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Optimizing landscape configuration: A case study of woodland birds in the Mount Lofty Ranges, South Australia

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Abstract

We formulate the optimal landscape reconstruction problem for 22 birds in the Mount Lofty Ranges (MLR), South Australia. The goal is to determine landscape configurations with revegetation that would maximize the projected number of bird species present across all revegetated sites in the landscape. We use simulated annealing and an iterative improvement heuristic algorithm to find the efficient solutions for different objective functions and budget sizes. Under scenarios assuming that possible sites for revegetation have equal costs, our analyses suggest that revegetation programs in the region should strive to create landscapes with a mean revegetation patch size ranging from 780 to 4010 ha. The inclusion of property value data as surrogates for revegetation costs results in optimal landscapes with more highly irreplaceable (priority) sites in less expensive parts of the region and smaller average patch sizes. This illustrates how the solutions to landscape design problems change with different assumptions of economic cost. The paper represents one of the first uses of decision-modeling tools for optimal habitat restoration on a real landscape. The software and methodology have applicability for general landscape design outside the Mount Lofty Ranges.

Keywords: Landscape design; Spatial optimization; Revegetation; Simulated annealing algorithm; Australian birds

1. Introduction

The area of landscape planning and design is increasingly becoming an important topic in conservation biology (Lambeck, 1997), as we shift from conservation within parks to that in highly human-modified, multi-use landscapes. One aspect of landscape planning is habitat reconstruction, or restoration, which besides being important for maximizing biodiversity in its own right can also have ancillary benefits. In Australia, for example, the "ghosts of vegetation clearance past", such as dryland salinity, affects almost 2.5 million ha and is responsible for an annual cost of $(Australian) 270 million (CSIRO Land and Water, 2003). Thus, it is essential that strategic habitat reconstruction be enacted that is both cost effective and efficacious in terms of promoting species conservation.

One way to reconstruct landscapes is to determine the required habitat content and context (i.e. type and spatial configuration) needs for several key species and restore the landscape accordingly. Habitat suitability models can be used to glean requirements of minimum patch size, habitat type and aspects of the landscape configuration (McGarigal and McComb, 1995; Trzcinski et al., 1999; Villard et al., 1999; Westphal et al., 2003a). Traditional population viability analyses (PVAs) can then determine the relative impact of altering the spatial configuration of habitat for each species (Beissinger and Westphal, 1998). However, with rather large landscapes, the number of permutations is immense. Moreover, it is not very tractable to gather the detailed demographic and dispersal data needed to build PVAs for a whole community of species. For most species, static distribution data are the best data available. Another approach is to design a landscape for a whole community of species with regard to surrogate landscape measures (e.g. amount of certain habitat

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in the landscape, patch isolation, road density, etc.). However, a study in a forested region of southeastern Australia has found no general applicability for this approach for large sets of species, due either to the inappropriateness of the measure or the incorrect scale (Lindenmayer et al., 2002a). Various bird species in the same study site responded differently to the landscape mosaic, underscoring the need to examine its effects separately for each species (Lindenmayer et al., 2002a). The focal species approach has been promoted for landscape reconstruction, where habitat is created that satisfies the ecological requirements of the most area-limited, resource-limited, dispersal-limited and process-limited (e.g. fire) species (Lambeck, 1997; Watson et al., 2001). However, the underlying theoretical basis for the focal species approach is questionable, and the data needed to adequately select focal species are often lacking (Lindenmayer et al., 2002b).

Most fundamentally, the focal species approach and the static measures of landscape configuration have no way of adjudicating among the possible conflicting needs of different species and explicitly including financial costs. This is the utility of a decision-theoretic framework. Decision theory tools, including linear programming, mixed integer programming and heuristics, have been used to solve spatial problems in natural resource management (Hof and Bevers, 1998, 2002), most notably for multi-species reserves design (Csuti et al., 1997; Pressey et al., 1997a,b; McDonnell et al., 2002), harvest scheduling problems in forestry (Hof and Bevers, 2000b; Boston and Bettinger, 2001; Kurttila, 2001), single species habitat reservation on hypothetical or real landscapes (Hof and Bevers, 2000a; Loehle, 2000; van Langevelde et al., 2000, 2002; Hof et al., 2002; Westphal et al., 2003b; Haight et al., 2004), urban growth (Ward et al., 2003) and land-use allocation (Aerts et al., 2003).

In this paper, we provide one of the first investigations of multi-species optimal habitat reconstruction for a real landscape (Westphal and Possingham, 2003), incorporating species-specific functions of landscape suitability. The goal is to maximize the number of species occurences over all revegetated sites in the landscape. Following Possingham and Shea (1999) and Possingham et al. (2001), we set up the optimal habitat reconstruction problem in a decision-modeling framework, which falls broadly under the rubric of decision theory (Keeney and Raiffa, 1976; Bell et al., 1988; Pratt et al., 1995), and show how heuristic algorithms can be used to solve the problem. The steps for the formulation of any decision theory problem are: (1) the description of the system and available management options; (2) the statement of the objective function and constraints and (3) the selection and execution of the algorithm used to solve the problem. The solution method is determined by the nature and complexity of the problem and algorithmic applicability and availability. We are focusing on the spatial aspect of the optimal habitat reconstruction problem, that is, what sites to select in the landscape for revegetation and, concomitantly, desired values for various landscape metrics, such as patch size and connectivity. We realize that the site-level problem of facilitating the development of a certain vegetation community composition and structure is a more arduous task than simply selecting areas for restoration, the concern of this paper.

2. Materials and methods

2.1. Study site and species distribution models

The Mount Lofty Ranges (MLR) of South Australia is a relatively high rainfall (400–1100 mm/year) area of Australia, embedded in a semi-arid region (Fig. 1). For the purposes of this study, we use the boundary of the region as defined hydrologically (Bryan, 2000). Of a total 500,000 ha, only about 16% is covered by native vegetation. The native vegetation is primarily eucalypt woodland (particularly *Eucalyptus baxteri*, *Eucalyptus fasciculosa*, *Eucalyptus leucoxylon*, *Eucalyptus obliqua* and *Eucalyptus viminalis*) in a matrix of mixed agricultural land, including pasture, crops, vineyards and orchards. The region is a “biological island”, and using atlas data, we defined 37 woodland bird species as having populations that are isolated or largely isolated from their nearest populations outside the MLR (Paton et al., 1994).

In 1984–1985, the South Australian Ornithological Association conducted an intensive survey of birds in Adelaide region of South Australia, including the MLR (Paton et al., 1994). Using survey data from 499 points in the region, we conducted logistic regression analyses on the effects of landscape configuration, as described by FRAGSTATS metrics, on the species distributions (Westphal et al., 2003a). At a scale of 2 km around the survey points, FRAGSTATS metrics were used as the explanatory variables of presence-absence for each species: total landscape area (TLA), number of patches (NumP), mean patch size (MPS), the size of the largest patch (Lrg), mean nearest neighbor distance (edge to edge) of patches (MNN) and landscape shape index (LSI), which is a measure of the total edge in the landscape (Westphal et al., 2003a). Due to the scale of the survey data, these aggregate measures of the landscapes around each survey were deemed more appropriate explanatory variables than patch-specific metrics. We employed the 2 km neighborhood scale because most species responded at this scale (Westphal et al., 2003a) and for computational efficiency. Likewise, to make the computation tractable, we used a raster landscape with a grain cell size of 6.25 ha, but this scale is also relevant from a planning perspective. Two grid cells (henceforth sites) are defined as separate patches if they are connected only by their vertices, but do not share edges. We distilled the landscape down to a binary depiction: native vegetation or matrix (e.g. pasture, vineyards, orchards, urban areas).

Only species whose distribution model had a Receiver Operating Characteristic (ROC) area under the curve value exceeding 0.6 were included in this optimal landscape restoration formulation. ROC is a measure of a model’s discrimination, and the area under the curve value is equivalent to the probability that the model can discriminate between a true positive and a true negative value (Hanley and McNeil, 1982; Fielding and Bell, 1997; Elith, 2000; Pearce and Ferrier, 2000). A value exceeding 0.6 implies that the model is at least 20% better than random. This exact value is arbitrary and depends on what conservation plan-