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Multi-criteria assessment for linking regional conservation planning and farm-scale actions

A. Zerger, G. Warren, P. Hill, D. Robertson, A. Weidemann, K. Lawton

Abstract

Regional-scale ecological restoration priorities such as increasing the extent and quality of native vegetation are generally planned at catchment scales, while on-ground restoration actions are generally implemented at paddock or farm scales. This paper describes the use of spatial multi-criteria assessment methodologies to construct maps of regional conservation priorities and assesses how these maps map influence farm-scale actions in Western Victoria, Australia (e.g. farm-scale revegetation for salinity, wind erosion, stock shelter, etc). The study also incorporates agricultural production in the decision analysis through the use of historical yield mapping data obtained from harvest logs from precision agriculture equipment. Via a stakeholder workshop, farmer land use priorities were elicited with and without access to maps of regional conservation priorities. Results highlight that production imperatives drive farmer-led conservation actions and that regional conservation priorities have only limited impact on actions. The paper also identifies limitations of applying MCA methods across multiple decision-making scales such as the need to generalise priorities where domain knowledge is relatively high, and the challenges associated with MCA criteria definition.

Keywords: MCA, Conservation planning, GIS, Precision agriculture

1. Introduction

Regional natural resource management (NRM) groups such as catchment management authorities in Australia face a number of challenges in delivering NRM programs, not least of which is how to achieve regional-scale outcomes, via paddock-scale actions. Traditionally ‘push’ approaches such as grant and incentive schemes delivered to landholders have been used to achieve NRM outcomes. Push approaches are generally driven by management agencies and can be seen as top-down strategies for improving resource condition. However, there are strong arguments for implementing more of a ‘pull’ philosophy (bottom-up) which may achieve similar NRM outcomes but with a reduced public investment. In some instances, ‘pull’ approaches are implemented by NRM groups by ‘scoring’ requests for conservation incentive payments by how well the application addresses regional conservation priorities (Parkes et al., 2003) and through the use of market-based instruments such as auctions (Hajkowicz and Collins, 2008; Windle et al., 2009). However, scoring methods can only be applied when delivering formal NRM incentive programs. They have limited impact when farmers fund their own conservation actions, which based on earlier research in Australia represents a substantial portion of on-ground conservation activity (Smith, 2008). Therefore there is a need for approaches which help farmers better understand regional-scale priorities with a view to coupling their actions to address these priorities, in addition to their farm-scale imperatives.

Regional-scale conservation planning typically involves natural resource management (NRM) organisations making decisions about competing criteria (or values) limited by the resources available for implementation. Resource limitations mean that a trade-off will exist between the choice of options which can be implemented to achieve NRM outcomes (e.g. improvements in vegetation condition, reductions in salinity, improvements in water quality, or enhancing species diversity and abundance). Recently we have seen the development of various tools and frameworks to support more structured decision-making in NRM planning and deployed at a range of scales (Roberts and Pannell, 2009).

Approaches can include cost–benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) (e.g. Moffett et al., 2005; Gamper and Turcanu, 2007). There also exist optimisation methodologies based on mathematical techniques...
such as integer programming and heuristics to find optimum solutions across competing criteria. Malczewski (2004) has labelled these as ‘multi objective’ approaches, in contrast to ‘multi-attribute’ decision-making methods such as MCA. The former have been applied widely in conservation planning. Examples include reserve selection software utilising heuristics such as MARXAN (e.g. Ball and Possingham, 2000; Possingham et al., 2000) and integer programming approaches (e.g. Cocks and Baird, 1989; Crossman and Bryan, 2006; Bryan and Crossman, 2008).

This paper pays particular attention to the use of MCA multi-attribute methods for developing maps of regional conservation priorities (revegetation). We focus on MCA methods because of their ability to incorporate stakeholder preferences, their relatively widespread application in NRM decision-making and the transparency they provide decision-makers. Hajkowicz (2008) notes that a strength of MCA is that it provides not an answer but rather a process and has likened the methodology to a ‘glass box’ because stakeholders can gain a detailed understanding of the inputs which have led to a particular decision outcome. These can be reviewed or modified at a later time and they provide a ‘transaction history’ that documents the decisions adopted to reach a particular end-point.

In MCA individuals can assign their preferences independent of any consensus imperative and results are aggregated to provide an overview of group preferences to assist in decision-making. The methodology is particularly useful in instances where decisions need to be reached between competing priorities, or criteria. Mendoza and Macoun (1999) list the following elements of MCA which make it a useful tool to support decision-making:

- Multiple criteria can be accommodated in the analysis
- It can work with mixed data and analysis of data is not data intensive
- It allows the direct involvement of multiple experts, interest groups and stakeholders
- Analysis methods are transparent to participants
- There are mechanisms in MCA for evaluating the consistency of the judgments made.

One of the most commonly applied methodologies for solving an MCA problem is the pair wise-comparison approach embedded within the Analytical Hierarchy Process (AHP) (Saaty, 1980, 2008). It is popular owing to its ease of implementation and transparency to stakeholders. Alternatively to AHP include concordance analysis; simple additive weighting; and more complex algebraic approaches such as binary combinatorial optimisation (Marinoni et al., 2009).

MCA methodologies can also be coupled with a GIS to parametrise the criteria and to derive a final map showing the sites in a landscape which best address stakeholder preferences (Strager and Rosenberger, 2006). Spatial MCA approaches couple a multi-criteria decision problem with GIS-based land use suitability modelling methodologies (Malczewski, 2004). The decision rules are derived from a stakeholder-driven MCA process and they are then applied as weights to rank particular spatial data layers which combine (usually via map algebra) to develop a final map of suitability (Rinner and Malczewski, 2002).

The paper describes research conducted in collaboration with the Wimmera Catchment Management Authority (CMA) (see Fig. 1) and three farmers in the Rupanyup district of Western Victoria to explore the potential of spatial information to inform farm-scale land use decision-making. The paper describes the spatial MCA methodology used to produce maps of revegetation priorities based on stakeholder preferences; it briefly examines the development of historical crop yield surfaces to assist with decision-making; and it describes the process and results from an MCA workshop with farmers designed to evaluate their response to maps of regional conservation priorities. We conclude with a discussion of the limitations of MCA for multi-scale decision-making.

2. Study area

The Wimmera is a region of approximately 23,500 km² that has been 85% cleared for agriculture, predominantly broad-acre cropping (Fig. 1). There are two large national parks in the region, the Grampians and the Little Desert. Excluding these large parks the remaining land is more than 95% cleared. The Wimmera is a semi-arid (400 mm per annum) flat or very gently undulating landscape with a mosaic of clay and sandy soils. Pre-clearing it supported native pine/buloke woodlands on clay soils and stringybark eucalypt scrub on sandier soils. Red gums eucalypts line the region’s waterways, only a handful of which hold water year round. The region is well suited to broad-acre cropping. The average farm size is 800 Ha having chiefly wheat, barley, lentils, canola – and sheep. Until relatively recently farmers had been encouraged to clear native vegetation in order to maximise the productivity of the land. This has been achieved, with remnant native vegetation now confined to the edges waterways or on the sandiest, least productive soils. The Wimmera Catchment Management Authority aims to maintain regional biodiversity by improving the quality of these remnants through stock and weed control, and linking existing patches through revegetation activities.

3. Methods

In this study we first apply spatial MCA (Malczewski, 2004; Strager and Rosenberger, 2006) in collaboration with regional NRM staff from the Wimmera Catchment Management Authority to develop hypothetical maps of preferred revegetation priorities. This workshop was conducted in early 2007 in Horsham, Victoria. We then conducted a second MCA priority-setting workshop with farmers to evaluate how farmers respond to these maps, and how revegetation priorities rank against agricultural production priorities. Revegetation criteria were partitioned into those which address soil health concerns, contribute to aesthetics, provide ecosystem services (e.g. pollination), improve stream health and finally those which provide conservation benefits. Hence farmers were asked to compare each criterion against the other to obtain an overall rank of criteria importance.

To assist with decision-making, agricultural production decisions were supported by mapped yield data derived from precision agriculture equipment (yield
monitors). This paper focuses on the MCA-based preference elicitation process and the results from the perspective of farmers.

The later farmer MCA workshop was conducted in Rupanyup in western Victoria in late 2007. The study follows the broad methodology for catchment planning described in Hill et al. (2006) which explores trade-offs between biodiversity, salinity and commodity production through the use of the MCAS-S spatial decision support system (Hill et al., 2005). The Hill et al. (2006) study focussed on identifying areas within the landscape where trees or perennial pastures could be planted to efficiently achieve environmental targets, using priorities identified by NRM personnel. This research follows a similar model but with a focus on incorporating production values and landholder priorities into the land use planning process. Fig. 2 provides a methodological overview.

3.1. Regional revegetation priorities

Prior to using the MCA preference elicitation process with farmers, there was a requirement to develop a map of CMA revegetation priorities. For simplicity, and in consultation with the CMA, this study focussed only on potential revegetation activities. As this study focuses on revegetation there are competing criteria such as increasing the extent, representativeness or configuration (linking remnants of a particular size and composition) of native vegetation via revegetation. As these criteria are fundamentally spatial, they lend themselves well to being mapped to assist with revegetation-focused land use decision-making.

To develop a map of revegetation-focused conservation priorities in the Wimmera region, an MCA approach was applied to elicit stakeholder preferences via a CMA-based workshop. Table 1 shows the initial criteria developed in collaboration with CMA staff and an ecological justification for their use in regional conservation planning. The Analytical Hierarchy Process (AHP) was used to convert subjective assessments of stakeholder preferences into a suite of final aggregate weights. The AHP process (Saaty, 1980) asks stakeholders to conduct a series of pair wise comparisons between pairs of criteria arranged in a matrix \( A \times B \). Pair wise comparisons are typically scored on a nine point scale (1–9). AHP is attractive for this study owing to its simplicity in a workshop setting. However, AHP has also received some criticism and in particular critiques have been directed to the ‘rank reversal phenomenon’ whereby the addition of another criteria may invert the relationship between two other criteria (Dodgson et al., 2001).

ArcGIS and the Python scripting language were used to spatially implement each criterion using known parameters where possible to maximise the likelihood of obtaining desired ecological restoration outcomes (Table 1). So for example, for the criteria ‘revegetate areas with dense patch distribution’, a high resolution woody vegetation layer was derived from sub-metre resolution aerial photography and a moving window was used to identify dense patch distributions. Areas proximal to other vegetation score a value closer to 100 and grid cells further from existing vegetation score values closer to 0. Automation of the process via Python was important as criteria parameters may change in the future, or new, higher resolution data may become available requiring one to rapidly recreate criteria layers. A grid resolution of 20 m was used for all modelling.

3.2. Precision agriculture data – yield maps

Unprocessed harvest log files derived from yield monitoring equipment were provided by three farmers for a number of crops for 7 years. Fig. 3 shows the paddocks for which yield information was collected. CASE IH AFS v4.02 and JD-Office
v1.5 software were used to convert the raw harvest data into an Ag-Leader basic and JD-Office standard text format. Text files containing yield data were batch converted into an ArcGIS geodatabase and stored as rasters of yield for individual paddocks. To preserve the high spatial resolution of the raw harvest data the output grid resolution was set to 10 meters. Processing of the yield data into an ArcGIS compatible format also involved removing errors inherent in precision agriculture yield monitoring data. This included erroneous readings associated with data loggers, GPS lag, overlapping paths and other errors.

### Table 1
Conservation criteria used as an input to MCA priority-setting exercise.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Ecological justification</th>
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<tbody>
<tr>
<td>Revegetate rare vegetation communities</td>
<td>This rule considers the broader context within which the study area sits by reflecting regional rarity of vegetation types that might be locally common.</td>
</tr>
<tr>
<td>Revegetate areas with dense patch distribution</td>
<td>Dense patch distribution is an important resource for wildlife; neighbouring patches of vegetation act as ‘stepping stones’, which enable movement through the landscape (Platt, 2002, p. 37).</td>
</tr>
<tr>
<td>Revegetate close to large patches</td>
<td>Westphal and Field (2007) found that ‘an average patch size of between 780 and 4010 ha is needed to maximise species numbers in the Mount Lofty Ranges, South Australia’.</td>
</tr>
<tr>
<td>Revegetate close to streams</td>
<td>Bennett et al. (2000, pg. 21)“Give priority to streams and watercourses as ‘natural corridors’”. Riparian areas are particularly important resources for wildlife and they introduce other benefits such as improved water quality (Platt, 2002, p. 33).</td>
</tr>
<tr>
<td>Revegetate enclosed areas</td>
<td>Infill plantings allow existing disparate plantings to be coalesced into a larger area by a block planting filling the void between the disparate plantings. Because of the viable area requirements of some species, infill plantings may transform two non-viable areas into a single viable area.</td>
</tr>
<tr>
<td>Revegetate to form corridors</td>
<td>For native mammals Bennett (1990) found that ‘The continuity between remnant habitats that is provided by a network of habitat corridors is an essential, and critical, component of this conservation strategy’.</td>
</tr>
<tr>
<td>Reduce patch isolation</td>
<td>McIntyre and Hobbs (1999) suggest a set of four states of landscape fragmentation — intact, variegated, fragmented, and relictual. These states are defined according to the percentage of native vegetation remaining in the landscape, i.e. the level of isolation. They suggest that highest priorities for vegetation management and protection should be allocated toward landscapes with the greatest vegetation cover because management actions for biodiversity within those landscapes are more likely to succeed.</td>
</tr>
</tbody>
</table>

### 3.3. Farmer preference elicitation

A farmer preference elicitation workshop was held on November 9th, 2007 in Rupanyup where farmers completed pair wise comparisons of different land use options (production versus revegetation). The workshop was conducted with the three farmers who provided yield data, in addition to three other farmers from this region. The candidate MCA criteria were derived from earlier work by Seabrook et al. (2008) which examined the factors which lead to farmers retaining...
trees. Unlike the CMA workshops which focussed only on conservation outcomes; the farmer workshops also included agricultural production criteria (keeping high yielding land under various proportions of production). Revegetation-focussed criteria were also included, but only in the context of their contribution to improving agricultural production (e.g. reducing salinity, stock health, erosion mitigation, protecting water quality) and for direct income generation such as farm forestry.

Farmers conducted two pair wise comparisons during their November workshop. In the first instance farmers were not shown maps of regional conservation priorities, while in the later maps were shown and discussed in detail prior to completing the pair wise comparisons. The method was designed to evaluate whether regional-scale conservation priority mapping influences farm-scale actions. In addition to evaluating how farmers respond to data pertaining to mapped regional conservation priorities, the workshop also provided an opportunity to evaluate the MCA-based land use planning methodology as applied at the scale of the farm, rather than for regional modelling and analysis (Bantayan and Bishop, 1998; Rinner and Malczewski, 2002; Malczewski, 2004; Strager and Rosenberger, 2006). Most land use suitability modelling studies which utilise MCA focus on regional-scale planning rather than the farm-scale planning as outlined here. This introduces challenges not readily apparent when MCA methods are applied to non-spatial regional-scale NRM problems (Rajkowicz, 2008; Rajkowicz et al., 2008), or when spatial MCA is applied at broader spatial scales (Wang et al., 2009). These challenges apply primarily to the reliance on mutually exclusive criteria in MCA, and the requirement to spatially generalise preferences.

4. Results & discussion

4.1. CMA preference elicitation and mapping of conservation priorities

Table 2 shows the final MCA preference weightings derived from the CMA-based preference elicitation process conducted with CMA staff. CMA preference results highlight that the preferred pathway for achieving conservation outcomes in this landscape is via revegetation of rare vegetation communities (those most cleared for achieving conservation outcomes in this landscape is via revegetation) and revegetation of stream corridors. Other criteria were perceived as being less important and consequently received lower weightings — in general contributing less than 10% each to the final outcome. Interestingly, whilst improving connectivity between remnant patches is often considered a high priority by NRM agencies (Scotts, 2003), in this case it was not ranked of high importance. This may reflect the fact that because much of this landscape is cleared, achieving connectivity goals poses a major challenge in terms of available ecological restoration resources.

Fig. 4 shows the final CMA revegetation priorities mapped across the study area. Spatial priorities are normalised to a range from 0 to 100. Actual suitability scores rarely exceed 80% as it is difficult to find locations in the study area where all criteria are met. Results highlight that as many of the CMA criteria focus on the enhancement and expansion of existing woody vegetation, possible locations for new activities will be proximal to existing vegetation. Hence the spatial patterns we see are driven not only by the weight placed on the criteria by stakeholders, but by the initial choice of criteria and how these criteria are expressed in the GIS. In the Wimmera example, the key input to many of the criteria is the high resolution woody vegetation layer (see Fig. 3) and hence we see that high priority areas are proximal to existing vegetation.

4.2. Farmer preferences — production & regional conservation priorities

Table 3 results show that when presented maps of proposed regional conservation priorities (revegetation focussed), farmers do not weight these highly relative to other farm-scale criteria and were fundamentally unwilling to forego production land. Despite this, verbally and via the exit interviews they did respond in a positive way when presented maps of regional conservation priorities, acknowledging the realistic nature of the ‘spatial plan’. To allow them to weight production imperatives, farmers were provided four conservative production-focussed land use options: keep all production land; keep the best 99%; keep the best 95%; and keep the best 90%. Farmers ranked ‘keep the best 99%’ under production over ‘keep all production land intact’ acknowledging that there were indeed some opportunities for alternate farm-scale land use options.

There are good reasons why farmers did not rank regional conservation priority mapping (revegetation) highly. First, farmers may not be likely to consider conservation priorities in their on-farm decision-making regardless of the data provided to them, owing to economic imperatives which mean agricultural productivity will be weighted highly. In such cases there are opportunities for incentives to compensate for lost production. However, historically farmers in the Wimmera region have demonstrated their willingness to consider conservation and biodiversity priorities in their decision-making, though this may be driven by farm-scale and personal objectives rather than regional priorities. For example, there are 56 Landcare groups involving around 1600 members in the Wimmera and a recent study of Wimmera farmers found that those taking part in Landcare training activities were 1.8 times more likely to revegetate, and 2.2 times more likely to fence remnants (Curts and Byron, 2002). So it is important to consider other reasons why farmers in this particular study were unlikely to rate regional conservation priorities highly.

It is also possible that the land included in this study is considered unlikely to contribute to positive conservation outcomes regardless of the management intervention. Indeed, one farmer mentioned in the workshop that had the study included parts of his farm to the south of the study area, he would be more likely to respond to regional revegetation priority maps in the farmer preference elicitation process. Farmers also agreed that the land in this study was likely to have been sparsely covered with trees prior to introduction of agriculture; hence it is possible that they felt that revegetation was therefore not necessary because degradation due to agriculture was minimal. This also indicates that in future studies we should consider interventions other than revegetation. Other interventions could include fencing, increasing groundcover, retention of coarse woody debris, and facilitating active regeneration by reducing fertilizer inputs, and strategic grazing in non-cropping systems. It is also important to note that this study was undertaken after several consecutive poor production years, which has impacted on farmers’ economic wellbeing. This in the short term may reduce the farmers’ willingness to consider land use change in favour of conservation or environmental objectives. Where longer term strategies are considered, the opposite may be true. Finally, it is possible that by selecting farmers who had precision agriculture data available, we inadvertently chose farmers who were particularly production focussed and therefore more likely to place high importance on production and economic priorities.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Final weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revegetate rare vegetation communities</td>
<td>0.25</td>
</tr>
<tr>
<td>Revegetate areas with dense patch distribution</td>
<td>0.13</td>
</tr>
<tr>
<td>Revegetate close to large patches</td>
<td>0.13</td>
</tr>
<tr>
<td>Revegetate close to streams</td>
<td>0.22</td>
</tr>
<tr>
<td>Revegetate enclosed areas</td>
<td>0.10</td>
</tr>
<tr>
<td>Revegetate to form corridors</td>
<td>0.08</td>
</tr>
<tr>
<td>Reduce patch isolation</td>
<td>0.08</td>
</tr>
</tbody>
</table>
Our use of MCA to integrate regional conservation planning with farm-scale actions has highlighted a number of challenges. The generalisations inherent in MCA preference setting may be acceptable at regional scales when detailed knowledge of environmental processes and interactions may be limited. When applying the methods at the scale of the farm where farmer domain knowledge is detailed, it is difficult to make the generalisations required by the pair wise comparisons. For example, farmers may weight revegetation to mitigate water erosion as more important than production, but only for one paddock on their property. Incorporating these exceptions is difficult with MCA pair wise comparison of criteria and it may require more sophisticated criteria definition, or a hierarchical approach to defining criteria to better incorporate decision-making scales (Dodgson et al., 2001).

The attempt to integrate regional-scale planning with farm-scale actions via an MCA methodology has also raised a number of challenges regarding spatial data suitability, and conceptual issues concerning MCA when applied across multiple management scales (regional to farm). These findings are general in nature and are designed to inform future applications of MCA for NRM priority setting. After running two MCA preference elicitation workshops,
one with NRM staff and a second with farmers, it is clear that
criteria definition is a major challenge. There are two components
to this challenge. The first is the assumption in MCA and AHP that
criteria are mutually exclusive. The second is the general inability of
MCA to incorporate interactions between criteria. Hajkowicz et al.
(2008) make similar observation noting the importance of criteria
and decision options in structuring an MCA problem, rather than
the MCA method itself.

In terms of spatial MCA coupled with land use suitability
modelling to develop the final maps of regional conservation
priorities, some additional challenges have also been raised
including the following:

- Obtaining accurate ecological parameters as an input to
  spatially implement criteria for specific study regions is diffi-
cult. The choice of parameters can play a major role in how the
final spatial NRM-derived land use suitability layer is
constructed.

- Spatial data which provides the input into the MCA criteria
  plays a major role in how the final spatial MCA-derived land
use suitability is mapped across the landscape. In this study the
primary input layer was a high resolution map of woody
vegetation derived from aerial photography. Hence there exists
an important interaction between criteria parameters and
input GIS data scale and resolution.

- In the absence of analytical methods to assess the role of input
GIS data and criteria parameters, detailed sensitivity analysis
should be applied to evaluate the reliability of the final
mapped results. However, options for sensitivity analysis in
such studies are limited as generating alternative realisations
of input GIS criteria layers can be computationally extremely
intensive.

5. Conclusion

This paper describes one of the first attempts to assess the
potential of regional NRM priority setting to influence farm-scale
decision-making. Such analyses are important as regional-scale
NRM planning and priority setting can be criticised for not
adequately accounting for farm-scale production impacts. One
could however argue that where incentive programs assess
proposals against regional conservation priorities and are deliv-
ered via a competitive tender process, farmer preferences and
production concerns will be implicit in the bids. However, owing
to the many informal and self-driven on-ground conservation
actions implemented by farmers, there are nevertheless oppor-
tunities to achieve multiple environmental benefits by making
landholders aware of regional conservation priorities. From this
study we believe that the mapping of regional conservation
priorities has greater value as a tool to support regional NRM
decision-making than as a tool to influence farm-scale actions.
Further, the use of MCA approaches to incorporate priorities
across multiple scales and where domain knowledge is detailed
will be challenging. Indeed, the strength of MCA in effectively
dealing with qualitative decision problems may also be a limita-
tion when dealing with problems where a detailed quantitative
understanding of interactions exists. In such instances, other
approaches such as decision trees and/or Bayesian belief
networks could be used to structure the problem. Finally, the
communication of regional conservation priorities to farmers
remains only one component of the NRM integration challenge.

For instance, to encourage strategic ‘pull’ approaches to NRM
delivery may also require more effective monitoring to assure
landholders that on-ground actions are effectively delivering to
regional targets.

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