ELSEVIER

Journal of Environmental Management 80 (2006) 167–176

Journal of Environmental Management

www.elsevier.com/locate/jenvman

A formal model for consensus and negotiation in environmental management

Helen M. Regan [a,*], Mark Colyvan [b], Lisa Markovchick-Nicholls [a]

[a] *Biology Department, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182-4614, USA*
[b] *Philosophy Program and The Ecology Centre, University of Queensland, Brisbane, Queensland 4072, Australia*

Received 31 January 2005; received in revised form 27 September 2005; accepted 29 September 2005
Available online 13 December 2005

Abstract

Environmental management decisions typically lie at the interface of science and public policy. Consequently, these decisions involve a number of stakeholders with competing agendas and vested interests in the ultimate decision. In such cases, it is appropriate to adopt formal methods for consensus building to ensure transparent and repeatable decisions. In this paper, we use an environmental management case study to demonstrate the utility of a mathematical consensus convergence model in aggregating values (or weights) across groups. Consensus models are applicable when all parties agree to negotiate in order to resolve conflict. The advantage of this method is that it does not require that all members of the group reach agreement, often an impossible task in group decision making. Instead, it uses philosophical foundations in consensus building to aggregate group members' values in a way that guarantees convergence towards a single consensual value that summarizes the group position. We highlight current problems with ad hoc consensus and negotiation methods, provide justification for the adoption of formal consensus convergence models and compare the consensus convergence model with currently used methods for aggregating values across a group in a decision making context. The model provides a simple and transparent decision support tool for group decision making that is straightforward to implement.

Keywords: Group decisions; Consensus; Negotiation; Multi-criteria decision making; Urban open space

1. Introduction

Environmental management decisions are the cause of much debate and disagreement. In the absence of means to resolve the disagreement, the outcome can be crippling standoffs that result in inaction or unacceptable delays in making important environmental decisions. The underlying source of disagreement may be traced to the interdisciplinary nature of most environmental problems. Environmental management decisions typically lie at the interface of science and public policy, and consequently take place at many levels (neighborhood, city, state, etc.) and involve a number of stakeholders (such as land owners, industry partners, urban planners, farmers) with disparate expertise and vested interests in the ultimate decision. Decisions involving diverse groups are the most difficult to make. This is particularly the case when group members have competing agendas and opinions and different knowledge bases. Such is the situation for most committees charged with making environmental decisions.

At present, there is no widely accepted systematic approach to making group decisions for the management of natural resources and the environment. Many decisions are achieved via an ad hoc process that subsumes the differences of opinions within stakeholder groups. Ad hoc approaches to consensus can include anything from small groups agreeing to a course of action through verbal discourse, to facilitation, moderation or mediation of large stakeholder groups to 'work out' solutions to problems. While these can be effective, they do not guarantee consensus or satisfaction among participants that their views have been fully considered in the decision. This is, in part, due to the complex nature of environmental issues and the difficulties in resolving disagreements within a group. Group decision making is often the result of a laborious course of unstructured negotiation that rarely yields repeatable results or outcomes acceptable to the entire group. Moreover, many strategies employed to arrive at a group decision cannot be transferred to alternative scenarios. This leads to decisions that are difficult to analyze retrospectively and cannot readily be used to inform other similar decision contexts.

Concern over human impact on the environment necessitates timely and effective management strategies. In the United

* Corresponding author. Tel.: +1 619 594 2738; fax: +1 619 594 5676.
E-mail address: hregan@sciences.sdsu.edu (H.M. Regan).

0301-4797/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jenvman.2005.09.004

States the effects of human activities on the biotic environment is more prominent in California than in any other of the 48 contiguous states. California is the most populous state in the US with a human population of almost 34 million. This population is expected to grow to about 45 million by 2020 and could reach 60 million by 2020 (The Resources Agency, 2001). To address the imperative of conserving California's remaining natural and agricultural resources and serve the needs of residents in the face of increasing urbanization and land use, a framework has been established to identify landscapes that are important for investment for conservation management, known as the California Legacy Project (CLP; California, 2000,http://legacy.ca.gov/). The main aim of the CLP was to develop a strategy for setting conservation priorities at a statewide level and to develop 'a long-term set of priorities and targets for future investment in resource protection and habitat acquisition and preservation' (The Resources Agency, 2001). The CLP considered priorities for the following areas: the protection of biodiversity, agriculture, rangelands, forestlands, recreational lands and urban open space. A preliminary step in the process involved multi-criteria decision making (MCDM) by stakeholder groups to specify criteria to identify lands for each priority area (such as urban open space) important for acquisition, management and stewardship. MCDM is a process where multiple criteria are incorporated into management planning. Each person weighted each criterion according to their view of its relative importance to the overall goal. However, this framework fails to achieve a satisfactory summary of weights aggregated across all group members. A simple central tendency of weights based on a geometric mean was used, but this failed to explicitly incorporate the variability across the group. As a result, stakeholders involved in the group decision-making process did not feel entirely satisfied with the final weights placed on criteria.

In this paper, we use the California Legacy Project MCDM framework as a case study to demonstrate the utility of a mathematical consensus convergence model in aggregating values (or weights) across groups. This method has been used in political contexts (Collignon, 2003) and in a greenhouse gas policy context (Ridgley, 1993). We will focus specifically on the issue of reaching group consensual criterion weights for the urban open space priority area. However, the method is general and can be extended to other contexts and subjectively assigned values and degrees of belief.

We argue for the development of formal methods for negotiation and consensus in environmental management, and we present the consensus convergence model and its implementation to the California Legacy Project criteria for identification of important areas for urban open space. We provide a much-needed framework for making group decisions that are transparent, repeatable and straightforward to implement.

In Section 2, we present a background to the environmental decision–making context used as a case study for the formal consensus convergence model. In Section 3, we present limitations to the types of ad hoc consensus-building processes that are usually used for decision making in environmental problems and explain the merits of formal methods for reaching consensus. In Section 4, we present the formal consensus convergence model and apply it to the case study at hand. In Section 5, we present the results of this application and compare results with two techniques commonly used to aggregate weights across a group. In Section 6, we discuss the philosophical implications and benefits of applying such a model compared to the methods currently used. We conclude with a discussion of the model's limitations and potential extensions.

2. Environmental management context: urban open space management

Urban open space provides a range of benefits to metropolitan populations. These include mitigating air and water pollution, ameliorating suburban sprawl, providing opportunities for recreation, promoting sound mental and physical health, reducing crime and fostering cohesive neighborhoods, attracting businesses, and stabilizing property values (The Trust for Public Land, 2004,http://www.tpl.org). Investment, management and stewardship of urban open space can assist in revitalizing neighborhoods and building healthy communities as well as protecting lands, which may have high natural and cultural resource values. However, not all lands accomplish these goals equally well, and resources to acquire such lands are often limited, so suitable lands must be well chosen and prioritized. Thus, the provision for open space in urban areas is a vital component of city planning (Erickson, 2004).

Many urbanized areas in the US, indeed in many countries across the globe, are under-served by local and regional recreational facilities. A projected minimum of an additional 2,376,000 acres of recreational and park space must be obtained to meet the need of an increasing population in California (The Resources Agency, 2001). The Resource Agency recognized this need to address urban open space in its mission of identifying important lands for acquisition, stewardship or management.

In 2002, a 2-day workshop involving academics, government agency administrators, consultants and practitioners was held to nominate criteria for the identification of high priority urban open space lands. The group members constructed a multi-criteria decision tree to define the list of criteria pertinent for identifying land important for acquisition, management or stewardship of open space in heavily urbanized areas in California. Fig. 1 contains the decision tree constructed by the group. Six over-riding criteria emerged as the most relevant for urban open space. These were: (i) Improves quality of urban system; (ii) Provides for multiple park and recreational opportunities; (iii) Physical and visual accessibility; (iv) Regional strategic significance; (v) Threats; and (vi) Restores and maintains natural resource and/or working landscape values. Each of the six major criteria was divided into a number of sub-criteria. For the purposes of illustration, we will focus solely on the six overriding criteria. A full description of

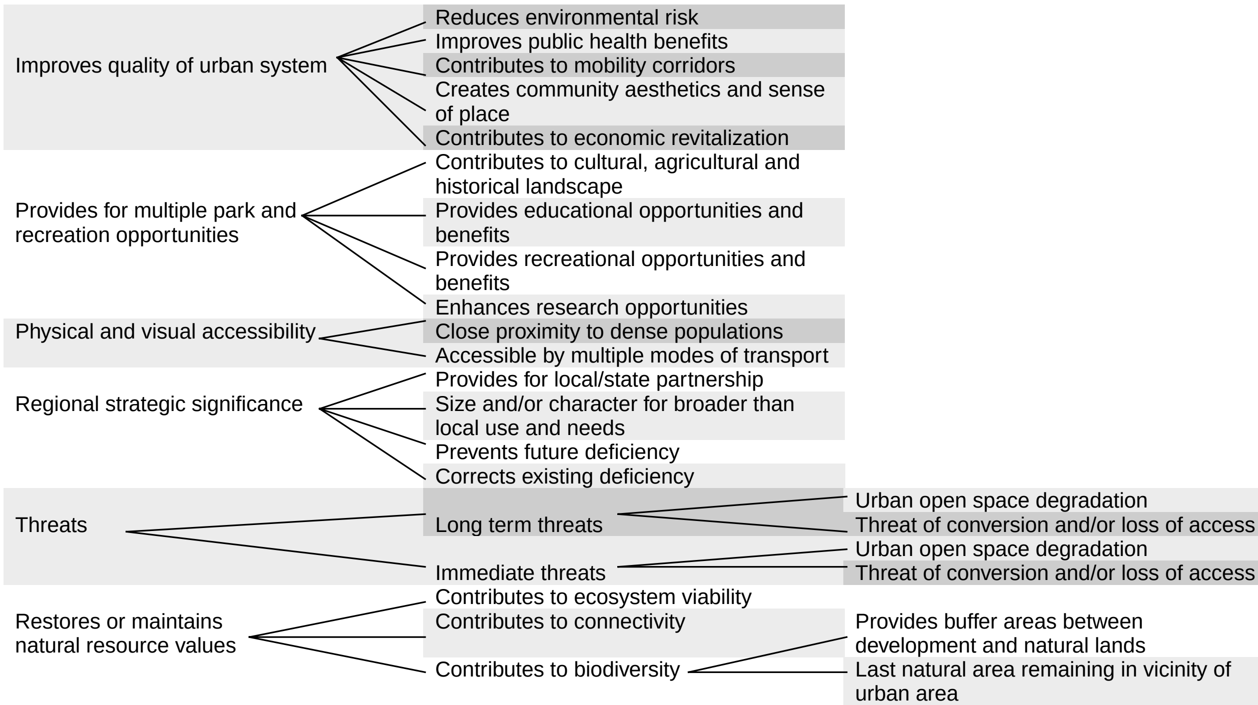

Fig. 1. Multi-criteria decision tree for identifying lands important for acquisition, management and stewardship of urban open space.

the urban open space decision-making application is provided in Regan et al. (2002).

Stakeholders weighted the criteria in the decision trees as more or less important than others in achieving the relevant goal. The Analytic Hierarchy Process (AHP; Saaty, 1980) was used to construct criteria weights of importance for each of the group members, via the scores placed on pair-wise comparisons of criteria. When the AHP is used within a group, it is usually necessary to summarize the preference scores into a single set of scores representative of the group. The geometric mean is the most widely used method of summarizing AHP scores across a group (Xu, 2000).

The use of the geometric mean to calculate the consensual AHP score is problematic and highly unsatisfactory for group decision making for a number of reasons. First, taking a geometric mean score completely ignores the actual range of values offered across the group. It has the same effect as all group members agreeing on the mean score, which is usually not the case. Second, a prerequisite for applying the geometric mean to AHP weights in group settings is that the group should be homogeneous (Saaty, 1980; Bolloju, 2001; Zahir, 1999). For many groups, especially in environmental contexts, there are distinct clusters of opposing opinions amongst group members (Brower et al., 2001; Van den Honert, 2001). Arithmetic and geometric means are inappropriate descriptors of data that are multi-modal or have extreme outliers. Third, all members of the group are treated as if they have equal expertise on the issues related to each criterion. This will not be the case for many group decision-making scenarios. Indeed, a primary motivation for group decisions is to bring together people with different expertise relevant to the decision at hand. If all group members had the same expertise (were that even possible), this would defeat the purpose of pursuing a group-based decision in the first place. To account for this, weighted arithmetic and geometric means of criterion weights are sometimes used in AHP group decision making where weights of importance are placed on each individual. However, these methods require a consensual weight of importance placed on each individual in the group, so the problem is merely shifted from providing consensual criterion weights to consensual weights of importance for each group member. In this paper, we present a formal method, consensus convergence modeling, to address all of these problems and improve the way values are aggregated in group decision making.

3. Merits of a formal model for reaching consensus

Popular wisdom dictates that group decisions for multi-faceted environmental management problems require consultation of relevant stakeholders and facilitation to ensure that protocols for negotiation and consensus are adhered to (Fearon, 2003; Gilman, 2001; Innes and Booher, 1999). This is supported by the literature on environmental decision making and by common sense. However, there are many instances where consensus building is thwarted by conflict or yields outcomes that are not truly representative of the group as a whole (Poitras et al., 2003; Margerum, 2002; Brower et al., 2001; Harrison and Burgess, 2000; Lubell, 2000; Kennedy and Loard, 1999). This can occur for a variety of reasons. Below we outline some of the pertinent reasons why ad hoc negotiation and consensus-building strategies might fail then argue for the incorporation of formal consensus models for components of the group decision-making process, and elucidate how formal methods avoid some of these pitfalls.

It is well documented that the composition of the group can affect the choices of individuals within the group. Thomas-Hunt et al. (2003) demonstrate that group members will evaluate more favorably the members with whom they have strong positive connections than members who they regard as social isolates. This is despite the fact that social isolates participate more than other group members and often have unique expertise and knowledge that is highly valued by socially connected members in the group. This has implications for the outcome of consensus building. If groups contain social clusters or cliques, then regardless of the value of the social isolate's knowledge, that group member may have little influence in the group decision.

Baumeister and Newman (1994) characterize two general motivational types in group decision making, which they call *intuitive scientist* and *intuitive lawyer*. Intuitive scientists aim to reach the correct conclusion using objective procedures to gather evidence that minimizes bias. They aim to form conclusions that are consistent with reality rather than with pre-existing beliefs. Conversely, intuitive lawyers 'marshal the best available evidence for the preferred conclusion, or against the unwanted conclusion' (Baumeister and Newman, 1994, p. 5). They selectively use only evidence favorable to their preferences and discredit unfavorable implications. It should be noted that this is a cognitive distinction—practicing scientists can be, and often are, intuitive lawyers. Lubell (2000) theorizes that conflict in consensus-building initiatives occurs when intuitive lawyers capitalize on uncertainty to interpret evidence in ways that are consistent with their self-interest. When groups contain intuitive lawyers with opposing agendas, the ensuing conflict can lead to a gridlock. Englehardt (1999) argues that consensus can only be achieved among people predisposed to common goals and ways of thinking. If this is truly the case then consensus in environmental decision making is unlikely, given its inherently interdisciplinary nature. Lubell (2000) offers policy recommendations to overcome conflict, the major one being the transformation of intuitive lawyers to intuitive scientists.

Status of group members and group size can have significant impacts on group decisions. Ohtsubo and Masuchi (2004) show that as group size increases beyond five individuals a high status member's influence on the group decision increases.Baumann and Bonner (2004) also found that in the presence of a high status member, the group will defer to that member most of the time. A possible reason for this is uncertainty. When group members are uncertain of the issues involved, they are unlikely to argue persuasively in support of their position even when they are in the majority faction. As a result, group members may defer to the high status member who can argue convincingly even when that member is equally uncertain.

Brower et al. (2001) found that in a conservation and water-use context, consensus-based management was vulnerable to control by special interests. Furthermore, their research suggested that 'the emphasis consensus-based management places on cooperation and agreement may actually harm the protected resource.' They identify two major weaknesses in consensus-based decision making for environmental management: (1) participants are preoccupied with political agendas, rendering the environmental goal secondary to the consensus-based process itself, and (2) although all relevant stakeholders may participate in the environmental management, not all voices carry equal weight. Some participants in their study highlighted the requirement for consensus as an impediment to progress and concluded that sub-optimal decisions were the result. Gregory et al. (2001) came to similar conclusions in their separate study of water-use planning.

Another way in which a group may be vulnerable to control by special interests is when a group member actively and intentionally influences or manipulates the decisions of other group members. Hamilton (2003) (and references therein) argue that participants will favorably suggest alternatives and points of view to others that they do not support themselves in order to influence other group members to adopt their preferences. By offering inferior alternatives and comparisons for consideration, a participant can guide others to the choice preferred by that participant. Steinel and De Dreu (2004) assert that participants will misrepresent facts to influence the group decision. Individuals in diverse groups find themselves in the *information dilemma*—'should they provide accurate information to achieve high collective outcomes or strategically misrepresent their preferences to secure good personal outcomes' (Steinel and De Dreu, 2004; Kelley and Thibaut, 1978; Murnigham et al., 1999)? Such behavior is counter to consensus building but nevertheless has the potential of occurring in diverse multi-faceted groups where the stakes are high, such as in environmental decision making.

Formal methods (such as consensus convergence modeling, or central tendency methods) avoid many of the pitfalls of ad hoc methods for consensus because they are inclusive of all group members, they use all the relevant information and not just information favorable to a particular point of view, they are blind to dominant personalities within the group (Burgman, 2005), and they allow for quantitative treatments of uncertainty in the decision-making process (Regan et al., 2005). Furthermore, formal decision– making methods are repeatable, enabling one to trace the ultimate decision back to its initial input. We believe that negotiation and consensus building using informal processes is a necessary component of environmental decision making, but should be restricted to the problem formulation tasks for which they are best suited. We believe formal methods should be adopted wherever possible for the aforementioned reasons, to augment and strengthen the informal methods.

It is important to note that in the case study at hand, informal consensus building was used to construct the decision tree in Fig. 1. Such a task is not conducive to formal mathematical methods for consensus. However, the task of assigning consensual weights of importance to criteria can and should be reduced to a formal method. A formal method avoids many of the pitfalls of consensus building highlighted above and has the advantage of being transparent, reproducible and resistant to manipulation and the vagaries of member status and group size.

4. Methods

4.1. The consensus convergence model

The method proposed here aggregates individuals' criterion weights to form a consensual weight for the group. The method assumes that members of a group have opinions about the expertise and rationality of other members in the group. Suppose there are n agents with initial criterion weighting assignments $p_1^0, p_2^0, \ldots, p_n^0$ for a particular hypothesis. The first step in the consensus model involves each agent, i, assigning a weighting of respect, w_{ij}, for herself and the other agents', j, positions, where $\sum_{j=1}^{n} w_{ij} = 1$. The higher the weight, w_{ij}, the greater the respect agent i has for the opinion or expertise of agent j. It is important to note that there are two types of weights discussed in this paper: weights of importance placed on criteria (p_i^m), and weights of respect each group member places on every other group member (w_{ij}). In order to avoid confusion, we will use the phrases 'criterion weights' and 'weights of respect' (respectively) for these two weights.

If agent i is committed to consensus, she is obliged to assign a positive weight to at least one other member of the group apart from herself. Furthermore, if she assigns positive weight to other members in the group then she should not behave as if she assigned a weight of 1 to herself. Hence, her original criterion weight, p_i^0, should be updated to incorporate the opinions of the other members of the group according to the weights of respect she assigned to them. This yields a weighted average for agent i's new criterion weight assignment as:

$$p_i^1 = w_{i1}p_1^0 + w_{i2}p_2^0 + \ldots + w_{in}p_n^0, \quad i = 1, \ldots, n. \tag{1}$$

If consensus is not reached on the first iteration of aggregation (that is if $p_i^1 \quad i = 1, \ldots, n$ are unequal for at least one agent i) the process will be repeated with the same weights of respect (if the agents have not changed their respect weights for each of the other members) or with new weights of respect (if new information is available that leads agents to update their respect weights). If agents keep the same weights of respect, then this second round of aggregation will give a state two criterion weight for agent i:

$$p_i^2 = w_{i1}p_1^1 + w_{i2}p_2^1 + \ldots + w_{in}p_n^1, \quad i = 1, \ldots, n. \tag{2}$$

When all agents are considered simultaneously, the consensus model is formalized as:

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1n} \\ w_{21} & w_{22} & \cdots & w_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ w_{n1} & w_{n2} & \cdots & w_{nn} \end{bmatrix}, \qquad P = \begin{bmatrix} p_1^0 \\ p_2^0 \\ \cdots \\ p_n^0 \end{bmatrix} \tag{3}$$

where W is the table of constant weights of respect, and P is the column of initial criterion weights for each of the n members in the group. A state-one criterion weight (i.e. criterion weights arising from the first round of aggregation) results from the matrix multiplication WP, a state-two criterion weight (when the same respect weights are maintained) is calculated as $W(WP) = W^2P$, and state-m is W^mP. As m approaches infinity, the updated criterion weights converge towards a single number that is the consensual criterion weight (p_c, i.e. $p_c = p_1^c = p_2^c = \ldots = p_n^c$ where c is the number of iterations it takes to reach convergence). Convergence is guaranteed when weights of respect are constant (and non-trivial) throughout the iteration process for each agent.

Readers are referred to Lehrer and Wagner (1981) for full details and mathematical proofs of the consensus convergence model. Table 1 displays the normalized weights calculated

Table 1
Group members' individual criterion weights and group criterion weights calculated using three methods of aggregation: geometric mean of the AHP scores; arithmetic mean of weights across the group; consensus convergence modeling. Integers in parentheses refer to the ranking of the criterion under each method/group member with (1) denoting the highest weighted criterion and (6) the lowest weighted criterion

Group member ID	Improves quality of urban system	Provides for multiple park and rec opps	Physical and visual accessibility	Regional strategic significance	Threats	Restores or maintains natural resource values
A	0.129 (4)	0.165 (3)	0.078 (6)	0.117 (5)	0.032 (2)	0.480 (1)
B	0.046 (5)	0.095 (4)	0.028 (6)	0.152 (3)	0.266 (2)	0.413 (1)
C	0.169 (3)	0.088 (4)	0.073 (5)	0.258 (2)	0.044 (6)	0.368 (1)
D	0.164 (3)	0.086 (4)	0.049 (6)	0.465 (1)	0.062 (5)	0.174(2)
E	0.349 (1)	0.065 (4)	0.036 (5)	0.252 (3)	0.028(6)	0.270 (2)
F	0.147 (4)	0.204 (3)	0.079 (5)	0.288 (1)	0.021 (6)	0.261 (2)
G	0.207 (2)	0.143 (3)	0.045 (6)	0.129 (4)	0.092 (5)	0.384 (1)
H	0.021 (6)	0.199 (2)	0.037 (5)	0.149 (3)	0.078 (4)	0.515 (1)
I	0.266 (1)	0.117 (4)	0.065 (5)	0.266 (1)	0.020 (6)	0.266 (1)
J	0.029 (6)	0.073 (3)	0.073 (3)	0.515(1)	0.237 (2)	0.073 (3)
Criterion weight from geometric mean of AHP scores	0.166 (3)	0.127 (4)	0.062 (6)	0.248 (2)	0.066 (5)	0.331 (1)
Normalized arithmetic mean of criterion weights	0.153 (3)	0.124 (4)	0.056 (6)	0.259 (2)	0.088 (5)	0.320 (1)
Consensus convergence weight	0.151 (3)	0.123 (4)	0.056 (6)	0.253 (2)	0.084 (5)	0.322 (1)

from each individual's AHP scores for the six criteria at Level 1 in the decision tree.

4.2. Application of adapted consensus convergence model to urban open space criteria weights

The consensus convergence model described above requires each individual in the group to assess all other group members and then assign a weight to each member according to their degree of respect for or agreement with that member's expertise or views on the issue at hand. For the urban open space MCDM case study, this approach is infeasible for a number of reasons. First, it would be a monumental task to obtain individuals' weights of respect for group members in addition to criteria weights. Second, group members may conceal their true agenda or distort their weights in order to enhance the likelihood of a preferred outcome (Condon et al., 2003). Third, and most important, the assignment of a numerical value on a person's degree of respect for each of the other members in the group is abstract and provocative. While most people would agree that they have different degrees of respect for, or agreement with, other group members' positions, translating that to a numerical value is non-trivial. Furthermore, group members may feel reluctant to explicitly quantify degrees of respect for other group members, or reveal their true weight of respect, as it could lead to rifts and ill feeling within the group. This is an undesirable outcome when the purpose of the exercise is to reach consensus. It is one thing to verbally disagree with a person with a reasoned argument, it is an entirely different matter to place a numerical value on the levels of respect a person has for the views or expertise of other members of the group for all to see. Hence, it is clear that an alternative approach that avoids these difficulties is necessary in assigning weights to individuals, if the approach is to be useful in environmental management.

Thus, we have adapted the original consensus convergence model to use a weight of respect based on the strength of the difference in the criteria weights assigned by individuals in the group. This has the advantage of placing weights on the differences in opinion behind the criteria weight assignments rather than on the individual assigning the weights. This method allows implementation of the consensus convergence model after the MCDM session, without requiring additional time from the stakeholders.

The aim here is to use the consensus convergence model to aggregate the weights corresponding to the 10 individual group members for each of the urban open space criterion appearing in Table 1. Let p_i^0 refer to the initial criterion weight held by group member i. Group member i is required to assign a weighting w_{ij} to each of the group members j (including herself) based on the strength of the differences between group member i's value of p_i^0 and the values p_j^0 held by the other group members. The weights of respect should have the following properties (Yaniv, 2004):

(a) the highest weight is given to herself (agents tend to weight their own views higher than others however, see Discussion for relaxations of this constraint)
(b) higher weights are given to individuals with similar values of p_i^0 (agents tend to weight those with similar views to themselves higher than those with disparate views)
(c) conversely, lower weights are given to individuals with more disparate values of p_i^0
(d) for each group member$i$, weights w_{ij} add to 1.0 when summed across all group members, j (Lehrer and Wagner, 1981).

A metric that calculates weights of respect with these properties is

$$w_{ij} = \frac{1 - |p_i^0 - p_j^0|}{\sum_{j=1}^{n} 1 - |p_i^0 - p_j^0|} \tag{4}$$

where i refers to the individual who is assigning the weights, i refers to the individual being assigned a weight and i is the number of group members. To illustrate, for the values for the criterion 'Improves quality of urban system' in Table 1 for group members D, E and H this results in the following weights of respect:

$$W_0 = \begin{bmatrix} 0.374 & 0.305 & 0.320 \\ 0.328 & 0.402 & 0.270 \\ 0.339 & 0.266 & 0.395 \end{bmatrix} \tag{5}$$

where each row in the matrix refers to the individual assigning the weights of respect, and each column refers to the individual being assigned the weight. It is now a simple matter to calculate the criterion weights p_i^1 for each group member i as the weighted average in Eq.(1). This results in the following set of updated criterion weights p_i^1

$$P_1 = W_0 P_0 = \begin{bmatrix} 0.374 & 0.305 & 0.320 \\ 0.328 & 0.402 & 0.270 \\ 0.339 & 0.266 & 0.395 \end{bmatrix} \times \begin{bmatrix} 0.164 \\ 0.349 \\ 0.021 \end{bmatrix}$$

$$= \begin{bmatrix} 0.175 \\ 0.200 \\ 0.157 \end{bmatrix} \tag{6}$$

This procedure may be repeated until all the values in the vector P_c are identical. A consensual vector of criterion weights can be reached by iterating Eq.(6) as $P_k = W_0 P_{k-1}$. For the set of criterion weights and corresponding weights of respect appearing in Eqs. (5) and (6) above the consensual criterion weight converges to 0.177.

5. Results

We applied the consensus convergence model to the Level 1 criteria for urban open space land identification. Convergence was reached in a few iterations. We also calculated the criterion weights resulting from the geometric mean of the AHP scores across group members and the arithmetic mean for each criterion weight across group members. Results appear in

Table 1. It is obvious from Table 1 that no two group members' weights are identical. More importantly, no two group members ranked criteria in the same order of importance. The ranks of the criterion 'Improves quality of urban system' span the entire range from lowest to highest, 'Regional strategic significance' spans 1–5 (highest to second lowest in importance) and 'Threats' span ranks 2–6. The tightest span of ranks across group members was 3–5 for 'Provides for multiple park and recreational opportunities' and 1–3 for 'Restores or maintains natural resource values'. It appears unlikely that ad hoc methods could reach consensus with such diverse sets of ranked criteria.

The results show that different consensus criterion weights are obtained under each different aggregation method chosen, with the weights calculated using the arithmetic mean and the consensus convergence model being the most similar. However, the ranking of criteria is the same when criterion weights are aggregated using the geometric mean of AHP scores to calculate weights, the arithmetic mean of AHP weights and the consensus convergence model.

The geometric mean of AHP scores is the most widely used method for aggregating criterion weights. Since the consensus convergence model is motivated by foundational issues in the theory of negotiation and consensus, and the geometric mean is adopted purely for mathematical convenience, the results suggest that the arithmetic mean of weights may be the more appropriate central tendency estimate than the geometric mean of AHP scores converted to a weight. We take up these matters further in the next section.

6. Discussion

Given the diversity of views about the relative importance of Level 1 criteria in the urban open space example, it is unlikely that ad hoc negotiation would lead to a consensus on criteria weights. Hence, this type of situation is ideal for application of a formal method for consensus.

6.1. Is the adapted consensus convergence model better than other formal methods?

From the results in Table 1, it may be tempting to believe that the consensus modeling approach to aggregating criterion weights is tantamount to a simple central tendency measure such as an arithmetic or geometric mean. We stress that this is not the case. The consensus convergence model has foundations in the philosophy of negotiation (Lehrer and Wagner, 1981 Lehrer, 1997) whereas simple central tendency measures are usually chosen for mathematical convenience. So, for example, in central tendency models, someone who expresses extreme views is factored in along with everyone else in the group. But their apparent extreme views might be because they know more than the other group members, because they know considerably less, or because they are deliberately misrepresenting their views to push the central tendency towards their own more moderate position. Central tendency models cannot distinguish these cases, but the adapted consensus convergence model is able to distinguish these cases via the weightings the other group members assign to the individual in question. Thus, deliberately misrepresenting one's view to push the end result in a certain direction is penalized because everyone in the group assigns, and is assigned, a weight of respect via the metric in Eq.(4). So even though the two methods may often give the same result, they will not do so in general. Moreover, when the consensus convergence model disagrees with a central tendency approach, it is the former that stands on firmer theoretical ground.

While the formal model for consensus is simple, it has considerable mathematical power that can expose the structure of negotiation (Lehrer, 1993). If each group member gives some positive weight to the views of other members and this process is iterated, the group will reach consensus. Indeed, an agent assigning non-trivial weights to the views of other group members is equivalent to the agent in question modifying her own preferences, since the latter is the end result of the former. Assigning a non-trivial weight is operationally equivalent to changing preferences towards the known views of other group members. Note that the model imposes a modification of preference assignments at each stage but it is worth bearing in mind that it is a model meant to simulate the convergence process. It may or may not accurately reflect the underlying psychological processes but it is intended to capture the spirit of the negotiation process in a formal way without the potential pitfalls inherent in informal methods. In effect, when an agent agrees to the formal consensus process they are agreeing to compromise their views in light of the views of others and in accordance with the details of the model.

The fact that in our example the consensual weights resulted in criteria ranking similar to the geometric mean of AHP scores and the arithmetic mean of group members' weights is encouraging for these simple central tendency measures, however, more research needs to be performed on the impact of different group structures and composition before any general claims can be made regarding the similarity of the two methods.

6.2. What if the outcome is one not desired by any single group member?

Another general concern about formal methods might be raised at this point: why should any group charged with an important environmental decision accept the outcome of the consensus convergence model, or even submit to such a formal process in the first place? After all, these models may not deliver results that any group member wants and it might even be thought to be irresponsible to leave important decisions up to a mathematical model when there is a room full of experts ready and willing to make the decisions in question. There are a couple of things to say in response to such concerns. The first is to reiterate some points made at the beginning of this paper: the motivation for formal models such as the consensus convergence model comes from the shortcomings of informal approaches to consensus. The thought is that perhaps formal methods can succeed where informal methods fail. The fact that the method presented in this paper comes equipped with a guarantee that (under fairly minor assumptions) consensus will occur, puts the burden of proof squarely on the informal methods. What guarantee is there that the room full of experts will reach consensus? Until assurances about the effectiveness of informal methods can be provided, the formal methods hold sway.

But there is a deeper issue about the adequacy of the results achieved by the formal method. What use is the guaranteed consensus, if the consensus is on an outcome that no one wants? First, it is important to note that this is a concern for any method of negotiation that involves compromise. Short of submitting to the will of a dictator, group decisions must allow for the possibility of arriving at an outcome that is not the desired outcome of the majority or even a single member of the group. (Think of a simple haggling exercise.) But most importantly there appears to be a mistake behind this whole line of objection. One should not think of a group outcome as acceptable or unacceptable in terms of how many (or if any) members of the group desire the outcome in question. At the negotiation table one needs to temper one's desire with others' desires. Reasonable and cooperative group members should be willing to temper their views with those of other members of the group. This means that no reasonable member should be aiming to have their views prevail. So each member should be willing to have the group consensus converge at an outcome that is not held by any one of them. In social choice theory, it seems that it is rationality along with fairness and reasonableness that is the driving force behind social decisions. But why be fair and reasonable? The adapted consensus convergence model has a very good answer to this. Suppose one group member tries to subvert the consensus process by deliberately shifting their criterion weights to an extreme, they will be assigned low weightings of respect. Thus, non-cooperation (i.e. shooting for outright victory rather than consensus) yields the risk of being excluded from the process or having very little impact on the outcome because of low respect weightings. In the consensus convergence model, as in life, cooperation is rewarded.

With that said, we wish to reiterate the role of formal methods in reaching consensus that we touched on in Section 3. Group decision-making problems for environmental management are complex and multi-faceted. Formal methods are unlikely to be able to address all the complexities of group decision-making problems. Nor is it desirable to enforce formal methods for every step in the process. At some point in the process, it is usually necessary to use ad hoc methods. For instance, the brainstorming session that resulted in the set of criteria for the Urban Open Space goal was well suited to an ad hoc process. In this paper, we wish to promote formal methods to augment existing informal methods for group decision-making. In doing so, we hope to minimize the opportunities for subversion of consensus-building activities. Hence, the consensus convergence model may be more acceptable to stakeholders in promoting the consensus building process because of its relative objectivity.

6.3. Questions raised by current method

There are some interesting ongoing questions arising from this work. We believe this model, with its basis in consensus and negotiation theory is a useful tool to answer questions about how consensus is affected by group composition. A number of questions are of particular importance in composing groups for environmental decision making:

(a) how does the distribution of criterion weights across individuals affect the consensual criterion weight? Is it important to always ensure homogeneous groups? Do clusters of opinions result in different consensual weights than homogeneous opinions?
(b) how does the number of group members impact the consensual criterion weight? Is it important to include group members with intermediate views between two extremes, or is it sufficient to include only members with views at either extreme? Conversely, is it necessary to include group members with extreme views if the bulk of the group is like-minded?

Other issues worthy of further exploration concern extensions of the model. One extension is obtained by relaxing the constraint that the weightings of respect should remain constant through all the iterations. If weightings are updated at each stage of the iteration under what conditions will convergence still be achieved? We hope to take up these more technical issues elsewhere (although see chapter 8 of Lehrer and Wagner, 1981 for some results in these directions).

Finally, in our model an agent must always assign the highest respect weighting to herself. But there is good reason, in some circumstances, for relaxing this constraint. It may be that for a particular decision, an agent may have little confidence in her own views. She may have more confidence in the views of some acknowledged expert. Moreover, the views of this expert may differ considerably from the agent's views. At present, our model is unable to accommodate the weightings of such a humble agent, since an agent's respect weighting for others in the group is determined by the distance from the agent's own views. The above scenario, however, presents the motivation for a potentially useful extension of the model in which humble agents are allowed.

In this paper, we have presented a simple and transparent means of assigning respect weights and we have implemented them in a formal consensus model. This method of assigning weights of respect, although it has considerable merit, is not an essential part of the consensus convergence model. Other methods of assigning respect weightings that are consistent with the Lehrer and Wagner model are worthy of further investigation. Furthermore, this method is not wedded to the AHP for assigning criterion weights in MCDM trees. This model can be applied to any MCDM tree with weights assigned by individuals within a group setting.

7. Conclusions

In this paper, we have presented a formal model for reaching consensus on criterion weights in MCDM trees. In particular, we have provided motivation for the use of such methods in-group decision-making contexts, including a survey of the pitfalls of traditional ad hoc consensus building processes and an explanation of how formal methods can avoid these pitfalls. We have shown that the standard method for aggregating weights in group AHP applications, the geometric mean of individuals' pairwise comparison scores, provides a different weighting of criteria than that achieved with the consensus model. Hence, it can make a difference which aggregation scheme is adopted. Furthermore, we have argued that the consensus convergence model for aggregation of criterion weights should hold sway because it is theoretically well grounded, it avoids many of the pitfalls of ad hoc methods, and it is easily implemented. We believe that such models will help reach consensus in complex, multi-faceted decision problems, because individuals may more readily accept its objectivity and explicit foundations in the structure of negotiation. Future work along these lines will provide improved decision-support tools for negotiation and consensus in environmental management.

Acknowledgements

The authors wish to thank Keith Lehrer for discussions, which helped clarify our ideas. The authors also wish to thank Frank Davis, Jeff Loux, Sandy Andelman and the participants of the California Legacy Project Urban Open Space Workshop for providing the motivation for this study. We also wish to thank the following people for useful discussions and comments on the ideas in this paper: Sandy Andelman, Yakov Ben-Haim, Mark Burgman, Atte Moilanen, Scott Rehmus, Sahotra Sarkar, Katie Steele and three anonymous referees.

References

Baumann, M.R., Bonner, B.L., 2004. The effects of variability and expectations on utilization of member expertise and group performance. Organizational Behavior and Human Decision Processes 93 (2), 89–101.

Baumeister, R.F., Newman, L.A., 1994. Self-regulation of cognitive inference and decision processes. Personality and Social Psychology Bulletin 20, 3–19.

Bolloju, N., 2001. Aggregation of analytic hierarchy process models based on similarities in decision makers' preferences. European Journal of Operational Research 128, 499–508.

Brower, A., Reedy, C., YelinKefer, J., 2001. Consensus versus conservation in the Upper Colorado River Basin Recovery Implementation Program. Conservation Biology 15 (4), 1001–1007.

Burgman, M.A., 2005. Risks and Decisions for Conservation and Environmental Management. Cambridge University Press, Cambridge.

California, State of. 2000. The California Legacy Project Archive, http://legacy.ca.gov/ 2005.

Collignon, S., 2003. The European Republic: Reflections on the Political Economy and Future Constitution. Federal Trust for Education and Research, London.

Condon, E., Golden, B., Wasil, E., 2003. Visualizing group decisions in the analytic hierarchy process. Computers and Operations Research 30, 1435–1445.

Englehardt, H.T., 1999. Bioethics in the third millennium: some critical anticipations. Kennedy Institute of Ethics Journal 9, 225–243.

Erickson, D.L., 2004. The relationship of historic city form and contemporary greenway implementation: a comparison of Milwaukee, Wisconsin (USA) and Ottawa, Ontario (Canada). Landscape and Urban Planning 68 (2–3), 199–221.

Fearon, R., 2003. Linking stakeholders and decision makers with science in managing the coastal water environment: case studies from urban, industrial and rural subtropical catchments in Australia. Water Science and Technology 47 (6), 179–184.

Gilman, E., 2001. Integrated management to address the incidental mortality of seabirds in longline fisheries. Aquatic Conservation—Marine and Freshwater Ecosystems 11 (5), 391–414.

Gregory, R., Daniels, T., Fields, D., 2001. Decision aiding, not dispute resolution: creating insights through structured environmental decisions. Journal of Policy Analysis and Management 20 (3), 415–432.

Hamilton, R.W., 2003. Why do people suggest what they do not want? Using context effects to influence others' choices. Journal of Consumer Research 29, 492–506.

Harrison, C., Burgess, J., 2000. Valuing nature in context: the contribution of common-good approaches. Biodiversity and Conservation 9, 1115–1130.

Innes, J.E., Booher, D.E., 1999. Consensus building as role playing and bricolage: toward a theory of collaborative planning. Journal of the American Planning Association 65 (1), 9–26.

Kelley, H.H., Thibaut, J.W., 1978. Interpersonal Relations: A Theory of Interdependence. Wiley/Interscience, New York.

Kennedy, D.S., Loard, W.B., 1999. Analysis of Institutional Innovation in the Natural Resources and Environmental Realm: The Emergence of Alternative Problem-Solving Strategies in the American West. University of Colorado Natural Resources Law, Boulder.

Lehrer, K., 1993. Conflict and consensus. Initiative: The Udall Center for Public Policy (Newsletter) 5.2 (1–3), 11–13.

Lehrer, K., 1997. Consensus, negotiation and mediation. In: Kacprzyk, J., Nurmi, H., Fedrizzi, M. (Eds.), Consensus Under Fuzziness. Kluwer, Boston, pp. 3–15.

Lehrer, K., Wagner, C., 1981. Rational Consensus in Science and Society. Reidel, Dordrecht.

Lubell, M., 2000. Cognitive conflict and consensus building in the National Estuaries Program. American Behavioral Scientist 44 (4), 629–648.

Margerum, R.D., 2002. Collaborative planning—building consensus and building a distinct model for practice. Journal of Planning Education and Research 21 (3), 237–253.

Murnigham, J.K., Babcock, L., Thompson, L.L., Pillutla, M., 1999. The information dilemma in negotiations: effects of experience, incentives, and integrative potential. International Journal of Conflict Management 10, 313–339.

Ohtsubo, Y., Masuchi, A., 2004. Effects of status difference and group size in group decision making. Group Processes and Intergroup Relations 7 (2), 161–172.

Poitras, J., Bowen, R., Wiggin, J., 2003. Challenges to the use of consensus building in integrated coastal management. Ocean and Coastal Management 46, 391–405.

Regan, H.M., Glickfeld, M., Barnett, H., Loux, J., McCarty, P., Doyle, R., Edelman, P., Kamradt, D., Beier, P., Luke, C., Denzler, S., Woodbury, J., Miller, C., Dinno, R., Dangermond, P., Metz, J., Angle, M., Greenwood, G., Scott, T., Davis, F., Beyeler, M., Rayburn, R., 2002. Report of NCEAS/California Legacy Project Workshop on Urban Open Space Conservation Criteria. A Report to The Resources Agency of California and the California Legacy Project, pp. 26.

Regan, H.M., Ben-Haim, Y., Langford, B., Wilson, W.G., Lundberg, P., Andelman, S.J., Burgman, M.A., 2005. Robust decision making under severe uncertainty for conservation management. Ecological Applications. 15 (4), pp. 1471–1477.

Ridgley, M.A., 1993. Equity and the determination of accountability for greenhouse-gas reduction. Central European Journal for Operations Research and Economics 3 (3), 223–242.

Saaty, T.L., 1980. The analytic hierarchy process: planning, setting priorities, resource allocation. McGraw-Hill, London.

Steinel, W., De Dreu, C.K.W., 2004. Social Motives and strategic misrepresentation in social decision making. Journal of Personality and Social Psychology 86 (3), 419–434.

The Trust for Public Land, 2004. Benefits of Urban Open Space, http://www.tpl.org.

Thomas-Hunt, N.C., Ogden, T.Y., Neale, M.A., 2003. Who's really sharing? Effects of social and expert status on knowledge exchange within groups. Management Science 49 (4), 464–477.

The Resources Agency, 2001. First draft report on the methodology to identify state conservation priorities: California Continuing Resources Investment Strategy Project. A Report by the State of California Resources Agency.

Van den Honert, R.C., 2001. Decisional power in group decision making: a note on the allocation of group members' weights in the multiplicative AHP and SMART. Group Decision and Negotiation 10, 275–286.

Xu, Z., 2000. On consistency of the weighted geometric mean complex judgment matrix in AHP. European Journal of Operational Research 12, 683–687.

Yaniv, I., 2004. Receiving other people's advice: influence and benefit. Organizational Behavior and Human Decision Processes 93 (1), 1–13.

Zahir, S., 1999. Clusters in a group: decision making in the vector space formulation of the analytic hierarchy process. European Journal of Operational Research 112, 620–634.