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Supporting multi-stakeholder environmental decisions

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Abstract

This paper examines how multiple criteria analysis (MCA) can be used to support multi-stakeholder environmental management decisions. It presents a study through which 48 stakeholders from environmental, primary production and community interest groups used MCA to prioritise 30 environmental management problems in the Mackay–Whitsunday region of Queensland, Australia. The MCA model, with procedures for aggregating multi-stakeholder output, was used to inform a final decision on the priority of the region's environmental management problems. The result was used in the region's environmental management plan as required under Australia's Natural Heritage Trust programme. The study shows how relatively simple MCA methods can help stakeholders make group decisions, even when they hold strongly conflicting preferences.

Keywords: Multiple criteria analysis; Decision support; Group decision making; Consensus

1. Introduction

The vast majority of environmental management decisions are guided by multiple stakeholder interests. Multiple criteria analysis (MCA), a framework for evaluating decision options against multiple objectives, is emerging as a popular approach for supporting multi-stakeholder environmental decisions (Teng and Tzeng, 1994; Maguire and Boiney, 1994; Bellehumeur et al., 1997; Regan et al., 2006; Gutrich et al., 2005).

Common reasons for applying MCA in multi-stakeholder decisions are to provide a transparent, structured, rigorous and objective evaluation of options. Typically, MCA helps not by providing 'the answer' but by providing a process. However, researchers are still learning how MCA impacts on what could otherwise be an intuitive or ad hoc group decision-making process. Some researchers have found MCA can alienate decision makers or experts in multi-stakeholder problems due to its complexity and 'black box' nature (Bojórquez-Tapia et al., 2005).

This paper shows how MCA was used to support multi-stakeholder priority setting decisions in the Mackay–Whitsunday region of Queensland, Australia. MCA provided a technique for structured ranking or scoring of decision options (environmental problems) against multiple objectives measured in different units. In the study a group of 48 stakeholders used MCA to produce a priority ranking of 30 environmental problems in the region. This provided a statement of where limited resources would be directed in coming years and was incorporated in the Mackay–Whitsunday Natural Resource Management (NRM) Plan (MWNRMG, 2005); a government policy document created under the Natural Heritage Trust (NHT) programme. The NHT is one of Australia's largest environmental programmes funded at A$2.5 billion nationally over the 10-year period 1996/1997 to 2006/2007 and is a major source of funds for Australia's regional NRM groups, including Mackay–Whitsunday.

The paper explores methodological issues surrounding the application of MCA in multi-stakeholder environmental management decisions. The level of *inter*- and *intra*-stakeholder group agreement achieved with MCA is examined. An assessment is made of how criteria weights impact the result. It is shown that a relatively simple MCA method, namely weighted summation, can improve the decision procedure by explicitly introducing weighted criteria into the evaluation of options. Whilst MCA was

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found to improve the decision procedure in the Mackay–-Whitsunday region it can never fully replace the intuitive judgements of decision makers. It is argued that MCA helps resolve conflict by pinpointing areas of agreement and disagreement, but is not a panacea to the difficult and time-consuming task of reaching consensus by negotiation.

2. The decision problem

The Mackay–Whitsunday region is located in Queensland, Australia and covers an area of 940 000 ha (Fig. 1). It has annual rainfall varying from 3000 mm/yr in the elevated coastal rangelands to 1 000 mm/yr in other inland areas. Agricultural production from relatively natural landscapes, such as cattle grazing, is the dominant land use and occurs on 55% of the land area. The dominant crop is sugarcane. The major industries are agriculture, grazing, tourism, fishing and aquaculture. The region has a population of 113 000 persons. The natural environment includes the Great Barrier Reef world Heritage Area, the Whitsunday Island Group, wetlands and protected wilderness areas (MWNRMG, 2005).

The Mackay–Whitsunday NRM Group is the leading institution for managing NHT funds within the region. Its offices are located in the city of Mackay and it employs around 10 staff. The activities of the group are overseen by a Management Committee comprising nine persons from a range of primary production and conservation backgrounds.

Under a bilateral agreement between the Australian Commonwealth Government and the Queensland State government, regional bodies are required to develop an accredited NRM plan and investment strategy (Australian Government, 2004). This involves a statement of environmental management priorities (Australian Government, 2004, Section 90, p. 18):

> In preparing Regional Investment Strategies, regions should prioritise actions and focus initially on those actions deemed to be most important.

Prioritisation was achieved in the Mackay–Whitsunday region by identifying 30 environmental problems and ranking them in priority order using MCA. The priority list, as published in the NRM Plan (MWNRMG, 2005), is shown in the Results section of this paper.

The criteria, used within the MCA model to score and rank the environmental problems, were identified using the assets, threats and solvability (ATS) framework by Hajkowicz and McDonald (2006). The ATS framework has previously been used to set environmental management priorities in the Wet Tropics region of North Queensland (FNQNRM and Rainforest CRC, 2004) and for the Western Australian Salinity Investment Framework (Government of Western Australia, 2003).

Under ATS environmental problems which have high physical severity, are causing damage to high-value assets, and are highly solvable are assigned high priority. Investing in these problems is likely to provide the greatest returns. Conversely, an environmental problem with low severity, acting on a low-value asset with little chance of being corrected is a low priority under ATS and large effort is most likely unwarranted.

The ATS criteria used in the MCA model for the Mackay–Whitsunday region are given in Table 1. These are similar to the criteria applied in the Wet Tropics region by Hajkowicz and McDonald (2006). The 48 stakeholders were asked to score the performance of each environmental management problem against each criterion on an 0–10 point scale, where 0 denotes lowest priority and 10 denotes

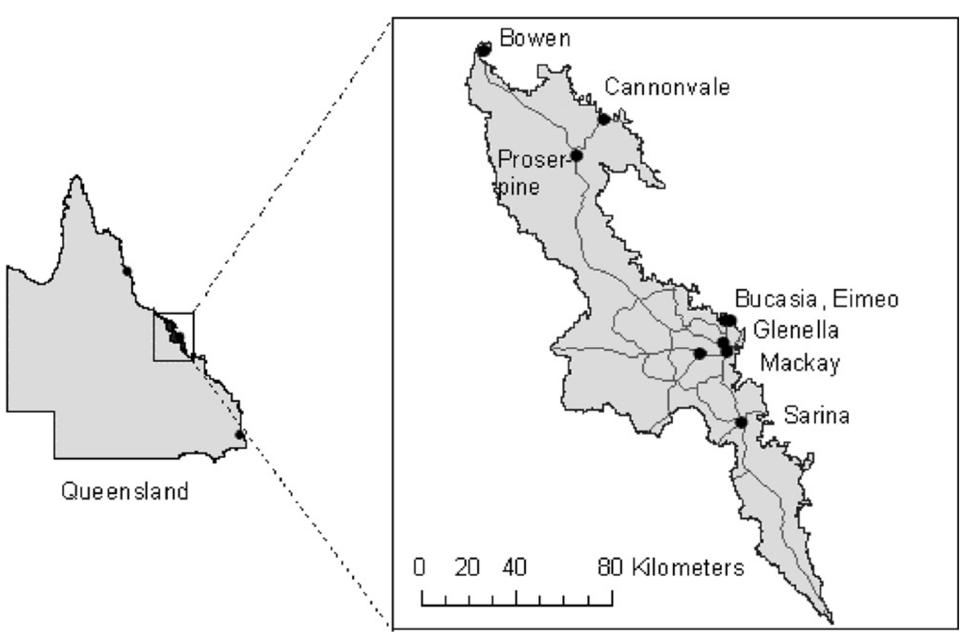

Fig. 1. Location of the Mackay–Whitsunday region.

Table 1
Criteria used to prioritise the environmental problems (adapted from Hajkowicz and McDonald, 2006)

Criteria	Description
Biodiversity	How severely is the environmental problem damaging the region's biodiversity assets? The biodiversity includes the flora, fauna and terrestrial, marine and aquatic habitats of the environmental management region. A higher score means a more severe impact and results in higher priority
Climate	How severely is the environmental problem damaging the region's climate assets? The climate asset includes local and global air quality. A higher score means a more severe impact and results in higher priority
Community	How severely is the environmental problem damaging the region's community, assets? The community asset includes community, includes government and non-government institutions, community groups and organisations, industry groups, and traditional owner people. A higher score means a more severe impact and results in higher priority
Land	How severely is the environmental problem damaging the region's land (agricultural) assets? The agricultural asset includes soils and landscapes used for primary production. A higher score means a more severe impact and results in higher priority
Water	How severely is the environmental problem damaging the region's water resource assets? The water resource asset includes streams, rivers, wetlands and estuarine habitats which support both primary industries, recreation and native ecosystems
Urgency	What is the rate at which this environmental problem is becoming worse? A higher score indicates the problem is more quickly worsening and will have higher priority
Irreversibility	To what extent is the environmental problem irreversible? A higher score represents greater irreversibility and results in higher priority
Extent	Over what area of the Mackay–Whitsunday NRM region is this problem occurring? A higher score indicates a more widespread problem and has higher priority
Tractability	How easy is it to address the problem's underlying causes? A higher score means the problem is more tractable and has a higher priority

highest priority. They were asked to weight the criteria by assigning percentage scores, which must add to 100%.

3. Stakeholders and decision makers

This study makes a subtle distinction between 'decision makers' and 'stakeholders'. Stakeholders are those persons with regional environmental management interests whose preferences guided the MCA model. Decision makers are those persons who made a final choice on environmental management priorities, *i.e.* the Mackay–Whitsunday NRM Committee, giving consideration to stakeholder preferences. The decision makers combine their judgements with the multi-stakeholder MCA model to set final environmental priorities.

Input to the MCA model was taken from 48 stakeholders classified into eight stakeholder groups. These persons were selected by staff and consultants acting on behalf of the Mackay–Whitsunday NRM group. The process made use of local knowledge and existing social networks. A database of stakeholders is maintained by the Mackay–Whitsunday NRM group and it was used to help identify people. The eight stakeholder groups included:

1. Grazing (six persons).
2. Community and government (14 persons).
3. Conservation (six persons).
4. Fruit and vegetable production (six persons).
5. Sugarcane production (six persons).
6. Tourism and economic development (five persons).
7. Fishing and marine (three persons).
8. Forest production (two persons).

The aim was to identify a set of persons representative of stakeholder interests within the region. The persons chosen had sound knowledge of the region, having lived and/or worked there for sometime. They were also aware of the functions and role of the Mackay–Whitsunday NRM group. There was an expectation that different stakeholder groups would promote different environmental management problems, and this was found to occur in the results.

A final decision on environmental priorities was made by the Mackay–Whitsunday Management Committee. This involved consideration of output from the multi-stakeholder MCA model and consideration of additional matters of deemed to be of relevance by the committee. The MCA model was an input to a broader decision-making process. Details on the decision-making process are supplied in the NRM Plan (MWNRMG, 2005).

4. Multiple criteria analysis model

An MCA model was used to rank the environmental problems in priority order. There exist hundreds of techniques for 'solving' an MCA problem and numerous software packages (e.g. Jiménez et al., 2003); a recent review of MCA techniques is provided in Figueira et al. (2005). In this study stakeholder comprehension and understanding of all procedures used to derive a result was mandatory. A complex mathematical procedure that was computationally precise but understood by only a few, if any, stakeholders would not have been accepted.

Given this requirement the MCA technique of weighted summation was applied. Janssen (2001) notes that although computationally simple, weighted summation provides a reasonable solution in many applications and the most important issue is selecting the correct criteria and right options in the first place. Weighted summation treats the performance data at a cardinal (as opposed to ordinal) level of measurement and assumes additive linear utility. These were considered realistic assumptions in this study.

In weighted summation there is an evaluation matrix (X) containing $n \times m$ performance scores where x_{ij} denotes the performance of option i against criterion j. In the Mackay–Whitsunday MCA all values for x_{ij} were an integer within the range 0–10, where 10 represents highest priority. The decision maker supplied a set of m weights of $w_{j=1};\ldots;w_{j=m}$. The weights sum to 1 and are non-negative. An overall priority score (u_i) for each environmental management problem was obtained by

$$u_i = \sum_{j=1}^{m} x_{i,j} w_j, \tag{1}$$

where

$$\sum_{j=1}^{m} w_j = 1,$$

$$0 < w_j \leqslant 1.$$

The environmental management problems are ranked according to u_i, where a rank of 1 denotes highest priority (assigned to the problem with the highest u_i) and a rank of n denotes lowest priority. The result is either a complete or partial rank order as tied rank positions are possible.

5. Aggregating MCA output

When MCA is applied in group decisions there is an aggregation problem. This can be stated as: Given k rankings of n objects, what ranking best represents group opinion (Emond and Mason, 2002)? As with the MCA method, the aggregation algorithm used in the Mackay–Whitsunday environmental management region needed to be simple enough for stakeholders to understand. This ruled out some of the more complex statistical procedures (Beck and Lin, 1983; Cook and Kress, 1990; Emond and Mason, 2002).

In this study multiple rank output was aggregated using the Borda Count method described by d'Angelo et al. (1998). This relatively simple approach determines an aggregate rank (R_i) for option i by determining the sum of ranks ($r_{h,i}$) across all stakeholders ($h = 1, \ldots, h = k$):

$$R_i = \sum_{h=1}^{k} r_{h,i}. \tag{2}$$

Decision options (*i.e.* environmental problems) are ranked in descending order of R_i. This approach can be considered an approximation to the more mathematically correct solution to the problem of rank-set aggregation by Emond and Mason (2002). It is also noted that when performance scores or criteria weights are subject to uncertainty there are alternative aggregation methods (e.g. Mateos et al., 2006). The need to provide understandable and transparent methods in multi-stakeholder MCA problems is a challenging issue, often involving a trade-off between computational rigour and ease-of-understanding. This issue of transparency and computational correctness is revisited in the concluding section of this paper.

6. Measuring agreement

Agreement between stakeholders is measured using Kendall's coefficient of concordance (z) with adjustments for tied rank positions. The coefficient measures the strength of correlation between multiple rank sets. Values for z range from 0 to 1 representing perfect disagreement to perfect agreement. The formula to calculate z is (Sheskin, 2004)

$$z = \frac{S}{\left(\frac{k^2 n(n^2-1) - k\sum_{h=1}^{k}\left[\sum_{a=1}^{k}(t_a^3 - t_a)\right]}{12}\right)}, \tag{3}$$

where: k is the number of stakeholders ($k = 48$ in this study); n the number of decision options ($n = 30$ environmental management problems in this study); s the number of tied rank positions ($a = 1, \ldots, a = s$) for stakeholder k; t the number of times tied position a is repeated;

$$S = \frac{nU - T^2}{n};$$

$$U = \sum_{i=1}^{n}\left(\sum_{h=1}^{k} r_{h,i}\right)^2$$

and

$$T = \sum_{i=1}^{n}\sum_{h=1}^{k} r_{h,i}$$

for $h = 1, \ldots, h = k$ stakeholders.

This coefficient was used for summary statistics, after completing the study, and was not needed for stakeholder and decision maker input. Consequently, there was no need to explain this particular method to stakeholders or decision makers.

7. Results

The MCA-derived ranking of environmental problems over all stakeholders ($K = 48$) on the basis of Eqs. (1) and (2) is shown in Table 2. This can be contrasted to the final decision adopted by the Mackay–Whitsunday Management Committee. The two rank sets are similar, though slightly different, and produce a correlation coefficient (z) of 0.747. This shows that decision maker judgements incorporate intuitive and subjective issues that are not captured within MCA. Nevertheless, the decision makers' final choice is still heavily based on MCA output. Issues surrounding the reconciliation of MCA results and decision maker judgements are revisited in the discussion and conclusion.

A test was made on whether any environmental problems were strictly dominated by another. Strict dominance occurs when an environmental problem performs equally, or better, to another problem for all stakeholders and better than another problem for at least one stakeholder. Based on a definition of strict dominance

Table 2
Environmental priorities in the Mackay–Whitsunday region

Environmental management issues	MCA priority rank[a]	NRM plan priority rank	Lowest MCA priority rank	Highest MCA priority rank
Lack of community awareness, knowledge and engagement in environmental management	1	8	25	1
Lack of facilitation and support	1	18	29	1
Lack of skills and training	1	10	30	3
Urban and industrial pollution	4	15	30	1
Water extraction	5	2	30	1
Soil salinity	6	11	23	1
Tourist and visitor impacts	7	28	27	1
Water quality decline	8	1	26	2
Land use change and building activity	9	7	30	2
Conflicting/inappropriate government policy	10	9	20	1
Acid sulphate soils	11	25	30	1
Lack of information/monitoring	12	5	28	1
Lack of community in environmental management	13	13	30	2
Aquatic pest plants and animals	14	17	29	3
Soil erosion	14	14	27	2
Terrestrial pest plants/animals	14	12	29	1
Vegetation clearing	14	3	27	1
Shipping and ship-sourced pollution	18	27	30	2
Diseases and pathogens	19	23	29	1
Waterway and wetland modification	20	6	30	1
Terrestrial habitat fragmentation	21	16	30	1
Grazing pressure	22	22	24	1
Over fishing and marine habitat modification	23	19	29	2
Aquaculture development	24	29	30	1
Greenhouse gas emissions	24	21	28	1
Lack of knowledge, recognition and culturally appropriate management of indigenous places and objects.	26	20	30	2
Episodic climatic events	27	4	26	1
Lack of indigenous involvement in environmental management programmes and projects	28	26	29	1
Lack of access to traditional land and sea country	29	30	30	1
Altered fire regimes	30	8	30	3

[a]A lower rank indicates higher priority.

by Yakowitz et al. (1993) problem i can be said to strictly dominate problem i' if:

$$r_{i,k} \leqslant r_{i',k} \text{ for all } k \text{ and } r_{i,k} < r_{i',k} \text{ for at least one } k.$$

Here $r_{i,k}$, an integer which is $\geqslant 1$, is the rank assigned to the ith problem by the kth stakeholder by using MCA. A lower value for $r_{i,k}$ means higher priority.

This was found not to occur; *i.e.* no environmental problem was strictly dominated and none could be considered strictly higher or lower priority to another. The range between the highest and lowest priority rank was considerable for each environmental problem. It can be seen in Table 2 that several environmental problems are rated between last (#30) and first (#1) by stakeholders. This made it impossible to relegate any environmental problem to 'lower priority' outright.

The 'urgency', 'land' and 'water' criteria were assigned the highest importance by the stakeholders (Fig. 2). The criteria of 'irreversibility', 'climate' and 'community' were

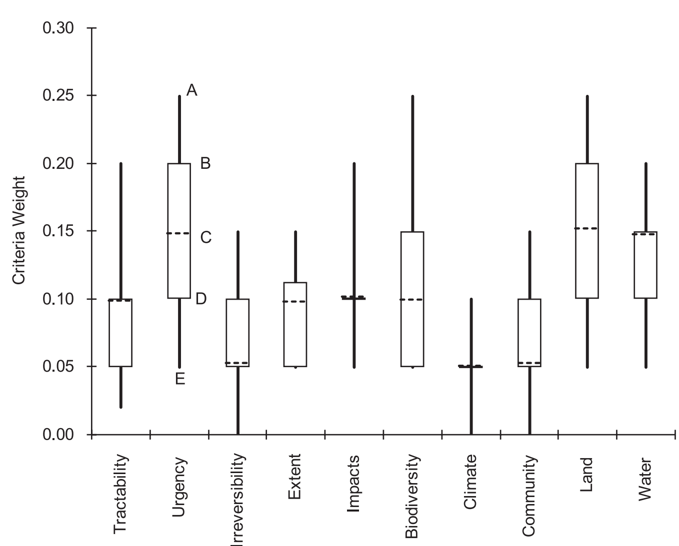

Fig. 2. Criteria weights for all ($k = 48$) stakeholders (A = maximum, B = 75th percentile, C = Median, D = 25th percentile, E = minimum).

Table 3
Inter- and intra-stakeholder group agreement measured with Kendall's coefficient of concordance (z)

Stakeholder group	With actual weights	With equal weights
All stakeholders ($K = 48$)	0.222	0.226
Grazing ($K = 6$)	0.291	0.284
Community and government ($K = 14$)	0.336	0.338
Conservation ($K = 6$)	0.437	0.422
Fruit and vegetable production ($K = 6$)	0.637	0.640
Sugarcane production ($K = 6$)	0.303	0.307
Tourism and economic development ($K = 5$)	0.328	0.337
Fishing and marine ($K = 3$)	0.423	0.439
Forest production ($K = 2$)	0.998	0.998

Table 4
Agreement amongst stakeholders on criteria performance scores

Criteria	Kendall's coefficient of concordance ($K = 48$)
Tractability	0.158
Urgency	0.171
Irreversibility	0.176
Extent	0.235
Impacts	0.202
Biodiversity	0.183
Climate	0.147
Community	0.105
Land	0.251
Water	0.243

seen as least important. For each criterion there was a considerable spread of weights.

Overall agreement on environmental management priorities within the entire group of all 48 stakeholders was low with a z of 0.22 (Table 3). For the most part, intra-stakeholder group agreement was also low with z values in the range of 0.30–0.44. The stakeholder groups with the highest levels of agreement were the fruit and vegetable producers and the forest production groups. These results show that the Mackay–Whitsunday stakeholders had considerable disagreement about regional environmental management priorities. Removing the criteria weights, by setting all equal, had little impact on overall levels of agreement.

A major source of disagreement was the performance matrix, in which environmental problems were scored against criteria by stakeholders. This was tested by ranking environmental problems in order of priority within each individual criterion. Kendall's coefficient of concordance (z) was then computed across all $K = 48$ stakeholders. Values for z ranged from 0.10 to 0.25 for individual criteria (Table 4).

8. Discussion

These results show a case where stakeholders had considerable disagreement, which made the determination of consensus challenging. This contrasts to other multi-stakeholder environmental studies using MCA which find high levels of agreement. Wattage and Mardle (2005), for example, used MCA and found agreement amongst 80% of stakeholders for a wetland management option in Sri Lanka. In the Mackay–Whitsunday case stakeholders had strongly divergent opinions about which environmental problems would receive the majority of the region's limited fiscal resources. Nevertheless, a consensus position was reached by the decision makers, *i.e.* the Mackay–Whitsunday Management Committee, and is published in the NRM plan which is a public document (MWNRMG, 2005).

The use of MCA did not eliminate the conflict, but helped identify points of disagreement and thereby facilitated a structured debate about priorities enabling a final decision. Decision makers used MCA as a process for eliciting stakeholder preferences, and judgements, to inform final choice. The MCA-based process satisfied the requirements under the NHT programme and helped the Mackay–Whitsunday Environmental Management Group produce a formally accredited environmental management plan. The results are now being used to target fiscal resources within the region. The usefulness of MCA in structuring a complex multi-objective and multi-stakeholder environmental problem is supported in other studies (Teng and Tzeng, 1994; Maguire and Boiney, 1994; Bellehumeur et al., 1997; Regan et al. 2006; Gutrich et al., 2005). As found in this study, prior applications of MCA typically find the real benefit not in providing an 'answer' but by providing a process.

In a multi-stakeholder setting, transparency in decision process is of paramount importance. If people cannot understand how a choice is made, they are unlikely to trust or implement that choice. The research team applying MCA in this study had to explain the calculations to both the stakeholders and the Mackay–Whitsunday Management Committee. Complex mathematical procedures, either MCA ranking/scoring algorithms or statistical methods for aggregating multiple rank sets, were beyond scope. They may have produced a more precise answer, but would have been inimical to improved decision process; the central objective of using MCA in a multi-stakeholder setting.

This study followed an observation by Janssen (2001) that often a simple MCA method will suffice, and what typically matters most is the selection of criteria and decision options (in this study, environmental management problems) in the first place. The weighted summation and Borda Count approaches are simple methods that most stakeholders can quickly understand. Some alternative MCA algorithms with more complex procedures include

ELECTRE (Roy, 1968), PROMETHEE (Brans et al., 1986), compromise programming (Zeleny, 1973, 1982) and the analytic hierarchy process (Saaty, 1987). These methods have previously been applied in multi-stakeholder environmental decisions with positive results (Teng and Tzeng, 1994; Gutrich et al., 2005; Wattage and Mardle, 2005). A possible difficulty, however, is that more complex algorithms and procedures can present a 'black box' analysis to stakeholders. For example, Bojórquez-Tapia et al. (2005) encountered problems of stakeholder acceptance with the analytical hierarchy process (AHP) to evaluate airport sites in Mexico City as part of an environmental impact assessment. They found some experts perceived the AHP software as a 'black box' and that (p. 480):

> … experts perceived the AHP as prone to manipulation, too technocratic, and deceptive. Specifically, they had reservations about the development of hierarchy structures, the validity of the pairwise comparisons, and the standardization procedure.

This does not mean AHP was unhelpful, Bojórquez-Tapia et al. (2005) concluded that it improved the decision process overall, but it does raise a potential problem in multi-stakeholder settings. One means of testing whether more sophisticated, and complex, MCA methods are needed is to apply multiple methods and compare the results. Numerous researchers have applied, and compared results from, several MCA methods in environmental management decisions (Gershon and Duckstein, 1983; Howard, 1991; Ozelkan and Duckstein, 1996; Eder et al., 1997; Raju et al., 2000). Typically, the result of MCA is relatively insensitive to changing the ranking/scoring algorithms (Hajkowicz and Higgins, 2006). If changing the MCA method does not significantly alter the result then a simple procedure may suffice.

Whilst an analytically robust algorithm is important to analysis, it needs to be considered alongside stakeholder understanding and capacity to participate. Often the choice of MCA method will have a minor impact on the final decision, but whether stakeholders understand and accept the MCA model is crucial. The field of MCA has been very enthusiastic in developing and applying ever more sophisticated ranking/scoring methods. Over 80 software packages are described in Weistroffer et al. (2005) and Figueira et al. (2005) review countless MCA methods. With such a powerful toolkit there is a growing requirement for improved means of selecting and applying MCA tools in real policy settings, especially those in which multi-stakeholder consensus is important.

Perhaps the main contribution of MCA is to have decision makers explicitly think about criteria and options in making choices. Were the MCA model removed from the Mackay–Whitsunday environmental priority setting problem how would the decision change? I believe the main difference would be a lack of structured debate about options (*i.e.* the environmental problems) and policy objectives (*i.e.* the criteria). Many stakeholders would have expressed opinions but it would have been unlikely they could have been recorded in a structured and repeatable manner to enable a final statement of priorities in the NRM Plan.

9. Conclusion

In this study the strength of MCA was not in prescription of an 'answer', but rather the provision of a transparent and informative decision process. For this a simple, and understandable, MCA methodology was most appropriate. Whatever result was obtained, decision makers would at some point introduce their own intuition and judgement. I believe this represents a sound decision procedure because MCA, or any other decision model, can never fully capture all matters of relevance to stakeholders. The use of MCA provides a solid analytical platform upon which judgements can be made. For improved consensus building in environmental management we need further research into how decision makers interact with an MCA model. This will help uncover how people's intuitive decision procedures can be informed by a structured, rational and analytic approach. It will also help identify where, in the decision procedure, analysis stops and judgement begins.

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