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Summary

Restoring native habitats in heavily cleared and fragmented areas such as agricultural landscapes is important to maintain and increase remaining native floral and faunal communities. Identifying priority vegetation types for restoration - as well as the parcels of land where this restoration could take place at a landscape scale - may assist in strategically protecting these biodiversity assets. In order to prioritise the restoration of terrestrial habitats around an ecologically and culturally significant Ramsar-listed wetland in South Australia, we used the spatial prioritisation tool Marxan. Originally designed for prioritising the protection of reserve areas, Marxan can also be used to identify parcels of land for restoration purposes. We tested how Marxan prioritised the restoration of four distinct vegetation types around the Coorong and Lower Lakes region of South Australia using the inverse of habitat remnancy as a cost and soil type and distance to ecologically significant bird species as a conservation feature. By prioritising restoration activities around certain landscape features, such as remnant areas, our results indicate that we would be able to strategically restore parcels of native habitat that would maximise biodiversity outcomes. This study highlights the need for robust input data, such as priority vegetation types and bird species associated with these habitats, to ensure informative modelling outputs. It also suggests that other measures, such as the cost of different land types, should be included in future restoration planning. Finally, we illustrate how prioritisation tools such as Marxan can be used by natural resource managers to restore areas within fragmented agricultural landscapes.

Introduction

Habitat fragmentation and habitat loss are the dominant factors influencing biodiversity loss in agricultural landscapes throughout the world (Hobbs and Norton 1996). In order to reduce the negative impacts of habitat loss and fragmentation on biodiversity, restoration of agricultural landscapes has become increasingly important (Hobbs, *et al.* 2014; Lindenmayer, *et al.* 2010). However, a criticism of many restoration projects is that they lack clear goals

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and a systematic planning process (Miller and Hobbs 2007;Wortley, *et al.* 2013). The Society for Ecological Restoration Primer (SER 2004) and the National Standards for the Practice of Ecological Restoration in Australia (SERA 2016) outline a number of factors to include when planning restoration activities, such as providing a clear rationale for undertaking restoration and an ecological description of the site to be restored. They also advocate the use of reference habitats to guide restoration planning and to assist in measuring the trajectory of restored habitats (Clewelly, *et al.* 2005;SER 2004). However, in many agricultural landscapes these reference habitats may have already been lost as a result of land clearing, or may be in a degraded state, making it difficult to plan restoration activities and measure their outcomes (Jellinek, *et al.* 2014).

There is also a need to prioritise the areas that require restoration so that limited conservation budgets can be strategically allocated to get the best biodiversity outcomes (McIlwee, *et al.* 2013). This can be done based on the amount of each vegetation community remaining in the landscape (Hobbs 2005;Hobbs 2008;Lindenmayer and Hunter 2010), and the communities at highest risk of losing biodiversity if interventions are not undertaken (Gibbons 2010). These priorities are important because loss of habitat below a threshold limit is likely to have negative impacts on remaining floral and faunal populations, especially those that require large remnant areas to persist (Radford, *et al.* 2005;Westphal, *et al.* 2003). To capture the conservation requirements of different vegetation communities in the landscape, coarse and/or fine filters can help define the factors most important in maintaining habitats or species of concern (Hunter Jr 1990;McIlwee, *et al.* 2013;Noss 1987). Overcoming the inherent complexity of planning in ecological systems can only be done by setting goals based on multiple levels of the biological hierarchy, thus ensuring habitat niches of all species are protected (Margules and Pressey 2000).

One way to identify coarse filters, such as key habitats for particular landscapes is to identify and define the ecosystem components and ecological processes occurring in that landscape, and where these processes are not meeting the requirements of the remaining biodiversity (McIlwee, *et al.* 2013). This can identify the plant communities that occur within the landscape, and the environmental factors that structure them into distinct vegetation types. It can also identify the processes that drive change within each of these vegetation types, and the ecological requirements of indicator flora and fauna (Rogers, *et al.* 2012). By synthesising this information vegetation types at greatest risk of further decline and loss can be identified and management interventions to reduce these declines can be implemented (McIlwee, *et al.* 2013).

This prioritisation process has been undertaken to identify the landscapes that require investment in South Australia (Bonifacio, *et al.* 2014; Rogers 2010; Willoughby 2011). However, while this and other methods have been developed to identify restoration targets and the management actions necessary to reduce these declines, the identification of discrete parcels of land to protect and restore has seldom been undertaken (Crouzeilles, *et al.* 2015; Noss, *et al.* 2009). Marxan is one tool that can assist in the prioritisation of parcels of land for restoration (Ball, *et al.* 2009; Game and Grantham 2008; Noss, *et al.* 2009).

We use Marxan to identify distinct parcels of land for restoration activities such as revegetation in a landscape dominated by agriculture in South Australia - the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. While Marxan has historically been used in conservation reserve design, a growing number of studies are using this program to identify priority parcels of land that could be restored (Crouzeilles, *et al.* 2015; Ikin, *et al.* 2016; Yoshioka, *et al.* 2014). Here we ask: (i) what variables will allow us to identify the highest priority parcels of land to restore, and (ii) where are the priority parcels of land that require restoration for each of our priority vegetation types. This method will be important for natural resource management agencies undertaking restoration into the future, as it will assist them to strategically identify discrete parcels of land to restore for the highest biodiversity gain.

Methods

Site description

The CLLMM region is at the terminus of the Murray-Darling Basin in South Australia (Cann, *et al.* 2000), and the study area includes terrestrial habitats within a 5 km radius of Lake Alexandrina, Lake Albert and the Coorong Lagoon (CLLMM recovery boundary, Figure 1). This area represents a buffer to the Ramsar-listed wetlands, an ecologically diverse and culturally significant region of South Australia (Matthews 1993). Mean annual rainfall varies from 255 - 706 mm, with the Mount Lofty Ranges generally having higher rainfall compared to other areas, resulting in different vegetation types being located in this area. Mean annual temperature throughout the entire area differs slightly (15.3 - 16.5 degrees Celsius). Topographic variation is also slight, with a maximum elevation of 180 m on the south eastern slopes of the Mount Lofty Ranges (Hall, *et al.* 2009).

The natural vegetation is diverse, ranging from wetland-associated communities such as reeds beds, semi-aquatic samphire habitats (Jellinek, *et al.* 2016) to terrestrial communities including grasslands, shrublands, heathlands, mallee and grassy woodlands (Berkinshaw

2009). Much of this natural vegetation has been cleared for agricultural purposes such as livestock grazing, cropping and viticulture. As a result, much of the CLLMM landscape is either fragmented or relictual with an average remnancy of 24%, requiring restoration activities to address these systemic issues of habitat loss.

This study draws on two bodies of work that identified the terrestrial vegetation types likely to occur in the CLLMM region. Firstly, Bonifacio, *et al.* (2014) utilised historic biological survey data and expert opinion to identify sixteen vegetation types that were likely to have occurred in the landscape prior to European settlement. Expert elicitation involved developing a questionnaire that was sent to nine people who had an in-depth knowledge of the native vegetation of the region (Burgman, *et al.* 2011; McBride and Burgman 2012; Speirs-Bridge, *et al.* 2010). The questionnaire divided the area into five different regions (otherwise known as management landscapes - Mount Lofty Ranges, Lower Lakes Terrestrial, Lower Lakes Aquatic, Coorong and South-east Coorong), and asked participants questions relating to the vegetation communities likely to occur in these areas and their status (common - rare). These nine experts then attended a one-day workshop to group the vegetation communities into vegetation types. This workshop was facilitated by a person with an understanding of expert elicitation techniques (McBride *pers. com.*). These results were cross-referenced with analysis of the vegetation communities identified from previous biological surveys to come-up with sixteen vegetation types (Bonifacio, *et al.* 2014).

Similarly, expert elicitation techniques were used to identify suites of bird communities that were reliant on the vegetation types identified in the above analysis. In this case four experts with over ten years of experience studying bird communities in the region identified the status (six categories: least concern - extinct) and trend (five categories: increasing - stable - decreasing) of bird species in the CLLMM region. This information was again compared to existing field data on the occurrence of bird species recorded in the CLLMM region to validate the suites of bird species that were likely to be associated with one or more of the sixteen vegetation types identified. Bayesian Belief Networks were used to compile this expert opinion and field data to identify six vegetation types that required restoration, based on the declining nature of the suites of bird species reliant on these habitats (Table S1, Figure S2). These were: (i) Samphire shrubland, (ii) Pink Gum (*Eucalyptus fasciculosa*) low woodland, (iii) Mallee Box (*E. porosa*) woodland, (iv) Peppermint Box (*E. odorata*) woodland, (v) Blue Gum (*E. leucoxylon*) woodland and (vi) non-eucalypt grassy woodland dominated by Sheoak (*Allocasuarina verticillata*) and Southern Cypress Pine (*Callitris gracilis*) (Bonifacio, *et al.* 2014). Jellinek and Te (2016) further clarified where these sixteen vegetation types were likely to be located in the landscape, using metrics such as soil type (subgroup),

landform and management landscape. This study used the six vegetation types identified as priorities, their underlying soil subgroups, and the suites of declining bird species reliant on these habitats in the analysis described below.

As some of these priority vegetation types had overlapping geographic ranges and were known to co-occur in nature, for this analysis we grouped these six into four vegetation types (Table 1). These were Samphire, Pink Gum woodlands, Gum woodlands and Peninsula woodlands. For each vegetation type we sought to identify 30% of the potential habitat area that could be restored. This target was set because studies have shown that when the vegetation cover of a landscape falls below 10 - 30%, a threshold is reached, causing the indicators of that landscapes functionality to fall dramatically (Andren 1994;Radford and Bennett 2007;Radford, *et al.* 2005).

Analysis

We used Marxan (Ball, *et al.* 2009;Watts, *et al.* 2009) to identify parcels of land within the four vegetation types that had been identified as priorities to restore through activities such as revegetation. We ran four separate Marxan analyses for the vegetation types identified (Table 1, Table S2). We used the solution output from Marxan to map the number of times a planning unit was selected in the final solution for each of the four vegetation types we studied. The more times a planning unit was selected, the more useful it was for creating a restoration area (Game and Grantham 2008). ArcGIS was used to map the planning units, while the Jenks optimisation method was used to find the most appropriate priority restoration classes according to the solution outputs (ESRI 2011).

Marxan is a modelling package widely used throughout the world as a support tool for conservation reserve design in both marine and terrestrial areas, where the goal is to protect a proportion of the biodiversity features that are available for the lowest cost (Ball, *et al.* 2009). Costs in Marxan can be any relative social, economic or ecological measure, or a combination of these. It uses simulated annealing, a probabilistic technique to find the best solution to an optimisation problem, involving a set of conservation targets and costs generated for planning units overlaid on a landscape of interest (Ball, *et al.* 2009;Game and Grantham 2008). Marxan required the following files: planning units, conservation features, planning units versus conservation features, boundary lengths and input parameters (Table S2).

Planning units

A hexagonal grid was placed over the CLLMM region, with each hexagon making up one 'planning unit'. Soil subgroup boundaries within the CLLMM region defined the extent of the hexagonal grid rather than the recovery boundary (Figure 1), because these areas represented the likely distribution of the selected vegetation types. Each planning unit held information on the areas costs and proposed reserve design, and was 100 ha in size. This size was chosen as it was the average size of privately owned land in the region (determined by an analysis in ArcGIS of average land parcel sizes) and also the most appropriate resolution for the conservation information available.

We used the inverse of the amount of remnant vegetation in a planning unit as a cost for the Marxan analysis. Native vegetation cover was the simplest and most intuitive surrogate for habitat area, as the loss of vegetation cover has consistently been found to have negative effects on native biodiversity (Fischer and Lindenmayer 2007; Westphal, *et al.* 2003). To estimate this cost we calculated the amount of remnant within, and 1 km surrounding, each planning unit. The total amount of remnant vegetation occurring in an extended planning unit was then normalised from 0 - 1, and given the inverse of this standardised number ($n - 1$). Thus, remnant cost was lowest (0) if a planning unit was entirely vegetated and highest (1) if it was entirely cleared.

Planning units covering the Coorong National Park were not included as native vegetation in this area was largely intact and protected from land clearing, and therefore not a target for restoration. Similarly, planning units that included parks, reserves or other protected areas (such as heritage agreements) in more than 75% of their area were 'locked-out' so they would not be included in the best restoration solution (Game and Grantham 2008). All spatial information was obtained from the South Australian Department of Environment, Water and Natural Resources (DEWNR) GIS database.

Conservation targets

We used two conservation features in our analysis: the proportion of selected soil subgroups in a planning unit, and the distance of selected bird species to a planning unit. We used soil as a surrogate of where each vegetation type was most likely to occur in the landscape, as soil is known to be a major factor influencing the location of plant communities (Berkinshaw 2009; Hall, *et al.* 2009). We used the occurrence of selected bird species (those that were associated with a certain vegetation type) from a vegetation type because birds are a good indicator of ecosystem health (Niemi and McDonald 2004), and because records of birds were relatively high for this study region compared to other fauna.

As outlined above, we set a target to restore 30% of each vegetation type, as determined by the soil subgroups that supported each vegetation type (Table 1). For each soil subgroup we set a Species Penalty Factor (SPF), otherwise known as the Conservation Feature Penalty Factor (Game and Grantham 2008), to determine the penalty that would be applied to the objective function if the conservation feature was not met. The higher the SPF, the greater emphasis Marxan puts on that conservation feature to ensure that the 30% target is met (Game and Grantham 2008). The results presented here are for a SPF of 10, as this met our greatest landscape targets.

For each planning unit in a given vegetation type we included all of the bird species associated with that vegetation type that were recorded in the last 25 years and were within a 20 km radius of the planning unit. A 20 km radius was selected based on expert opinion (Willoughby *pers. com.*) and previous studies (Willoughby 2005). Bird species were selected if they were declining and required that vegetation type to persist in the landscape, as discussed above (Table S1). The distance that a bird species was recorded to a planning unit was normalised from a distance in metres (0 - 2,000 m) to a scale from 0 - 1. Bird records were obtained from the Biological Database of South Australia.

Boundary length

Boundary length in Marxan refers to the length of shared boundaries between planning units, and allows reserve solutions to be more connected (Game and Grantham 2008). While other connectivity functions have been shown to be more effective when reserve targets are greater than 50% (e.g., Euclidean distance and landscape-value approaches), boundary length is an effective method when restoration targets are around 30% or lower (Lentini, *et al.* 2013). We calculated the boundary length of each planning unit using the JNCC extension in ArcGIS (ESRI 2011).

Results

We found that priority areas for restoration within the Samphire Shrubland vegetation type were restricted to lower lying areas around Lake Alexandrina and Lake Albert, particularly to the east of these lakes. Areas in the South-East Coorong were also high priority areas to revegetate, probably because of the large areas containing saline soils and their proximity to remnant vegetation. The Mount Lofty Ranges region was not highlighted as a priority as it has a higher elevation and therefore does not contain saline soils. Although most of Hindmarsh Island was not a high priority, the areas selected for restoration in the east of the

island were adjacent to remnant samphire and are known to be important habitats for threatened bird species such as Orange-bellied Parrots (Figure 2).

Gum Woodland and Pink Gum Woodland planning units, and therefore restoration areas were restricted to the Mount Lofty Ranges region (Figure 3 & 4). Gum Woodlands also extended towards the eastern edge of the Mount Lofty Ranges, probably due to the influence of Mallee Box (*E. porosa*) Grassy Woodland habitat (Figure 3). While Pink Gum Woodland overlap some priority areas of the Gum Woodland, the restoration areas for Pink Gum are largely restricted to an area between the two major river systems, the Finniss River and Currency Creek. Although this area has been heavily cleared for agriculture, there are still small remnants scattered throughout this area where restoration for connectivity could be beneficial, making this area a priority.

Gum Woodland priority restoration areas were restricted to areas closer to the Mount Lofty Ranges, because these areas had higher amounts of remnant vegetation and had a higher density of bird species that were associated with that vegetation type. In comparison, areas further away from the Mount Lofty Ranges, such as flatter parcels surrounding Lake Alexandrina, have been more heavily cleared and lacked connectivity to remnant bushland and were therefore of lower restoration value.

The Peninsula landscape is highly fragmented due to agriculture, although it does have two large remnant areas in the centre that are currently protected. These remnants were important in determining where restoration activities should be focussed, as Marxan prioritised areas around these remnants for restoration (Figure 5). Only one area on the Paltalloch peninsula was listed as a moderate priority for revegetation. This was probably because the soil types that these three vegetation types (Mallee Box, Blue Gum & Non-Eucalypt Woodland) grew on are in lower densities on Paltalloch, and because there are relatively few remnant areas in this heavily cleared landscape.

Discussion

Prioritising habitat restoration in a largely cleared and fragmented landscape dominated by agriculture is often difficult due to the social and ecological drivers that influence restoration activities (Wyborn, *et al.* 2012). One way to ensure that restoration money gets spent effectively and strategically is to prioritise where those restoration activities occur based on available ecological data (Adame, *et al.* 2015). Our analysis using Marxan enabled us to prioritise parcels of land for restoration based on the amount of remnant vegetation,

connectivity through the landscape and suites of bird species that required these habitats to persist. Marxan also allowed us to focus restoration activities on specific vegetation types that were a priority for restoration in the landscape.

While Marxan has been used by other researchers to select areas to restore (Adame, *et al.* 2015; Yoshioka, *et al.* 2014), our study was unique as it focussed on a single landscape and prioritised the restoration of multiple vegetation types. For example, a study by Yoshioka, *et al.* (2014) focussed on restoring landscapes on a national scale (Japan), while Crouzeilles, *et al.* (2015) used the habitat requirements of two species to prioritise areas for restoration in the Brazilian Atlantic Forest. Similarly, Ikin, *et al.* (2016) used Marxan to identify the extent to which existing restoration plantings supported landscape-scale bird occurrence. As restoration and especially revegetation is required to maintain and increase native flora and fauna in landscapes dominated by agricultural productivity (Hobbs, *et al.* 2014; Lindenmayer, *et al.* 2010), such as the area we studied, we believe Marxan could provide an important tool for restoration planning. Through the strategic restoration of important habitat elements, Marxan is likely to effectively prioritise the areas that require restoration now and in the future.

The mapping we have undertaken identifies priority areas where restoration activities could be focussed, however there are a number of limitations that should be recognised when using this information for restoration planning. Firstly, our analysis uses the inverse of remnant vegetation as a cost, and this strategy has positive and negative consequences for restoration outcomes. As the areas of land identified during this analysis are generally on private land and grazed to some extent, including this information as a cost ensures the protection of remaining remnant vegetation (through fencing of restored areas) and enables them to become larger and more connected (through revegetation and natural regeneration). However, prioritising land that has some remnant vegetation can have negative consequences, as poorer quality land (e.g., sand hills or rocky hillsides) may be selected, leaving more fertile land in agricultural production. This more fertile land may provide better biodiversity outcomes than less fertile areas. Given that it is unlikely that landholders will be willing to give-up highly productive (and therefore more expensive) land without adequate compensation (Jellinek, *et al.* 2013), the strategy discussed here is probably justified.

Although agri-environmental schemes have been designed to compensate farmers for the loss of income that results from undertaking environmental works on their property (Wade, *et al.* 2008), few studies actively integrate cost (those incurred by the public or the landholder)

or cost-effectiveness in their evaluation of these schemes (Ansell, *et al.* 2016). As suggested by Ansell, *et al.* (2016), these evaluations are seldom undertaken partly due to the availability of cost data, such as the cost of highly productive land in comparison to poorer quality land. While restoration activities are usually restricted to less productive areas of land because they cannot adequately compensate landholders, programs need to not only provide restoration incentives to landholders, but also compensate them for the loss of productive land if restoration of more fertile land is to be possible. In this case including cost information in prioritisation analysis is likely to be crucial for restoration programs.

Similarly, while the planning units show areas of land that could potentially be restored, access to private land and the works required on this land depend on how supportive the landholder is to these activities (Wyborn, *et al.* 2012). Research has shown that a landholder's decision to take part in conservation activities is dependent on a variety of personal, cultural, social and economic drivers (Pannell, *et al.* 2006). For example, landholders are most likely to take part in conservation activities if they have previously experienced the benefits of these activities on their farm (Fielding, *et al.* 2005;Jellinek, *et al.* 2013), they are not reliant on the land as a primary source of income (Schrader 1995), or if the conservation techniques proposed will be practical and profitable to their property (Cary and Wilkinson 1997;Wilkinson and Cary 1992).

Planning restoration with landholders that have previously been involved in conservation activities could be one way to reduce this risk, as well as using existing community groups and organisations that have established links with local landholders (Curtis and De Lacy 1996). The project described here was fortunate to collaborate with an active community group and Indigenous organisation who had existing relationships with local landholders, and were therefore able to assist in gaining access to parcels of land for restoration. Another way to focus restoration activities would be to exclude parcels of land from the Marxan analysis if certain properties were unlikely to participate in conservation initiatives. This would provide more realistic areas where restoration could be undertaken.

Another factor to consider is the accuracy of the data that is informing the Marxan analysis, and if that data is appropriate for the size of the planning units being used (Underwood, *et al.* 2010;Wilson, *et al.* 2005). For example, the bird records we used were obtained from a state-wide biological database, where there were adequate records of each species to ensure that the data was reliable. Where species data is minimal or spatially biased, predicting a species occurrence using models could be one way to obtain this data (Wilson, *et al.* 2005). However, these results can be sensitive to the predictions of species

occurrences, ultimately impacting the overall reserve design (Wilson, *et al.* 2005). Similarly, in this study the soil mapping was relatively accurate (Hall, *et al.* 2009), but was not at a resolution to accurately allow smaller parcels of land to be identified for restoration. If soil mapping was not accurate the analysis could misrepresent the location of selected vegetation types, thereby selecting areas that may not be suitable for restoring that community.

Overall, Marxan is a useful tool to undertake reserve design or designate areas of a landscape that require restoration, but it requires a good knowledge of the landscape in question, accurate data and a good understanding of the analysis package. As stated by Munro (2006), Marxan 'effectively requires technical and ecological expertise, a comprehensive GIS infrastructure, good data and time'. It is also an iterative process, requiring that as new data becomes available, and as restoration activities are undertaken, mapping be updated to better inform where new restoration should occur. The inputs we used in this study - remnant vegetation cover, soil data based on vegetation priorities and occurrences of selected bird species - are reasonably accessible datasets available to natural resource managers. We have shown that by using these metrics it is possible to prioritise restoration activities in a strategic manner that will increase landscape biodiversity. If future restoration programs compensate landholders for the loss of productive land, then prioritisation tools should include the cost of private and public land and use the input of remnant vegetation data as a cost.

References:

- Adame M., Hermoso V., Perhans K., Lovelock C. and Herrera-Silveira J. (2015) Selecting cost-effective areas for restoration of ecosystem services. *Conservation Biology* **29**, 493-502.
- Andren H. (1994) Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: A review. *Oikos* **71**, 355-366.
- Ansell D., Freudenberger D., Munro N. and Gibbons P. (2016) The cost-effectiveness of agri-environment schemes for biodiversity conservation: A quantitative review. *Agriculture, Ecosystems & Environment* **225**, 184-191.
- Ball I. R., Possingham H. P. and Watts M. (2009) Marxan and relatives: Software for spatial conservation prioritisation. In: *Spatial conservation prioritisation: Quantitative methods and computational tools* eds A. Moilanen, K. A. Wilson and H. P. Possingham pp. 185-195. Oxford University Press, Oxford, UK.
- Berkinshaw T. (2009) *Mangroves to mallee : the complete guide to the vegetation of temperate South Australia*. Greening Australia, Pasadena, South Australia.

- 1 Bonifacio R. S., Rogers D., Jellinek S., Willoughby N. and Thompson D. (2014) The identification and
2 assessment of ecosystems within the Coorong, Lower Lakes and Murray Mouth (CLLMM) Region - An
3 application of the Landscape Assessment Framework. DEWNR, Adelaide South Australia.
- 4 Burgman M., Carr A., Godden L., Gregory R., McBride M., Flander L. and Maguire L. (2011) Redefining
5 expertise and improving ecological judgment. *Conservation Letters* **4**, 81-87.
- 6 Cann J. H., Bourman R. P. and Barnett E. J. (2000) Holocene Foraminifera as Indicators of Relative Estuarine–
7 Lagoonal and Oceanic Influences in Estuarine Sediments of the River Murray, South Australia: Volume 53,
8 Number 3 (2000), pages 378–391. *Quaternary Research* **54**, 439.
- 9 Cary J. W. and Wilkinson R. L. (1997) Perceived profitability and farmers' conservation behaviour. *Journal of*
10 *Agricultural Economics* **48**, 13-21.
- 11 Clewell A., Rieger J. and Munro J. K. (2005) Guidelines for developing and managing ecological restoration
12 projects. Society for Ecological Restoration International, Arizona USA.
- 13 Crouzeilles R., Beyer H. L., Mills M., Grelle C. E. V. and Possingham H. P. (2015) Incorporating habitat
14 availability into systematic planning for restoration: a species-specific approach for Atlantic Forest mammals.
15 *Diversity and Distributions* **21**, 1027-1037.
- 16 Curtis A. and De Lacy T. (1996) Landcare in Australia: Does it make a difference? *Journal of Environmental*
17 *Management* **46**, 119-137.
- 18 ESRI (2011) ArcGIS Desktop. Environmental Systems Research Institute, Redlands, Canada.
- 19 Fielding K. S., Terry D. J., Masser B. M., Bordia P. and Hogg M. A. (2005) Explaining landholders' decisions
20 about riparian zone management: The role of behavioural, normative, and control beliefs. *Journal of*
21 *Environmental Management* **77**, 12-21.
- 22 Fischer J. and Lindenmayer D. B. (2007) Landscape modification and habitat fragmentation: a synthesis. *Global*
23 *Ecology and Biogeography* **16**, 265-280.
- 24 Game E. T. and Grantham H. S. (2008) Marxan User Manual: For Marxan Version 1.8.10. University of
25 Queensland, British Columbia Canada.
- 26 Gibbons P. (2010) Prioritising conservation in temperate woodlands. In: *Temperate Woodland Conservation*
27 *and Management* eds D. Lindenmayer, A. Bennett and R. Hobbs pp. 15-21. CSIRO Publishing, Melbourne.
- 28 Hall J., Maschmedt D. and Billing N. B. (2009) *The Soils of Southern South Australia*. Department of Water,
29 Land and Biodiversity Conservation: Government of South Australia.
- 30 Hobbs R. J. (2005) Landscapes, ecology and wildlife management in highly modified environments – an
31 Australian perspective. *Wildlife Research* **32**, 389-398.

- 1 Hobbs R. J. (2008) Goals, targets and priorities for landscape-scale restoration. In: *Managing and Designing*
2 *Landscape for Conservation* eds R. J. Hobbs and D. B. Lindenmayer pp. 511-526. Zoological Society of
3 London and Blackwell Publishing, Oxford.
- 4 Hobbs R. J., Higgs E., Hall C. M., Bridgewater P., Chapin F. S., Ellis E. C., Ewel J. J., Hallett L. M., Harris J.,
5 Hulvey K. B., Jackson S. T., Kennedy P. L., Kueffer C., Lach L., Lantz T. C., Lugo A. E., Mascaro J., Murphy
6 S. D., Nelson C. R., Perring M. P., Richardson D. M., Seastedt T. R., Standish R. J., Starzomski B. M., Suding
7 K. N., Tognetti P. M., Yakob L. and Yung L. (2014) Managing the whole landscape: historical, hybrid, and
8 novel ecosystems. *Frontiers in Ecology and the Environment* **12**, 557-564.
- 9 Hobbs R. J. and Norton D. A. (1996) Towards a conceptual framework for restoration ecology. *Restoration*
10 *Ecology* **4**, 93-110.
- 11 Hunter Jr M. L. (1990) Coping with ignorance: the coarse-filter strategy for maintaining biodiversity. *Balancing*
12 *on the brink of extinction*. Washington (DC): Island Press. p 266-81.
- 13 Ikin K., Tulloch A., Gibbons P., Ansell D., Seddon J. and Lindenmayer D. (2016) Evaluating complementary
14 networks of restoration plantings for landscape-scale occurrence of temporally dynamic species. *Conservation*
15 *Biology*.
- 16 Jellinek S., Parris K. P., Driscoll D. A. and Dwyer P. D. (2013) Are incentive programs working? Landowner
17 attitudes to ecological restoration of agricultural landscapes. *Journal of Environmental Management* **127**, 69-76.
- 18 Jellinek S., Parris K. P., McCarthy M., Wintle B. A. and Driscoll D. A. (2014) Reptiles in restored agricultural
19 landscapes: The value of linear strips, patches and habitat condition. *Animal Conservation* **17**, 544–554.
- 20 Jellinek S. and Te T. (2016) *A guide to restoring the Coorong, Lower Lakes and Murray Mouth region*.
21 Department of Environment Water and Natural Resources, Adelaide South Australia.
- 22 Jellinek S., Te T., Gehrig S., Stewart H. and Nicol J. (2016) Facilitating the restoration of aquatic plant
23 communities in a Ramsar wetland. *Restoration Ecology*.
- 24 Lentini P. E., Gibbons P., Carwardine J., Fischer J., Drielsma M. and Martin T. G. (2013) Effect of Planning for
25 Connectivity on Linear Reserve Networks. *Conservation Biology* **27**, 796-807.
- 26 Lindenmayer D. and Hunter M. (2010) Some Guiding Concepts for Conservation Biology. *Conservation*
27 *Biology* **24**, 1459-1468.
- 28 Lindenmayer D. B., Knight E. J., Crane M. J., Montague-Drake R., Michael D. R. and MacGregor C. I. (2010)
29 What makes an effective restoration planting for woodland birds? *Biological Conservation* **143**, 289-301.
- 30 Margules C. R. and Pressey R. L. (2000) Systematic Conservation Planning. *Nature* **405**, 243-253.

- 1 Matthews G. V. T. (1993) The Ramsar convention on wetlands: its history and development. ed E. Luthi
- 2 Ramsar Convention Bureau Gland, Switzerland.
- 3 McBride M. F. and Burgman M. A. (2012) What Is expert knowledge, how is such knowledge gathered, and
- 4 how do we use it to address questions in landscape ecology? In: *Expert Knowledge and Its Application in*
- 5 *Landscape Ecology* eds A. H. Perera, C. A. Drew and C. J. Johnson pp. 11-38. Springer New York.
- 6 McIlwee A. P., Rogers D., Pisanu P., Brandle R. and McDonald J. (2013) Understanding ecosystem dynamics
- 7 in South Australia's arid lands: a framework to assist biodiversity conservation. *Rangeland Journal* **35**, 211-224.
- 8 Miller J. R. and Hobbs R. J. (2007) Habitat restoration - Do we know what we're doing? *Restoration Ecology*
- 9 **15**, 382-390.
- 10 Munro K. G. (2006) Evaluating Marxan as a Terrestrial Conservation Planning Tool. *School of Community and*
- 11 *Regional Planning* University of British Columbia.
- 12 Niemi G. J. and McDonald M. E. (2004) Application of ecological indicators. *Annual Review of Ecology,*
- 13 *Evolution, and Systematics* 89-111.
- 14 Noss R., Nielsen S. and Vance-Borland K. (2009) Prioritizing Ecosystems, Species, and Sites for Restoration.
- 15 In: *Spatial Conservation Prioritization: Quantitative Methods and Computational Tools* eds A. Moilanen, K. A.
- 16 Wilson and H. P. Possingham pp. 158–171. Oxford University Press, Oxford, UK.
- 17 Noss R. F. (1987) From plant communities to landscapes in conservation inventories: A look at the nature
- 18 conservancy (USA). *Biological Conservation* **41**, 11-37.
- 19 Pannell D. J., Marshall G. R., Barr N., Curtis A., Vanclay F. and Wilkinson R. (2006) Understanding and
- 20 promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental*
- 21 *Agriculture* **46**, 1407-1424.
- 22 Radford J. Q. and Bennett A. F. (2007) The relative importance of landscape properties for woodland birds in
- 23 agricultural environments. *Journal of Applied Ecology* **44**, 737-747.
- 24 Radford J. Q., Bennett A. F. and Cheers G. J. (2005) Landscape-level thresholds of habitat cover for woodland-
- 25 dependent birds. *Biological Conservation* **124**, 317-337.
- 26 Rogers D. J. (2010) A Landscape Assessment for the Southern Mt Lofty Ranges Landscape. Version 2. Part 1.
- 27 Summary. Department of Environment and Natural Resources, South Australia.
- 28 Rogers D. J., Willoughby N., Pisanu P., McIlwee A. and Gates J. A. (2012) Landscape Assessment: A Process
- 29 for Identifying Ecosystem Priorities for Nature Conservation. Technical Report 2012/01. Department of
- 30 Environment and Natural Resources, South Australia.

- 1 Schrader C. C. (1995) Rural Greenway Planning - The role of streamland perception in landowner acceptance of
2 land management strategies. *Landscape and Urban Planning* **33**, 375-390.
- 3 SER (2004) The SER international primer on ecological restoration. ed Society for Ecological Restoration
4 International Science & Policy Working Group Arizona, USA.
- 5 SERA (2016) National standards for the practice of ecological restoration in Australia. Society for Ecological
6 Restoration Australasia, Australia.
- 7 Speirs-Bridge A., Fidler F., McBride M., Flander L., Cumming G. and Burgman M. (2010) Reducing
8 overconfidence in the interval judgments of experts. *Risk Analysis* **30**, 512-523.
- 9 Underwood J. G., D'Agrosa C. and Gerber L. R. (2010) Identifying Conservation Areas on the Basis of
10 Alternative Distribution Data Sets. *Conservation Biology* **24**, 162-170.
- 11 Wade M. R., Gurr G. M. and Wratten S. D. (2008) Ecological restoration of farmland: progress and prospects.
12 *Philosophical Transactions of the Royal Society B-Biological Sciences* **363**, 831-847.
- 13 Watts M. E., Ball I. R., Stewart R. R., Klein C. J., Wilson K., Steinback C., Lourival R., Kircher L. and
14 Possingham H. P. (2009) Marxan with Zones: software for optimal conservation based land- and sea-use zoning,
15 Environmental Modelling & Software.
- 16 Westphal M. I., Field S. A., Tyre A. J., Paton D. and Possingham H. P. (2003) Effects of landscape pattern on
17 bird species distribution in the Mt. Lofty Ranges, South Australia. *Landscape Ecology* **18**, 413-426.
- 18 Wilkinson R. and Cary J. (1992) Monitoring Landcare in north central Victoria. School of Agriculture and
19 Forestry, University of Melbourne, Melbourne.
- 20 Willoughby N. (2005) Comparative Ecology, and Conservation, of the Melithreptus Genus in the Southern
21 Mount Lofty Ranges, South Australia. The University of Adelaide.
- 22 Willoughby N. (2011) Landscape Assessment for the Murray Mallee – Evaluation of Current Status, July 2011.
23 Department of Environment and Natural Resources, South Australia.
- 24 Wilson K. A., Westphal M. I., Possingham H. P. and Elith J. (2005) Sensitivity of conservation planning to
25 different approaches to using predicted species distribution data. *Biological Conservation* **122**, 99-112.
- 26 Wortley L., Hero J.-M. and Howes M. (2013) Evaluating Ecological Restoration Success: A Review of the
27 Literature. *Restoration Ecology* **21**, 537-543.
- 28 Wyborn C., Jellinek S. and Cooke B. (2012) Negotiating multiple motivations in the science and practice of
29 ecological restoration. *Ecological Management & Restoration* **13**, 249-253.
- 30 Yoshioka A., Akasaka M. and Kadoya T. (2014) Spatial Prioritization for Biodiversity Restoration: A Simple
31 Framework Referencing Past Species Distributions. *Restoration Ecology* **22**, 185-195.

Table 1: The conservation features in the CLLMM region.

Vegetation type	Vegetation type	Target area to restore (30% of total)	Dominant soil subgroups (Hall, <i>et al.</i> 2009)
Samphire	Samphire	10,824 ha	N2, N3
Mallee Box, Blue Gum & Non-Eucalypt Woodland	Peninsula	4,900 ha	B2, B3, B6, B8, D3, G3
Peppermint Box & Mallee Box	Gum Woodland	4,983 ha	B2, B3, D3, G4
Pink Gum	Pink Gum	4,185 ha	G3, G4, H3

Figure 1. The Coorong, Lower Lakes and Murray Mouth study region in South Australia

Figure 2. Samphire shrubland priority restoration areas showing the planning units chosen for the highest (dark grey) to the lowest (light grey) restoration value.

Figure 3. Gum Woodland priority restoration areas showing the planning units chosen for the highest (dark grey) to the lowest (light grey) restoration value.

Figure 4. Pink Gum Woodland priority restoration areas showing the planning units chosen for the highest (dark grey) to the lowest (light grey) restoration value.

Figure 5. Peninsula Woodland priority restoration areas showing the planning units chosen for the highest (dark grey) to the lowest (light grey) restoration value.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

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