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Using dynamic ecological-economic modeling to facilitate Deliberative Multicriteria Evaluation (DMCE) in quantifying and communicating bio-invasion uncertainty

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Abstract: Uncertainty is a ubiquitous feature of biosecurity and for this reason managing invasive species has long been a reactive business. In order to move towards proactive management it is critical to communicate uncertainties to the stakeholders. The uncertainty components exist not only in biological but also socio-economic processes during an invader's entry, establishment, spread and impact creation.

A *STELLA* model was developed to capture the dynamics of this socio-ecological system and to estimate the expected economic costs of the apple maggot (*Rhagoletis pomonella*) over the next 30 years for the entire country of Australia. Like complex climate models, it cannot be meaningfully calibrated because it is simulating a never before experienced state of the system. Therefore it is inappropriate to apply generic techniques which utilize observations to calibrate models to forecast the economic cost of bio-invasion in the real world. Instead of forecasting, a more proper use is as a communication tool for uncertainty, which organizes our existing understanding and present "what if" scenarios in front of stakeholders in a DMCE environment.

One of the major modelling outputs, the potential economic cost of the apple maggot, was used in DMCE as a criterion. The DMCE participants were asked to weigh the same criterion twice, before and after the modelling uncertainty was exposed and discussed. The effectiveness of the model as a communication tool was examined by comparing the average group weights and standard deviation of the individual weights before and after the uncertainty injection.

Preliminary results showed that after the parameter uncertainty was exposed the mean weight did not change significantly yet the standard deviation of the weights did become smaller. We hypothesized that this could be because of the anchoring effect: economic cost was one of the most important criteria therefore the uncertainty exposure would not make much of a difference in weighting. The decreased dispersion of weights among DMCE participants, as reflected in a smaller standard deviation of the individual weights, indicated that uncertainty communication has a potential of building consensus. This is certainly an area for future research.

This integrated modelling–DMCE approach seeks to combine the advantages of dynamic modelling in providing a systematic analysis with the benefits of DMCE. The ecological-economic modeling offers a systematic and more objective way of organizing data and synthesizing knowledge. The DMCE allows a participatory decision-making process with active involvement and commitment from the participants. The integrated approach is more effective in quantifying and communicating bioinvasion uncertainty to stakeholders.

Keywords: *Invasive species, Economic cost, STELLA, Parameter uncertainty*

1. INTRODUCTION

Uncertainty is a ubiquitous feature surrounding management of invasive species (Caley, Lonsdale et al. 2006; Perrings 2005; Touza, Dehnen-Schmutz et al. 2007). Components of uncertainty in the existing biosecurity economic analyses include at least: arrival (Batabyal and Nijkamp 2007) and demography and dispersal (Buckley, Brockerhoff et al. 2005) of invasive species, on-site plant biomass data (Rinella and Luschei 2007), rates of industry growth (de Wit, Crookes et al. 2001), discounting rate (Settle and Shogren 2004), and impacts of invasive species (Horan, Perrings et al. 2002). These uncertainty features are likely to become more prominent in future in association with a wider range of global changes. Indeed, a major uncertainty in assessing patterns of invasion will be in predicting the “time bombs” or sudden non-linearity of invasions that occur in the context of global environmental change (Naylor 2000)

Considering the ubiquity and importance of uncertainty, it is surprise to know that adequate treatment of uncertainty in policy analysis is still the exception, not the rule (Ascough II et al. 2008). There are more and more voices calling for considering uncertainty in environmental decision-making in an explicit manner (Halpern, Regan et al. 2005). Efforts in communicating uncertainties are even less seen in the literature and this is not only the case for invasive species management. For instance, uncertainty inherent in the application of environmental models has been discussed for two decades and yet uncertainty estimation is still not the standard practice (Beven 2008).

To fill this gap in the management of invasive species A *STELLA* model was developed to be used in a DMCE environment as a communication tool for uncertainty. Equipped with an interactive and user-friendly interface, it has the capacity of re-running and re-presenting economic costs inflicted by potential agricultural invasive species using DMCE participants’ input. The effectiveness of the model as a communication tool is demonstrated by changes in the weights assigned by DMCE participants.

2. METHODOLOGY

2.1. Model construction

An ecological-economic model is developed to capture the dynamics of the socio-ecological system of biological invasion by combining an ecological spread model (Diggle, Salam et al. 2002) and an economic model (Cook, Thomas et al. 2007). The invasive species of concern is the apple maggot (*Rhagoletis pomonella*), also known as railroad worm, which is a pest of several fruits, mainly apples. The apple maggot (*R. pomenella)*, is an insect native to North America and has historically been a pest of apples in the north eastern United States and eastern Canada. The pest has not been found in Australia yet.

The model is built with a temporal scale of 30 years, which starts from establishment of the apple maggot. The spatial scale of the model is the whole country of Australia and two spatial levels were specified: orchard level and country level. Infestation of the pest begins at the orchard level and gradually spreads to the whole country without being controlled. The major modelling outputs are four types of economic costs incurred by the invasion of the apple maggot, market cost due to drop in apple production after infestation, control cost at the farm level (e.g. cost of chemical spray etc), inspection cost before and after the pest is found, and eradication cost when a productive apple orchard is being closed down.

2.2. Communicate parameter uncertainty using STELLA

In the environmental modelling process there are five major sources of uncertainty, including context and framing uncertainty, input uncertainty, model structure uncertainty, parameter uncertainty and model technical uncertainty (Refsgaard, van der Sluijs et al. 2007). Only parameter uncertainty is discussed here.

Table 2 listed all the parameters, their units, values and uncertainty levels for apple maggot. Those parameters with an uncertainty level marked as “uncertain” are included in sensitivity analyses.

Table 1. Parameters used and their uncertainty levels

parameter	unit	current value	uncertainty
local infestation rate	# trees/infested tree	2	uncertain
spatial infestation rate	# farms/infested tree	0.1	uncertain
average farm size	ha	11	fairly certain
total area of Australian orchards	ha	13260	certain
area occupied by a host	ha/tree	0.00067	fairly certain
time to maturity	year	6	certain
cost of control technique	$/ha	105	fairly certain
cost of inspection	$/ha	40	fairly certain
cost of eradication	$/ha	270	fairly certain
inspection budget pre-1st detection	**$**	**100,000**	**uncertain**
inspection budget post-1st detection	$	500,000	uncertain
central control choke price	$	10,000,000	uncertain
total Australian apple production	kg	270,500,000	fairly certain
pre-infestation production	kg/ha	20400	fairly certain
post-infestation production % left	unitless	0.8	fairly certain
pre-infestation export ratio	unitless	0	fairly certain
post-infestation export % drop	**unitless**	**0.25**	**uncertain**
pre-infestation domestic price	$/kg	1.2	fairly certain
supply elasticity	unitless	0.2	fairly certain
demand elasticity	unitless	-0.5	fairly certain
export price	$/kg	1.38	fairly certain
discount rate	**unitless**	**0.08**	**uncertain**
start control threshold	unitless	0.05	uncertain
control tech effectiveness	unitless	0.7	uncertain
detection probability if inspected	unitless	1	uncertain
search efficiency	unitless	1	uncertainty

Sensitivity analysis showed major modeling outputs are sensitive to three parameters (in bold), inspection budget pre-1st detection, export percentage drop after infestation, and the discount rate. These three sensitive parameters are presented as slider bars in the STELLA interface along with the potential market cost of apple maggot invasion. This allows DMCE workshop participants to change the parameter values and re-run the model to see how much impact the parameter uncertainty has on model output.

2.3. Test effectiveness of the model as a communication tool for uncertainty in a DMCE environment

Multi-Criteria Decision Analysis (MCDA) proposes an analytical approach to deal with mixed sets of data (both qualitative and quantitative) and to take explicit account of both conflicting criteria and uncertainty (Mendoza and Martins 2006; Wittmer, Rauschmayer et al. 2006). Deliberative Multicriteria Evaluation (DMCE) seeks to combine these advantages of MCDA in providing analytical structure together with the benefits of citizen/stakeholder participation (Proctor and Drechsler 2006). Compared to MCDA without a participatory component, DMCE offers an opportunity for explicitly allowing diverse views to enter the process, for facilitating consensus-building and for initiating a dynamic process of social learning (Rauschmayer and Wittmer 2006).

DMCE has been applied in the natural resource management arena as a decision-aid tool (Bojorquez-Tapia, Sanchez-Colon et al. 2005; Hajkowicz and Collins 2007). Only very recently did researchers start to use DMCE in Invasive Alien Species (IAS) risk management (Cook and Proctor 2007).

In our study, apple maggot damage cost was selected as one of the criteria in the DMCE. Participants were asked to weight a set of criteria related to social, environmental and economic impacts of the apple maggot twice, before and after the parameter uncertainty is presented with STELLA. The effectiveness of the dynamic model as a communication tool is tested by comparing the average weights and standard deviation of the group.

3. RESULTS

(Note: this part is mostly hypothetical because our DMCE workshop will not be held until May 6 and 7, 2009. The result presented below is from another DMCE study we did previously on the European House Borer, *Hylotrupes bajulus*.).

3.1. Weight changes before and after

Figure 1 below showed the average group weights for each criterion before and after parameter uncertainty was presented. The weight put on apple maggot damage costs was not changed significantly after the uncertainty injection. Group average weights remain very high for this criterion, and it seems that participants as a group did not change their mind much on how importance damage cost is compared to other criteria.

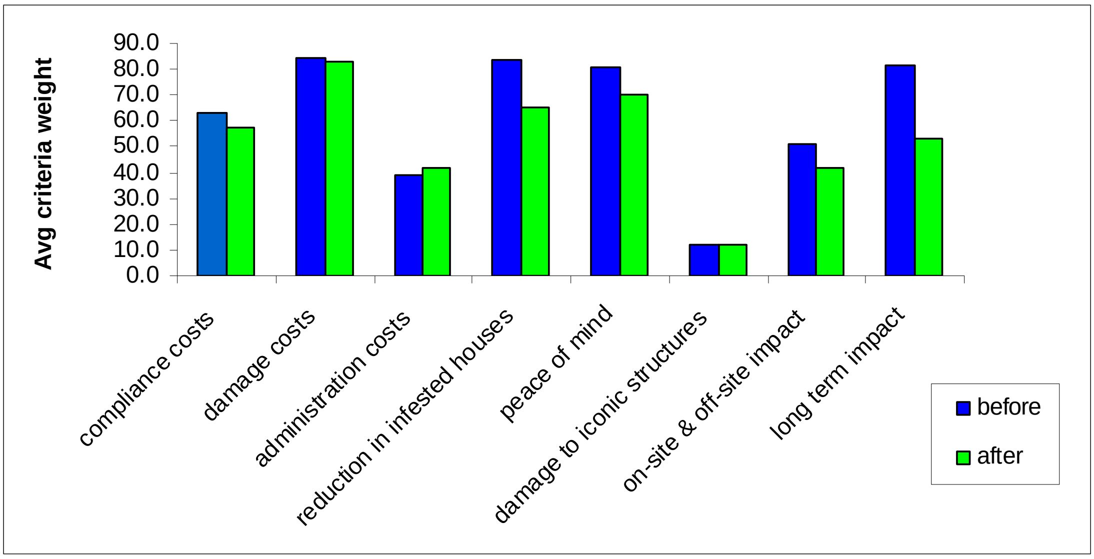

Figure 1. Average group weight for criteria before and after uncertainty information presented.

However, the uncertainty injection did affect the standard deviation of the group weights as shown in figure 2. After parameter uncertainty was presented, participants were less divergent in putting weights on damage cost.

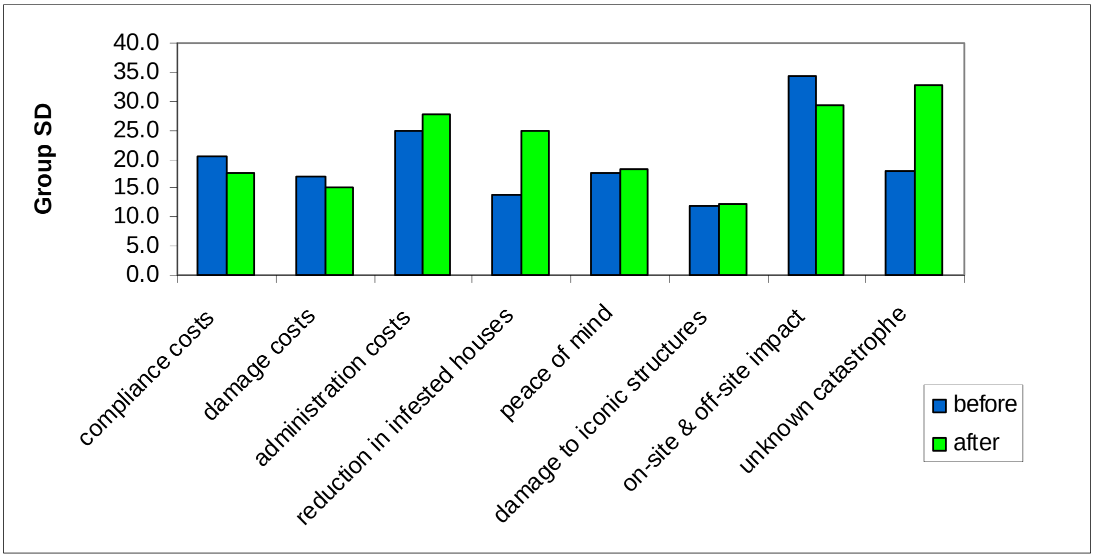

Figure 2. Average group standard deviation (SD) for criteria weight before and after uncertainty information presented.

4. DISCUSSION AND CONCLUSIONS

The uncertainty injection did not affect the average weight for damage cost. Although it is too early to explain exactly why that is, we do have a hypothesis for further testing: damage cost is one of the most important, if not the most important, criteria and the uncertainty exposure will not make a difference. It would be interesting to test whether there would be some anchoring effect (Green, Jacowitz et al. 1998) as in whether the initial weight of a criterion matters, e.g. an uncertainty injection will make a greater difference for those criteria with low weights?

After the presentation and discussion of uncertainty that followed, the group standard deviation became smaller. This could be because overall the participants had a better idea of how the cost figure was calculated and therefore gained some confidence. Can uncertainty communication using dynamic modeling be used as a consensus building tool then?

This integrated modelling-DMCE approach seeks to combine the advantages of dynamic modelling in providing a systematic analysis with the benefits of DMCE. The ecological-economic modeling offers a systematic and more objective way of organizing data and synthesizing knowledge. The DMCE allows a participatory decision-making process with active involvement and commitment from the participants. The integrated approach is more effective in quantifying and communicating bio-invasion uncertainty to stakeholders.

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