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How Model Outputs Can Be Used To Improve Decision-Making: Using Bio-economic Model Outputs in Deliberative Multi-criteria Evaluation to Prioritize Invasive Pest Species

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Abstract: The sheer number and complexity of biophysical and socio-economic models and their outputs can quickly overwhelm stakeholders who are trying to make sense of a natural resource-related issue. Add uncertainty to this bulk of multi-faceted information from risk analyses and the justification for selecting a course of action becomes an even more daunting endeavour. Decision and policy makers have to combine model outputs with a variety of other information sources in order to make difficult trade-offs between often conflicting investment options. A transparent and flexible decision facilitation process is required to help assimilate complex model outputs and other information within the context of policy considerations and guide decision-makers toward agreed conclusions on the issue at hand.

To aid stakeholders in the prioritization of biosecurity risk investment options, we provide information on invasive pest risk including a bio-economic pest impact model, socio-economic activity and ecological impacts. The specialized nature of the information, such as pest impact models, inevitably reach beyond the expertise of a participant group comprised of the public or a policy-making group, thus requiring decision support in the form of interpreting key findings and the corresponding uncertainty. The bio-economic model makes predictions concerning the costs incurred by the industry if the pest becomes part of the production scheme. The model has an associated sensitivity analysis that presents the full range of uncertainty surrounding possible costs. With this knowledge of uncertainty, the stakeholders can gauge how much confidence they want to place in the model output for use as a reference in ranking the pest risks. Outputs of the impact model along with other pest impact information are integrated using a deliberative decision facilitation methodology in order to bridge the communication and knowledge gap between the results and policy making participants. Upon consideration of stakeholder discussion and expert-based information provided, the role of participants is then to weight the factors they deem to be the most important in rating the "relative severity" of a set of biosecurity threats/pests. As a result, the process immerses the stakeholder or policy maker into the discussion of information sources such as model results, and goes a step further by eliciting opinion regarding the most important consequences within the context of the issue.

This decision support, primarily by means of a structured participatory configuration, aids the policy maker to understand the information being used to base the decisions on. This increased understanding helps lead to a sanctioning of the policies concerned – i.e., decisions are more likely to command assent and therefore lead to the desired outcomes if they have been formulated with a wide range of support. Stakeholder inclusion is also beneficial as participants can be the source of relevant local and social knowledge.

Keywords: *bio-economic model, biosecurity, decision making, Deliberative Multi-Criteria Evaluation, policy, risk, uncertainty*

1. INTRODUCTION

Natural resource management is essentially conflict analysis characterised by socioeconomic and environmental value judgements making straightforward solutions difficult (Munda *et al*., 1994). Natural resource management policy makers draw on a range of information to make decisions. Consideration is typically given to scientific results, information about social demographics and economic activity. The challenge for all policy makers is to weigh each piece of information by its importance and reliability. To add to the intricacy of this task, when decision-makers include model outputs in the development and implementation of public policy, they are often confronted by contradictory outputs from different models. On top of this, the output for each model varies in terms of quality or uncertainty. Thus there is evidence to expect that individuals, be they lay or expert, will likely not make informed, thoughtful choices about complex issues involving uncertainties and value tradeoffs (McDaniels *et al*., 1999). In order to help guide a decision-maker in effectively resolving an issue that is informed by multiple, uncertain, and conflicting model inputs, a set of rules is required to transform the broad goals, with multiple decision options, into agreements (Munda *et al*., 1994). This set of rules is called an evaluation method which aims to rationalise a given problem by systematically structuring all decision-makers' value judgements alongside relevant information sources for each policy choice following an iterative and dynamic process (Munda *et al*., 1994).

We used a multi-criteria decision analysis method embedded within a deliberative framework to engage stakeholders in the Australian horticultural field. We created a structured discussion in regards to which invasive pests pose the largest risk in terms of economic, social, and ecological impacts. A range of data was collected to help inform stakeholders and enable them to rank the risk of an invasive plant pest from entering Australia based on the relative scoring of economic, social, and ecological criteria within our deliberative decision making framework. Bio-economic pest impact was modelled and included the compiled dataset to inform stakeholders in their structured decision-making.

2. DELIBERATIVE MULTI-CRITERIA EVALUATION

Multi-criteria methods can provide an adaptive way to deal with quantitative and qualitative multidimensional factors and to help guide conflict analysis toward effective solutions. In general, preferred alternatives represented by criteria are weighted by stakeholders (Munda *et al*., 1994; Rauschmayer and Wittmer, 2006). These weightings are then aggregated into a single `compromise' rank order in order to work toward a decision solution. The purpose of using Multi-criteria decision analysis (MCDA) models is to find solutions to complex and uncertain decision-making issues, characterized by multiple alternatives that can be evaluated using weighable criteria (Jankowski and Nyerges, 2001). MCDA provides policy decision-makers with a holistic insight and structure in order to effectively assess complex problems. MCDA offers possibilities outside of economic efficiency, such as non-market considerations of ecological and social evaluation criteria, which a decision can be based (Brouwer and van Ek, 2004). Proctor (2001) outlines the advantages of MCDA as the ability to structure decision-making, include a variety of values, unravel complexities, include community and stakeholder preferences, encourage transparency of the process, and avoid monetary valuation of intangible environmental assets.

2.1. Background of deliberative participatory approaches

As a natural resource issue such as biosecurity involves a range of stakeholders with various levels of interest and influence, we required a methodology that combines the organization and aggregation features of MCDA (Munda *et al*., 1994) with deliberation and consensus-building features of citizens' jury processes (Crosby, 1999; Dienel and Renn, 1995). We combine a deliberative participatory framework with MCDA methods to form Deliberative Multi-Criteria Evaluation (DMCE). The application of the deliberative participatory framework to environmental problems is effective as their characteristics include complexity (Brown *et al*., 2001), uncertainty (Fox and Irwin, 1998), large temporal and spatial scales (Faith *et al*., 1996), and irreversibility (Van den Hove, 2000). The DMCE facilitates the creation of a participatory decision-making process with active involvement and commitment from the participants.

A transparent, participatory, and flexible decision facilitation process is required to help assimilate complex model outputs and other information within the context of policy considerations. Community involvement in decision-making regarding environmental policy formulation is a growing, recognised, and now essentially required consideration in Australia (Proctor and Drechsler, 2006). DMCE encloses the central theme of modelling human judgment through a structured framework to guide and improve the decision-making (von

Winterfeldt and Edwards, 1986) and can be an effective tool for science and policy communication, particularly in many natural resource issues, concerning public goods, seeking community ownership and local knowledge (Cook and Proctor, 2007). DMCE has been developed for more effective engagement of multiple stakeholders in the decision making process, which overcomes some of the problems associated with MCDA which has been essentially developed for a single decision maker (Cook *et al*., in press).

Biological invasion risk, specifically the threat of Emergency plant pests (EPPs) (Cook and Proctor, 2007), has been comprehensively assessed using a DMCE framework (Born *et al*., 2005). Born *et al*. (2005) suggest that the strength of DMCE is the ability to use non-monetary qualitative data analysis in assessing aspects associated with risk. We aim to use the DMCE to facilitate a transparent process whereby decisions are more likely to be accepted and supported in a democratic manner (Gilmour and Beilin, 2007).

3. CASE STUDY

3.1. Decision-making support in relation to EPP risk

To prioritise the risk of EPPs, we use DMCE. Stakeholder inclusion is essential to the biosecurity risk analysis process as participants can be the source of relevant local and social knowledge (Gilmour and Beilin, 2007). EPPs can be described as invasive species that, if they enter and establish in a given area, could potentially risk the agricultural market values, socio-economic and environmental viability of commercial and/or native flora and fauna.

3.2. Bio-economic impact model as input into DMCE

As previously mentioned, policy makers have to juggle a range of complex and uncertain model outputs with a variety of other information sources in order to make difficult trade-offs between often conflicting investment options. In the current study, an array of data was collected to help stakeholders rank the risk of an EPP from entering Australia based on the relative scoring of economic, ecological, and social criteria within a DMCE methodological framework. Potential risk analysis data sources include a bio-economic spread model for each EPP considered, qualitative risk scores from the literature and additional first-hand expert-knowledge. The bio-economic model makes predictions concerning the costs incurred by the industry if the EPP were to enter Australia and become part of the production scheme. The model captures the dynamics of the bio-economic system and quantifies the uncertainties in estimating invasion costs via sensitivity analysis. Essentially, the elements of a biologically modelled component are combined with an economic model component. First, the probability of entry and establishment of an invasive species is modelled as a stochastic process. Secondly, we assume that once an EPP becomes established it becomes naturalised, spreading to the extent dictated by biological and ecological circumstances. The biological model therefore predicts the likely spread of an EPP, while the economic model converts this to a cost.

Using an interactive and user-friendly interface, the bio-economic pest impact model can run and present different EPP arrival scenarios using participant input within the DMCE workshop. This dynamic learning approach allows participants to interact with the model's representation of the EPP impact. The integrated approach facilitates collective decision-making in prioritizing EPP risk by both allowing participants to provide first-hand knowledge in regard to model scenario building and by the resulting model information being provided to the participants.

3.3. Addressing uncertainty

The bio-economic pest impact model has an associated sensitivity analysis that presents the full range of uncertainty surrounding possible costs. With this knowledge of uncertainty, the stakeholders can gauge how much confidence they want to place in the model output for use as a reference in prioritizing the pest risks

Explicit uncertainty is now the norm for informing environmental decision-making (Halpern *et al*., 2006; Georgiou, 2008). The output from our bio-economic pest impact model is designed to be used in DMCE workshops to provide an increased understanding of system complexity and uncertainties. Stakeholders are then able to consider the uncertainties and complexities while weighting criteria importance. A proposed plan is to delay presenting the uncertainty information at the beginning, instead comparing the differences in stakeholder weighting before and after this uncertainty release.

The current research attempts to combine an explicit measurement and communication of uncertainties to participating stakeholders within the DMCE workshop. DMCE offers an outlet to communicate scientific findings and associated uncertainties to the stakeholders, have stakeholders provide feedback and updated first-hand knowledge, and to make a collective decision by means of deliberation and consensus-building.

4. STEPS OF THE DMCE

Figure 1 represents a flow diagram with the main components of a deliberative multi-criteria evaluation exercise. DMCE is an iterative and flexible methodology. Even though the overall pest risk rankings might not change much (or at all) after deliberation, the iterations are still worthwhile to decrease variation and increase the likelihood of a particular rank order occurring (Proctor and Drecsler, 2006). Each person discussing their position is necessary as the exercise is not only important to reach an outcome but to gather and understand the information that is revealed throughout the process (Proctor and Drecsler, 2006). We explain each component.

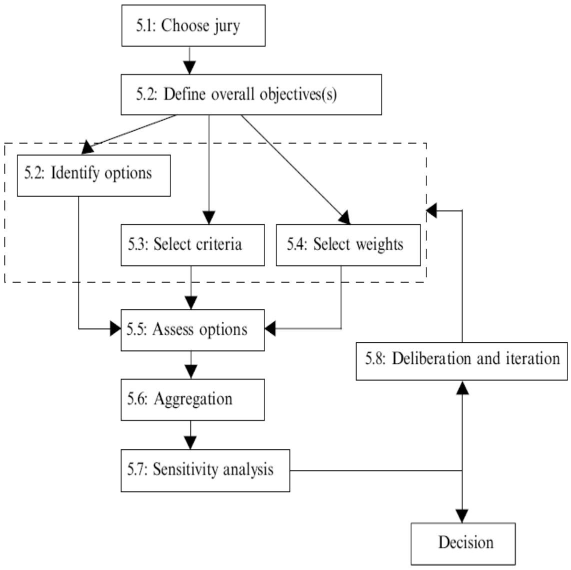

Figure 1. Deliberative Multi-Criteria Evaluation flowchart (Proctor and Drechsler, 2006)

4.1. Choosing the jury
Proctor and Drechsler (2006) selected natural resource managers who represented the decision-makers in the issue at hand, rather than randomly chosen community members. We used Stakeholder Analysis to select the jury (Frost, 1995; Bryson, 2004; Svendsen and Laberge, 2006). Stakeholder analyses can help to understand the environment in which one is operating, the key players in that environment and the interactions among them, the issues and values that are important to these players, and what opportunities exist to mobilize their support (Gilmour and Beilin, 2007). Stakeholders included scientists, government representatives, horticulture growers, farmer organization representatives, horticulture research, development, and marketing bodies, and non-profit organizations.

4.2. Choosing the options and the overall objectives
The choice of EPP options and the overall objectives can be developed by various sources including the jury, expert advice, computer simulation models, and/or political processes (Proctor and Drechsler, 2006). EPPs were selected for potential inclusion based on a search of the Crop Protection Compendium (CPC) published by Centre for Agricultural Bioscience Information (CABI). EPP inclusion potential was filtered by pest impact severity and horticultural industry host spectrum.

4.3. Selecting the criteria
Criteria selection was decided based on a combination of literature review where pre-determined criteria were flexible to stakeholder changes. Criteria are included as a means to evaluate and rank each of the options, and must therefore fit within the overarching context as defined by the objective (Proctor and Drechsler, 2006). The criteria must be measurable as they are weighted by participants and represent the preferred options for reaching a decision (Munda *et al*., 1994; Rauschmayer and Wittmer, 2006). Natural resource management-related issues can often be broken down into `ecological', `economic', and `social and cultural' based criteria groupings/objectives (Cook and Proctor, 2007). The criteria were therefore grouped under the three broad headings to reflect the desire for a holistic assessment of EPP risk.

4.4. Weighting the criteria

Within the MCDA procedure, the preferences of the participant are represented by the relative weighting of each of the criteria. The weights were quantitatively defined with all the participants involved. The first ranked criterion is given 100 "rating points", the second ranked criterion some number between zero and 100 that represents relative importance to the first ranked criterion, and the third ranked criterion a number between zero and the number for the second ranked criterion in terms of importance relative to the 100 given to the first ranked criterion. This procedure is continued until all the criteria have been rated.

4.5. Assessing the options using model output

Once criteria have been individually weighted, the EPPs must be assessed in relation to the criteria weights. This assessment is completed through an impact matrix whereby each criterion is evaluated in relation to each EPP (Proctor and Drechsler, 2006). In making a determination of the impact of each EPP relative to each criterion, the following matters should be considered:

- the severity of the impact

- the extent of that impact

The bio-economic pest impact model results were presented to the stakeholder group with an overview of how the model is built and the uncertainty in model predictions. Socio-economic and ecological impacts from the literature that are perceived to be of relevance were also presented at this time.

4.6. Aggregating the criteria

An aggregation method will calculate a rank order or similar rating, be it partial, semi, or total (Guitouni and Martel, 1998), while some such as Bayesian techniques are also able to explicitly account for uncertainty (Benke *et al*., 2007). We used Compromise programming (Zeleny, 1973) with MCAT (multi criteria analysis tool) software (Marinoni, 2008). Compromise programming was selected as a suitable approach since it effectively creates scores of criteria within suitable (or expert defined) upper and lower bounds (Marinoni *et al*., 2007).

In the conventional compromise programming we define u^-_j as the dis-utility of option $j \in J$, which is calculated as:

$$u_j^- = \left[\sum_{i=1}^{m} w_i^c \left(\frac{f_i^+ - f_{ij}}{f_i^+ - f_i^-} \right)^c \right]^{1/c} \quad (1)$$

where:

f_i^+ = the best score (or ideal/target score) for criteria $i \in I$

f_i^- = the worst (or least ideal value) for criteria $i \in I$

c = a parameter that reflects the importance of maximal deviation from the ideal solution. MCAT uses a c value of 1

4.7. Sensitivity analysis and deliberation

Once the criteria weights, impact matrix scores and resulting aggregation have been determined, a deliberative process is begun with the aid of a facilitator. The aggregation software described in Step 4.6 is used interactively during the process and the results of each iteration displayed to the participants. The objective of the deliberations is for the participants to reach an agreement on a set of weights for the decision criteria that would be used to determine an optimum management scenario (Cook and Proctor, 2007).

Sensitivity analysis is a well-known and widely used tool for the investigation of the impact of uncertainty and variability on the outcome of a particular analysis (see, for example, Benke *et al*., 2007). Although uncertainty stems from a variety of sources both epistemic and linguistic (Burgman, 2005), a sensitivity analysis will typically focus on the uncertainty around individual criterion. Essentially, sensitivity analysis is required for deliberation aid given that a set of weights from one participant will inevitably be different from that of another which could lead to different rank orders of options. The sensitivity analysis examines the variation within a set of weights to pinpoint where more deliberation may be required.

4.8. Interacting and iterating

The DMCE is characterised by close and real-time interaction with the decision-makers. Criteria are continuously being updated, dropped, replaced, modified, and/or simplified (Proctor and Drechsler, 2006). These processes lead to the requirement for iteration as the deliberation proceeds. In the DMCE, the process of interaction among a mediator, participants, and expert presentations, as well as allowing for several iterations of particular aspects of the analysis, is crucial for a final outcome to be reached (Proctor and Drechsler, 2006).

5. DISCUSSION

The DMCE methodology links the dichotomy of risk assessment and risk management by encouraging the partnership between scientists and stakeholders whilst simultaneously revealing the social dimensions of biosecurity risk to enhance collective decision making (Cook *et al*., 2009). The bio-economic pest impact model can present a number of EPP arrival scenarios using real-time stakeholder input through an interface designed for user-friendly data input. The resulting model figures based on this sensitivity analysis can help stakeholders to achieve a firm grasp of the results so that their scientific relevance can be better integrated into the DMCE forum.

The DMCE methodology cannot be advocated as a fix-all solution to making biosecurity decisions as some challenges still remain, as experienced while prioritizing the risk of EPPs. One facet in the application of DMCE that can be further explored in the future is the effectiveness to assess and capture uncertainty (Gregory, 2006). As the central tenet of the process is based on stakeholder discussions, subtle uncertainty intricacies, such as group preference shifts, can be difficult to capture. Within the DMCE process, group preference shift could be due to the nature and presentation of uncertainty information, the group dynamic, the time allocated to the process, the quality of the group's level of education, etc (Cook *et al*., 2009). In addition, the interpretation of the meaning of a criteria term can be quite different, given the varied background and experience of all stakeholders present. A potential option for the DMCE workshop would be to complete a final round of weighting after all uncertainty components are explicitly exposed. The effect of this uncertainty information release could, however, be compounded by the ever-present group dynamics, presenting a difficulty in extracting interpretation.

An additional consideration is that the DMCE methodology does not allow for comparative measures among multiple workshops, as each is unique with a different problem structure, different stakeholders, updated information, and changes in decision options and criteria selection due to the flexible nature of the process. Although the comparison among workshops would be theoretically beneficial in order to measure the effectiveness of different treatments of uncertainty presentation and additional methodological improvements, this is not the workshop objective and cannot be helped due to the uniqueness of each DMCE application. More energy should be appended in running the workshops for issues that require decision-making facilitation and enhancement, be it an iterative update in light of a change in information and participants or be it applied to a new issue altogether.

6. REFERENCES

Benke, K. K., Hamilton, A.J., and Lowell, K.E. (2007), Uncertainty analysis and risk assessment in the management of environmental resources. *Australasian Journal of Environmental Management,* 14, 243-249.

Born, W., Rauschmayer, F., and Brauer, I. (2005), Economic evaluation of biological invasions - a survey. *Ecological Economics,* 55(3), 321-336.

Brouwer, R., and van Ek, R. (2004), Integrated ecological, economic and social impact assessment of alternative flood control policies in the Netherlands. *Ecological Economics*, 50(1-2), 1-21.

Brown, K., Adger, W. N., Tompkins, E., Bacon, P., Shim, D., and Young, K. (2001), Trade-off analysis for marine protected area management. *Ecological Economics,* 37(3), 417-434.

Bryson, J. M. (2004), What to do when stakeholders matter: A Guide to stakeholder identification and analysis techniques. *Public Management Review,* 6(1), 21-53

Burgman, M. (2005), Risks and decisions for conservation and environmental management. Cambridge, Cambridge University Press.

Cook, D., and Proctor, W. (2007), Assessing the threat of exotic plant pests. *Ecological Economics,* 63(2-3), 594-604.

Cook, D., Liu, S., and Proctor, W. (2009), Deliberative multi-criteria evaluation of invasive alien species management alternatives, ACERA Project 08/03 - Deliberative Methods for Assessing Utilities.

Crosby, N. (1999), Using the Citizens Jury Process for Environmental Decision Making, In: *Better Environmental Decisions: Strategies for Governments, Businesses and Communities,* Edited by Sexton K, Marcus A, Easter K, Burkhardt T., Washington DC: Island Press.

Dienel, P. and Renn, O (1995), Planning Cells: A Gate to Fractal Mediation, In: *Fairness and Competition in Citizen Participation,* Edited by Renn O, Webler T, Wiedemann P., Dordrecht: Kluwer Academica Publishers.

Faith, D. P., Walker, P. A., Ive, J. R., and Belbin, L. (1996), Integrating conservation and forestry production: Exploring trade-offs between biodiversity and production in regional land-use assessment. *Forest Ecology and Management,* 85(1-3), 251-260.

Fox, C. R., and Irwin, J.R. (1998), The role of context in the communication of uncertain beliefs. *Basic and Applied Social Psychology*, 20, 57-70.

Frost, F.A. (1995), The Use of Stakeholder Analysis to Understand Ethical and Moral Issues in the Primary Resource Sector. *Journal of Business Ethics,* 14, 653-661.

Georgiou, I. (2008), Making decisions in the absence of clear facts. *European Journal of Operational Research*, 185(1), 299-321.

Gilmour, J. and Beilin, R. (2007), Stakeholder mapping for effective risk assessment and communication, ACERA Project 06/09.

Gregory, R.S. (2006), Improving Deliberative Environmental Management Under Uncertainty, In: US-NSF Proposal.

Guitouni, A., and Martel, J. M. (1998), Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research,* 109(2), 501-521.

Halpern, B.S., Regan, H.M., Possingham, H.P., McCarthy, M.A. (2006), Accounting for uncertainty in marine reserve design. *Ecology Letters,* 9(1), 2-11.

Marinoni, O., Higgins, A., Hajkowicz, S. (2007), Portfolio optimisation of water management investments, In: *Adaptive and Integrated Water Management*, Edited by Pahl-Wostl, C., Kabat, P, Möltgen, J. Springer, pp 423-437.

Marinoni, O. (2008). MCAT (Multi criteria analysis tool), Version 1.0.0 (Beta), April 2008.

Jankowski, P., and Nyerges, T. (2001), GIS-Supported Collaborative Decision-making: Results of an Experiment. *Annals of the Association of American Geographers,* 91(1), 48-70.

McDaniels, T. L., Gregory, R. S., and Fields, D. (1999), Democratizing Risk Management: Successful public involvement in local water management decisions. *Risk Analysis*, 19(3), 497-510.

Munda, G., Nijkamp, P., and Rietveld, P. (1994), Qualitative Multicriteria Evaluation for Environmental-Management. *Ecological Economics*, 10(2), 97-112.

Proctor, W. (2001). Multi-Criteria Analysis and environmental decision-making: a case study of Australian forests. Centre for Resource and Environmental Studies, Canberra, The Australian National University, PhD.

Proctor, W., and Drechsler, M. (2006), Deliberative multicriteria evaluation. *Environment and Planning C: Government and Policy,* 24(2), 169-190.

Rauschmayer, F., and Wittmer, H. (2006), Evaluating deliberative and analytical methods for the resolution of environmental conflicts. *Land Use Policy*, 23(1), 108-122.

Svendsen, A. and. Laberge, M. (2006), Beyond Consultation: A Co-Creative Approach to Stakeholder Engagement. www.corelation.com/publications.html

van den Hove, S. (2000), Participatory approaches to environmental policy-making: the European Commission Climate Policy Process as a case study. *Ecological Economics*. 33 (3), 457-472.

von Winterfeldt, D., and Edwards, W. (1986), Decision analysis and behavioral research. Cambridge, New York, Cambridge University Press.

Zeleny, M. (1973), Compromise programming, in Cocharane, J.L., Zeleny, M. (eds.) Multiple Criteria Decision Making, University of Southern Carolina Press, Columbia, 262–301.