policy decisions are needed on how to interpret the information. These decisions range from strategies for integrating the C&I at different levels (Fig. 4), to decisions about which kind of operators to utilize to combine information (Fig. 6), and decisions about sustainability thresholds in comparing indicator values to reference conditions (Fig. 7).

Therefore, we make three recommendations: (1) to acknowledge the policy decisions involved in any evaluation of the sustainability of forests; (2) to acknowledge the kinds of policy decisions that are needed to successfully utilize the Montreal C&I in this evaluation and (3) to undertake a pilot effort between policy makers, scientists and managers to develop a prototype logic-based evaluation of sustainability for a large region.

4.2. Identify measurement endpoints for indicators of criterion 7

Criterion 7 covers legal, institutional and economic frameworks for forest conservation and sustainable management. The indicators for criterion 7 are especially difficult to develop and measure because they deal with such fundamental aspects of forest management as land tenure arrangements, due process and public participation. How do you measure these things and develop reference conditions for them? Recent efforts, such as that for the State of Oregon tend to be more descriptive than analytical (ODF, 2000). We recommend that a special effort be undertaken to making operational the sustainability assessment for the indicators associated with criterion 7.

4.3. Recognize the need for reference conditions and shift a portion of the scientific and technical energy on indicator measurement to developing reference conditions

Much worthwhile scientific and technical effort is going into applying the Montreal C&I to assessing the sustainability of temperate forests. Almost all this effort is going into the second and third elements of assessing sustainability mentioned above (picking a measure for the indicator and calculating the level of the indicator over time using the measure). Relatively little effort is going into the fifth element (defining reference conditions). Yet without reference conditions, we cannot assess the risk to sustaining the values in which we are interested. We recommend that the need for reference conditions be recognized and that a significant portion of the effort going into measurement of indicator values be shifted to development of reference conditions.

4.4. Develop a well-defined protocol for coordinated assessment over a range of geographic scales

Federal agencies within the United States have been developing logic models for evaluation of SFM at national, regional and forest management unit scales. In the early stages of development, efforts focused at different scales have only been loosely coordinated. However, a more deliberate, strategic approach to integration over a range of scales has some advantages in terms of realizing efficiencies in analysis at specific scales, ensuring appropriate flow of information from fine to course scale, and enhancing the likelihood of scale-appropriate analysis.

References

Adriaanse, A., 1993. Policy Performance Indicators. SDU Publishers, The Hague.

Castañeda, F., 2001. Collaborative action and technology transfer as a means of strengthening the implementation of national-level criteria and indicators. In: Raison, R.J., Brown, A.G., Flinn, D.W. (Eds.), Criteria and Indicators for Sustainable Forest Management. IUFRO 7 Research Series. CABI Publishing, New York, pp. 145–163.

CIFOR (Center for International Forestry Research), 1999. The CIFOR criteria and indicators generic template. Criteria and Indicators Toolbox Series, No. 2. CIFOR, Bogor, Indonesia.

Colfer, C.J.P., Woelfel, J., Wadley, R.L., Harwell, E., 1996. Assessing people's perceptions of forests in Danau Sentarum Wildlife Reserve. CIFOR Working Paper No. 13. CIFOR, Bogor, Indonesia.

Davis, L., Johnson, K.N., Bettinger, P., Howard, T., 2000. Forest Management. fourth ed. New York, McGraw Hill.

FEMAT. 1993. Forest ecosystem management: an ecological, economic, and social assessment. Report of the Forest Ecosystem Management Assessment Team. 1993-793-071. Government Printing Office, Washington, DC.

Franklin, J., 1993. The fundamentals of ecosystem management with applications to the Northwest. In: Aplet, G., Johnson, N., Olson, J., Sample, A. (Eds.), Defining sustainable forest. Island Press, pp. 127–144.

FSC (Forest Stewardship Council), 2000. FSC principles and criteria. Document 1.2 Revised February 2000. Available from http://www.fscoax.org/principal.htm.

FuzzyTech, 1999. FuzzyTech User Guide. FuzzyTech, Berlin.

Haggith, M., Prabhu, R., Purnomo, H., Sukadri, D., Yasmi, Y., 1998. CIMAT criteria and indicators modification and adaptation tool. Available from http://www.cifor.cgiar.org/cimatweb/ie4/cimat.htm.

Hammond, A., Adriaanse, A., Rodenburg, E., Bryant, D., Woodward, R., 1995. Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development. World Resources Institute, Washington, DC.

Johnson, K.N., Swanson, F., Herring, M., Greene, S., 1999. Bioregional Assessments: Science at the Crossroads of Management and Policy. Island Press, Washington, DC.

Lélé, S., Norgaard, R.B., 1996. Sustainability and the scientist's burden. Conservation Biology 10, 354–365.

Montreal Process, 1997. First Approximation Report of the Montreal Process. The Montreal Process Liaison Office, Ottawa, Canada.

Oregon Department of Forestry (ODF), 2000. Oregon's First Approximation Report for Forest Sustainability. Oregon Department of Forestry, Salem, Oregon.

Prabhu, R., Colfer, C.J.P., Dudley, R.G., 1999a. Guidelines for developing, testing and selecting criteria and indicators for sustainable forest management. Criteria and Indicators Toolbox Series, No. 1. CIFOR, Bogor, Indonesia.

Prabhu, R., Haggith, M., Purnomo, H., Rizal, A., Sukadri, D., Taylor, J., Yasmi Y., 1999b. CIMAT (Criteria and Indicators Modification and Adaptation Tool). Criteria and Indicators Toolbox Series, No. 3. CIFOR, Bogor, Indonesia.

Prabhu, R., Ruitenbeek, H.J., Boyle, T.J.B., Colfer, C.J.P., 2001. Between voodoo science and adaptive management: the role and research needs for indicators of sustainable forest management. In: Raison, R.J., Brown, A.G., Flinn, D.W. (Eds.), Criteria and Indicators for Sustainable Forest Management. IUFRO 7 Research Series. CABI Publishing, New York, pp. 39–66.

Raison, R.J., Flinn, D.W., Brown, A.G., 2001. Application of criteria and indicators to support sustainable forest management: some key issues. In: Raison, R.J., Brown, A.G., Flinn, D.W. (Eds.), Criteria and Indicators for Sustainable Forest Management. IUFRO 7 Research Series. CABI Publishing, New York, pp. 2–18.

Reynolds, K.M., 1999. NetWeaver for EMDS version 2.0 user guide: a knowledge base development system. Gen. Tech. Rep. PNW-471. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

United Nations, 1992. Forest Principles: Report of the United Nations Conference on Environment and Development. United Nations, New York.

USDA Forest Service, 1996. Status of the interior Columbia Basin: summary of scientific findings. Gen. Tech. Rep. PNW-385. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

WGCICSMTBF (Working Group on Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests) 1995. Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests: the Montreal Process. Canadian Forest Service, Hull, Quebec.

Zadeh, L.A., 1976. The concept of a linguistic variable and its application to approximate reasoning, Part III. Information Science 9, 43–80.