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Modelling the benefits of habitat restoration in socio-ecological systems

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ABSTRACT

Decisions affecting the management of natural resources in agricultural landscapes are influenced by both social and ecological factors. Models that integrate these factors are likely to better predict the outcomes of natural resource management decisions compared to those that do not take these factors into account. We demonstrate how Bayesian Networks can be used to integrate ecological and social data and expert opinion to model the cost-effectiveness of revegetation activities for restoring biodiversity in agricultural landscapes. We demonstrate our approach with a case-study in grassy woodlands of south-eastern Australia. In our case-study, cost-effectiveness is defined as the improvement in native reptile and beetle species richness achieved per dollar spent on a restoration action. Socio-ecological models predict that weed control, the planting of trees and shrubs, the addition of litter and timber, and the addition of rocks are likely to be the most cost-effective actions for improving reptile and beetle species richness. The cost-effectiveness of restoration actions is lower in remnant and revegetated areas than in cleared areas because of the higher marginal benefits arising from acting in degraded habitats. This result is contingent on having favourable landowner attitudes. Under the best-case landowner demographic scenarios the greatest biodiversity benefits are seen when cleared areas are restored. We find that current restoration investment practices may not be increasing faunal species richness in agricultural landscapes in the most cost-effective way, and that new restoration actions may be necessary. Integrated socio-ecological models support transparent and cost-effective conservation investment decisions. Application of these models highlights the importance of collecting both social and ecological data when attempting to understand and manage socio-ecological systems.

1. Introduction

Biodiversity loss is occurring on an international scale and habitat loss and fragmentation resulting from clearing for agriculture is a major contributor (Gibbs et al., 2009; McIntyre and Hobbs, 1999). Land management agencies are increasing their investment in biodiversity conservation efforts on private land because it covers a higher proportion of many continents and habitat loss is increasingly occurring in these areas (Soulé et al., 2004; Soulé and Sanjayan, 1998). However, this raises potential difficulties for decisions about biodiversity conservation, as decisions are often complicated by multiple and competing social, ecological and economic objectives (Allison and Hobbs, 2004; Olsson et al., 2006). Some of the most important management decisions are about how to improve biodiversity cost-effectively and how to involve private landowners in conservation efforts (Holzkamper and Seppelt, 2007; Sebastián-González et al., 2011).

Landowner decisions about conservation initiatives are influenced by their values, beliefs, and personal and social norms (Stern et al., 1995; Whittaker et al., 2006). Having an understanding of these drivers of landowner management decisions and how these decisions impact biodiversity on privately owned land can better inform natural resource management actions (Carr and Hazell, 2006; Jellinek et al., 2013b). However, few ecological studies have researched landowners' attitudes towards remnant and restored land, their adoption of restoration activities, and how this influences faunal persistence in agricultural landscapes (Morton et al., 2010; Smith, 2008). By incorporating social and ecological data into the decision making process we can better understand the impacts of landowner attitudes and management on biodiversity (Olsson et al., 2006; Ticehurst et al., 2011). A socio-ecological approach identifies management needed to achieve conservation objectives, and defines the social constraints and opportunities for implementing that management (Wyborn et al., 2012).

Given environmental management budgets are small relative to the scale of biodiversity loss, it is critical that we have tools that enable managers to improve biodiversity cost-effectively (Menz et al., 2013; Polasky et al., 2011; Sebastián-González et al., 2011), and evaluate and justify the budgets required to achieve biodiversity objectives (Rumpff et al., 2011). This includes understanding the social opportunities and constraints that are likely to enable

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this management to occur, or inhibit it (Smith, 2008; Wyborn et al., 2012). To reduce the uncertainty about what environmental benefits and ecosystem services can result from restoration (Duncan and Wintle, 2008; Vesk and Mac Nally, 2006), there is also a need to explicitly calculate the cost-effectiveness of competing restoration options (Measham, 2007; Rumpff et al., 2011).

Uncertainty about investment effectiveness can be partly addressed by integrating existing expert knowledge with available field data into a process model that represents the relationships between restoration actions and biodiversity outcomes (Rumpff et al., 2011). Expert opinion is increasingly being used to make ecological decisions as field data is often lacking (McBride and Burgman, 2012), although there is often uncertainty about the robustness of this expert knowledge (Marcot et al., 2006). Such models enable investigation and evaluation of competing management investment options and underpin transparent management decision-making (Duncan and Wintle, 2008; Rumpff et al., 2011). Bayesian Networks are a good basis for building process models as they help to structure reasoning and to identify causal relationships between multiple variables (Marcot et al., 2006). Bayesian Networks are an ideal tool for facilitating better management decisions as they allow the quantitative integration of field data and expert opinion (Burgman et al., 2010; Ticehurst et al., 2011); allow the explicit incorporation of uncertainty; and can be updated with new monitoring data to reflect a better understanding of the natural system over time (Glendining and Pollino, 2012; Rumpff et al., 2011).

Combining sources of data in a Bayesian Network framework to analyze the impact of management scenarios on a performance measure (or variable) of interest is not new (McCann et al., 2006; Pollino et al., 2007; Ticehurst et al., 2011). However, we aim to use Bayesian Networks to combine expert opinion with ecological and social data from two agricultural regions in south-eastern Australia to enable investigation of: (i) the restoration actions that most cost-effectively increase reptile and beetle species richness (as a measure of a biodiversity objective); and (ii) how landowner demographics and management decisions influence reptile and beetle species richness. This approach provides a useful tool for management agencies attempting to understand the social opportunities and constraints associated with making cost-effective decisions about biodiversity conservation in agricultural landscapes.

2. Materials and methods

We developed a process model to represent existing knowledge about the ecological and social cause-and-effect relationships relevant to our aim of predicting the outcomes of restoration actions on a performance measure of interest. In our case-study, we focussed on how social and ecological processes mediate the impact of restoration actions on the richness of reptile and beetle species at the patch scale (Fig. 1). The environmental, social and management variables included in the model were recorded during a field study of reptile and beetle communities and their response to habitat restoration in two agricultural landscapes in south-eastern Australia: the Wimmera and the Benalla regions (Jellinek et al., 2013a, 2013b, in revision).

2.1. Data collection

2.1.1. Study area

The Wimmera region (36.3333°S, 141.6500°E) receives an average annual rainfall of 350–500 mm with mean daily temperatures varying from 14 to 40 °C (Bureau of Meteorology, 2010). Prior to European settlement, this area supported grassy woodlands dominated by buloke (*Allocasuarina luehmannii*) and black-box (*Eucalyptus largiflorens*) on rises and flats, and grasslands on clay pans and shallow depressions (Morcom and Westbrooke, 1998). The Benalla region (36.5519°S, 145.9817°E) has an annual average rainfall of 400–670 mm and mean annual temperatures vary from 15 to 31 °C in different months (Bureau of Meteorology, 2010). Vegetation varies from box-ironbark forests containing red-ironbark (*E. tricarpa*) or yellow gum (*E. leucoxylon*) and grey-box (*E. macrocarpa*) to grey-box, white-box (*E. albens*), yellow-box (*E. melliodora*) and river red gum (*E. camaldulensis*) grassy woodlands in the more fertile soils (Radford et al., 2005). Since the 1850s these regions have been heavily cleared for intensive agriculture such as cropping and livestock production (Radford et al., 2005). These landscapes are now highly fragmented and contain less than 10% of their native vegetation cover, negatively impacting native flora and fauna (Duncan et al., 2007).

2.1.2. Landowner data

We used demographic information and data on landowners' intentions to manage remnant and revegetated areas – obtained from landowner social surveys – to describe the social drivers that influenced habitat variables and faunal species richness at a patch scale (Fig. 1) (Jellinek et al., 2013b). We defined the patch scale as the local level of habitat and species variables located within a landscape. In this study patches were usually larger than 4 ha but smaller than 600 ha and contained either remnant or restored habitat. This differs to landscape scale processes that incorporate multiple patch scale processes (Graham and Blake, 2001).

Our study of landowners in the Wimmera and Benalla region investigated their adoption of revegetation activities and their opinions on remnant vegetation and revegetated land. Private landowners were surveyed using postal questionnaires to determine (i) their previous and/or future revegetation activities and (ii) their attitudes towards remnant and revegetated areas, and how these attitudes influenced their intention to manage these areas for conservation. As far as possible we ensured that samples were unbiased by randomly selecting landowner names and addresses from publically available documents, and by minimising interviewer and researcher bias (Bryman, 2004). Questions were developed with the assistance of social scientists and the questionnaires were trialled with local landowners and natural resource managers prior to their distribution. Overall, two hundred postal questionnaires were sent to landowners in each of the two regions (Jellinek et al., 2013b).

The demographic information we recorded included the respondent's age, property size, primary source of income, enterprise type, and their membership of a Landcare group. Landcare is a community-based natural resource management group operating in 22 countries (Landcare International, 2013). A landowner's intention to undertake management actions such as weed control or the removal of ground cover were gathered using a Likert scale that offered five possible answers ('definitely' through to 'definitely not') (Bryman 2004). A Likert scale was used as it measures levels of agreement or disagreement and is the most relevant method for assessing attitudes (Seale, 2004). These answers were split at the mid-point (3) to give a binary (yes/no) response (Fielding et al., 2005). Management decisions to plant native trees, shrubs and/or grasses, and to revegetate along linear strips or in patches were gathered on a binary scale (Appendix A). A landowner's intention to manage revegetated and remnant areas was a function of their attitudes to these areas.

2.1.3. Ecological data

We undertook a two-year study to investigate the response of reptile (Class Reptilia) and beetle species (Order Coleoptera) to habitat type and environmental variables (Jellinek et al., 2013a, in revision). In this study, we simplify the species-level data to