Using spatial modelling to plan for the conservation of biodiversity within the Goulburn Broken Catchment, Victoria

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Abstract

The problems of allocating resources to achieve multiple benefits, such as controlling salinity, improving water quality and conserving biodiversity, are complex. A great deal of information is required before sensible decisions can be made. We know that there is a need for land use change at large scales. At the catchment scale, changes require planning and assessment that need to be derived from biophysical models, rather than being directly observed. The Department of Sustainability and Environment is developing a catchment analysis tool (CAT) for this purpose, through the National Action Plan for Salinity and Water Quality initiative. The CAT is a modelling tool that simulates water–soil–plant interactions at a land management scale. Information from the scientific literature was used to develop a set of rules to model changes to landscapes (400 ha blocks) within the Goulburn Broken Catchment. The mapped data layers of existing vegetation, roads and streams were used as a basis for creating vegetation in key areas of each landscape within a catchment, using a geographic information system. The modelling of the rules resulted in a change of landscapes within the catchment, particularly in agriculture-dominated regions, from highly fragmented with few large remnants to highly connected landscapes with large remnants. This project was useful in identifying gaps in our knowledge of how best to configure landscape change for the effective conservation of biodiversity. Potential applications are discussed.

Keywords

agriculture, biodiversity conservation, geographic information system, landscape ecology, revegetation, sustainability.

Introduction

The Department of Sustainability and Environment (DSE) has initiatives and policies in place that promote biodiversity enhancement. For example, the Native Vegetation Management Framework establishes the strategic direction for the protection, enhancement and revegetation of native vegetation throughout the state. Other initiatives include Bioregional Action Planning, which recognises that planning for biodiversity conservation needs to occur at several scales: catchment, bioregional, landscape and local (Platt and Lowe 2002).

If we wish to conserve biodiversity then we must efficiently and effectively plan for land use change. Current land uses in fertile areas continue to have profound effects on the wildlife adapted to these areas, undoubtedly causing the loss and continuing decline of many species of birds and mammals, reptiles, amphibians and probably invertebrates (Saunders 1989, Robinson and Traill 1996, Bennett and Ford 1997). Farming has resulted in the fragmentation of habitat into mostly small, isolated remnants. So how do we efficiently and effectively plan for land use change? What do we know about the types of landscapes that are required to progress towards the conservation of indigenous flora and fauna?

There are three main paradigms in the science that underpins restoration of landscapes to functioning systems. These are conservation biology, landscape ecology and metapopulation theory.

Conservation biology informs us that the greatest priority for biodiversity conservation is to protect and enhance existing remnants because these are irreplaceable (Yates and Hobbs 1997, Bennett et al. 2000). We also know that larger remnants are generally better than smaller ones. The species–area relationship has consistently shown a significant positive relationship between the number of bird, mammal and reptile species present and the size of remnant vegetation (Kitchener et al 1982, Howe 1984, Caughley and Gall 1985, Bennett 1987, Loyn 1987, Deacon and MacNally 1998, MacNally and Horrocks 2002). The results of several studies in a range of ecosystems suggest that the smallest remnant that will result in the greatest species richness is at least 40 ha (Loyn 1987, Bennett 1990, MacNally and Horrocks 2002). Remnants that are at least 10 ha may also provide biodiversity benefits when part of a connected landscape (Freudenberger 2000, Taws 2001).

Vegetation extent — the percentage of indigenous vegetation within a defined area — is an important factor that affects species richness within a landscape (Hargis et al. 1998, MacNally 1999). In Victoria and New South Wales, several targets for vegetation extent have been given from at least 10% (Bennett and Ford 1997) to 15% (Garnett and Crowley 2000) to 30% or more (Barrett 2000; Reid 2000).

Landscape ecology focuses on the connections between species, landscape patterns and processes (Forman 1995). The configuration of remnants (i.e. their isolation, size and connectivity) may also affect the species found within remnants (Bennett 1999). The relationships between bird species richness and configuration of native vegetation at a landscape scale are currently being examined (Bennett and Radford, pers. comm.). Preliminary results suggest that it is important to provide (or maintain) a mix of broad vegetation types, particularly riparian vegetation (Radford, pers. comm.).

Riparian zones are disproportionately important landscape elements because they contain species that both occur only within the riparian zone, and more terrestrial species (Knopf and Sampson 1994, Bennett 1999, Freudenberger 1999). The mesic streamside vegetation is also often structurally and floristically distinct from adjacent habitat and is therefore an important part of our biodiversity assets (Bennett 1997). Waterways and associated vegetation can be important corridors for the movement of animals. Bennett et al. (2000) suggested that strips of vegetation along streamsides that are more than 100 metres wide have the highest biodiversity benefit, but that strips 50–100 metres wide still have a high value.

Roadside vegetation is of major ecological significance, functioning as conduit, habitat, a source of dispersing animals, and a sink of animals (that is, more animals die than are replaced by dispersers) (Bennett 1991, 1999; Forman 1995; Bennett and van der Ree 2001). In highly modified landscapes, roadsides are among the largest and most extensive systems of linear habitat, spreading throughout many different environments. Roadsides that are near large forest remnants can be of particular importance to a wide range of fauna (Downes et al. 1997).

Metapopulation theory suggests that, in general, the aim of revegetation should be to produce a connected network of remnants (Leck 1979, Gilpin and Hanski 1991, Recher and Serventy 1991, Bennett 1999). Isolation reduces the ability of animals to move between remnants, resulting in the decline of populations that cannot be supplemented, and local extinction can occur (Arnold et al. 1993). To be potentially effective conservation systems, corridor networks must connect larger habitat patches with other vegetation (Wilson and Lindenmayer 1995, Bennett 1991). The 'best' corridor width may vary between habitat types, but in general corridors 40–50 m or greater have the greatest biodiversity benefits (Lynch and Saunders 1991, Mann and Davidson 1993, Robinson 1998, Bennett et al. 2000).

While there is an abundance of analyses and reporting of the problems and a range of responses to species decline, there is a lack of long-term planning (Saunders 1996). Revegetation activities are often *ad hoc* and might not result in benefits to biodiversity. The planning of land use change needs to be at large scales that have ecological relevance, such as the catchment scale (Saunders and Hobbs 1995). At such a scale it is necessary to formulate models of landscape change and assess likely outcomes from these models.

The Department of Sustainability and Environment (DSE) is developing a Catchment Analysis Tool (CAT) to assess land use change activities at the catchment scale (NRE 2002).

The project concept recognised that the problem of allocating resources to the control of salinity, the improvement of water quality and the conservation of biodiversity is complex (NRE 2002). A great deal of information is required before reasonable decisions can be made. We do not have time to create change, monitor and asses outcomes and change management scenarios based upon explicit data, because change, cause and effect are separated by long time periods (decades) and space (sometimes hundreds of kilometres). Therefore, any assessment of the impact of the effects of a prescribed landscape change needs to be estimated (i.e. derived from models) rather than directly observed. This approach to land management should result in improved outcomes for biodiversity, particularly on private land, that can be incorporated into other models of economic and hydrological impacts of land use change. Integrated planning for a range of outcomes will be able to identify areas that have dual or multiple benefits. For example, revegetation can be targeted in areas where there is both a biodiversity and salinity control benefit.

This project aims to use the scientific literature to develop a set of rules that can be used to model changes to landscapes that progresses towards the conservation of the majority of species. This included building on the existing pattern of vegetation to increase the habitat value of existing remnants, and improving the connectivity of remnants. The model will be used as a planning tool within the CAT to more strategically direct resources into biodiversity conservation at large scales. The rules were generated from scientific literature and then modelled within a geographic information system (ArcView and ArcInfo).

Methods

Study area

The Goulburn Broken Catchment

The Goulburn Broken Catchment encompasses part of the mountains and foothills of the Great Dividing Range in the north, down to the riverine plains to the Murray River in the south. This region includes a diverse range of vegetation (Berwick 2001). The fertile plains have become important areas for agriculture, but this has also caused problems such as salinity, soil acidity and nutrient run-off (GBCMA) 2000.

There are seven bioregions recognised within the catchment (Figure 1). Bioregions are land units that transverse catchments (but for this study bioregions within catchments were used) that reflect the natural patterns of ecological characteristics of the landscapes, and can be used to identify the relationships between many natural resource based activities and biodiversity assets (NRE 1997). In the Goulburn Broken Catchment the more fertile bioregions have been selectively cleared to a greater extent than other bioregions (Figure 1). For example, in the fertile Riverina Bioregion approximately 5% of native vegetation cover remains (GBCMA 2000). Extant vegetation exists mostly as small isolated remnants within paddocks, and usually narrow linear strips of vegetation along roadsides and streams. Remnants are often degraded and have little or no understorey. In contrast, over 98% of the Victorian Alps Bioregion remains vegetated (GBCMA 2000). If biodiversity is to be conserved in this catchment, and sustainable and functioning systems are to be achieved, rapid and extensive land use change from production to conservation is required.

Within bioregions, ecological vegetation classes (EVCs) have been identified. EVCs are plant associations that occur in an inferred environmental niche and can be identified by a typical structure and combination of floristics, life forms and ecological characteristics (Muir et al. 1995). Revegetation targets that would achieve 15% of the pre-European cover of the original extent of each EVC within each bioregion have been proposed (NRE 2000).

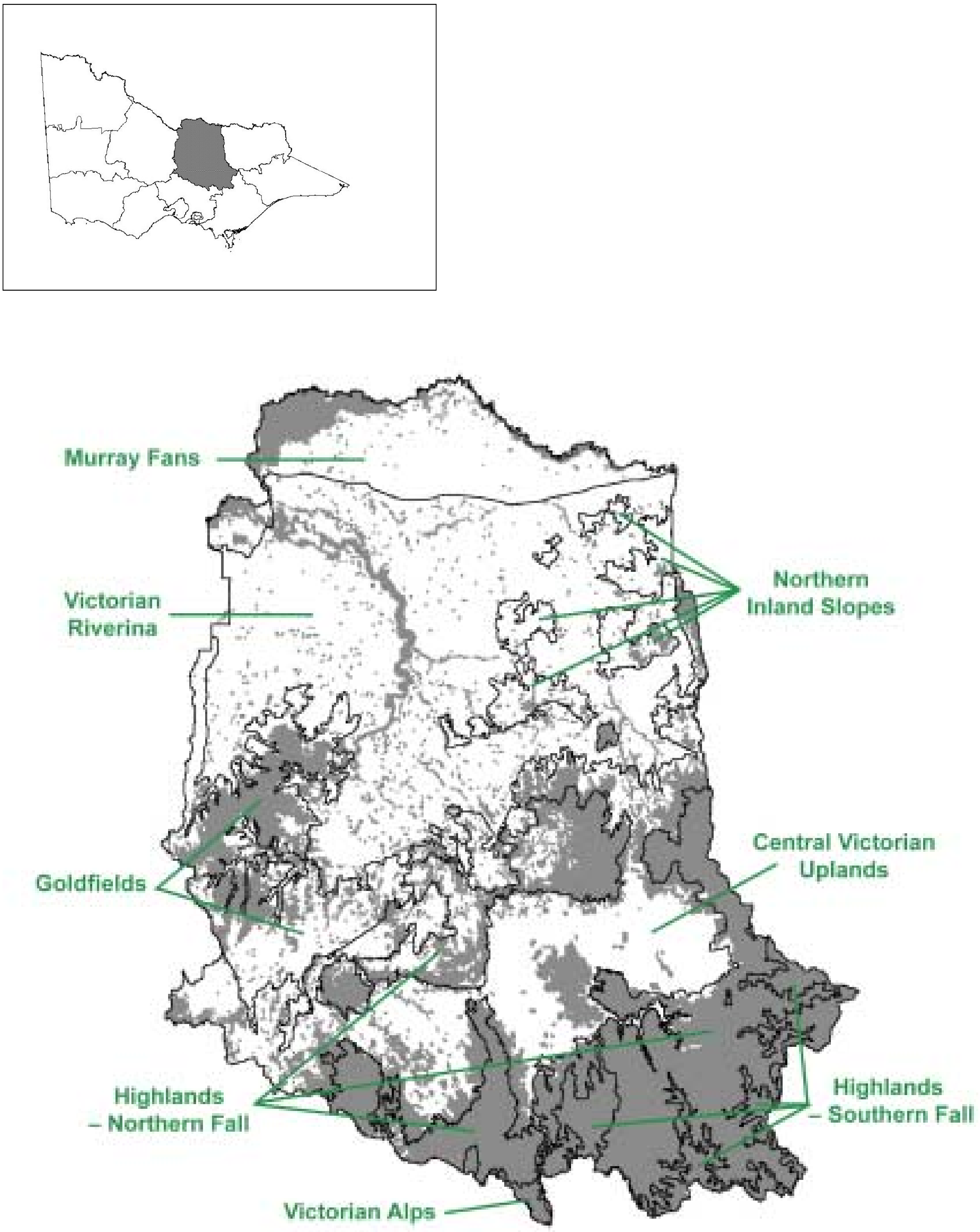

Figure 1 Extant native vegetation (shaded areas) and bioregions in the Goulburn Broken Catchment. Insert: location in Victoria.

Model development

Literature based model

To generate rules for a land use change scenario for the conservation of biodiversity, the general principles of conservation biology (based upon scientific literature) were used within a framework of government policy. Major paradigms of biodiversity conservation were derived from the disciplines of conservation biology, landscape ecology and metapopulation theory. These principles, together with prescriptions where available, were used to generate rules that addressed vegetation extent, connectivity, remnant size and proximity, and identified important landscape elements. A summary of the findings from the literature include the following:

- Remnants larger than 40 ha have the highest biodiversity benefit for the least remnant size.
- Remnants that are less than 10 ha can have high biodiversity values.
- A connected landscape, with terrestrial corridors at least 40 m wide and riparian corridors 50 m wide, are likely to improve population dynamics.
- A vegetation extent of at least 15% is required to conserve the majority of species.

The geographic information system

A geographic information system (GIS) (ArcView and ArcInfo) was used to spatially model the rules. First, data layers already available were used as the basis for modelling land use changes. The data layers used were from the NRE Corporate Geospatial Data Library (Honeyman 1997), and were:

- Tree cover (TREE_100 layer) mapped at a scale of 1 : 100 000. Polygons display tree cover as defined by woody vegetation greater than 2 metres in height and with a foliage density greater than 10%, mapped to a minimum of 1 ha. Derived from LANDSAT TM digital data.
- Bioregions — (VBIOREGION250 layer) mapped at a scale of 1 : 250 000.
- Ecological Vegetation Classes (EVC_CMP100 layer) mapped at a scale of 1 : 100 000. These have been mapped pre-1750 (i.e. pre-European). The tree_100 layer was cut from the pre-1750 EVC layer and was used to determine the current extent of each EVC.
- Hydrology (HYDRO500 layer) mapped at a scale of 1 : 500 000. Hydrological features, including lakes, swamps, rivers and dams. Only primary and secondary waterways were included, because including all waterways (e.g. streams to drainage lines) would cover the majority of a catchment.
- Roads (ROAD100 layer) mapped at a scale of 1 : 100 000. Delineates roads, identified and coded according to the AS2482 standard. The following roads were extracted from ROAD25 AS2482 codes: 2005 (main road – sealed), 2006 (main road – unsealed), 2016 (other roads – sealed), 2017 (other roads – unsealed).

Although there was some inconsistencies in scale between data sets, this did not create problems of unaligned data layers. Prior to modelling, town boundaries, a 1 km wide zone around major highways, and plantations were removed.

The data layers of existing vegetation, roads and streams were used as a basis for creating new landscapes with increased ‘vegetation’ (i.e. polygons within the GIS) in key areas of each landscape. To simulate revegetation, landscape features were buffered; that is, polygons of a specified distance around features were created.

It was necessary to divide the catchment into smaller landscape units to ensure that revegetation occurred in all natural landscape elements (e.g. from ridges to gullies, EVCs) and across a range of vegetation communities (as recommended by Saunders et al. 1991, Woinarski et al. 1992, Margules and Pressey 2000). A grid cell size of 400 ha (termed a ‘landscape unit’ here) was chosen as this should ensure that these aims are met. This landscape unit approximates 10-minute square Australian Map Grid coordinates, which has been considered as a ‘landscape unit’ in other key studies (A.F. Bennett, pers. comm.).

Rules generated for a land use change scenario

To develop the machine rules within the GIS environment, we utilised the general conservation principles outlined above. Six machine rules were developed.

- Rule 1: Increase the size of the largest remnant to achieve one remnant ≥40 ha for each 400 ha grid cell in the 400 ha landscape units that do not have a remnant ≥40 ha.
- Rule 2: Link each remnant ≥40 ha with riparian or roadside vegetation or other remnant ≥40 ha, whichever is closest, with 40 m wide strip of vegetation.
- Rule 3: Increase the size of the largest remnant(s) closest to a first or second order stream to achieve two remnants ≥10 ha within each 400 ha grid cell in the 400 ha landscape units that do not have two remnants >10 ha.

- Rule 4: Link all remnants ≥10 ha with riparian or roadside vegetation, or remnants > 40 ha, whichever is closest, with 40 m wide strip of vegetation.
- Rule 5: Create a 50 m buffer both sides of all first and second order streams.
- Rule 6: Create a 40 m buffer both sides of secondary and tertiary roads, terminating buffers within 1 km of major roads.

Results

The rules were applied to the Goulburn Broken Catchment and modelled using a GIS. Buffering of landscape features resulted in an increase in the number of large remnants (>40 ha and >10 ha), a linked and diverse landscape, and an increase in total vegetation extent, both in Bioregions and for each Ecological Vegetation Community.

Because of the size of the Goulburn Broken Catchment it is not possible to display the entire catchment, so an example of changes to the catchment is given in Figure 2. This is an area typical of the Riverine Plains, and it can be seen that the landscape contains small, scattered and isolated remnants. Changes to the landscape after each rule was modelled are shown (Figure 2).

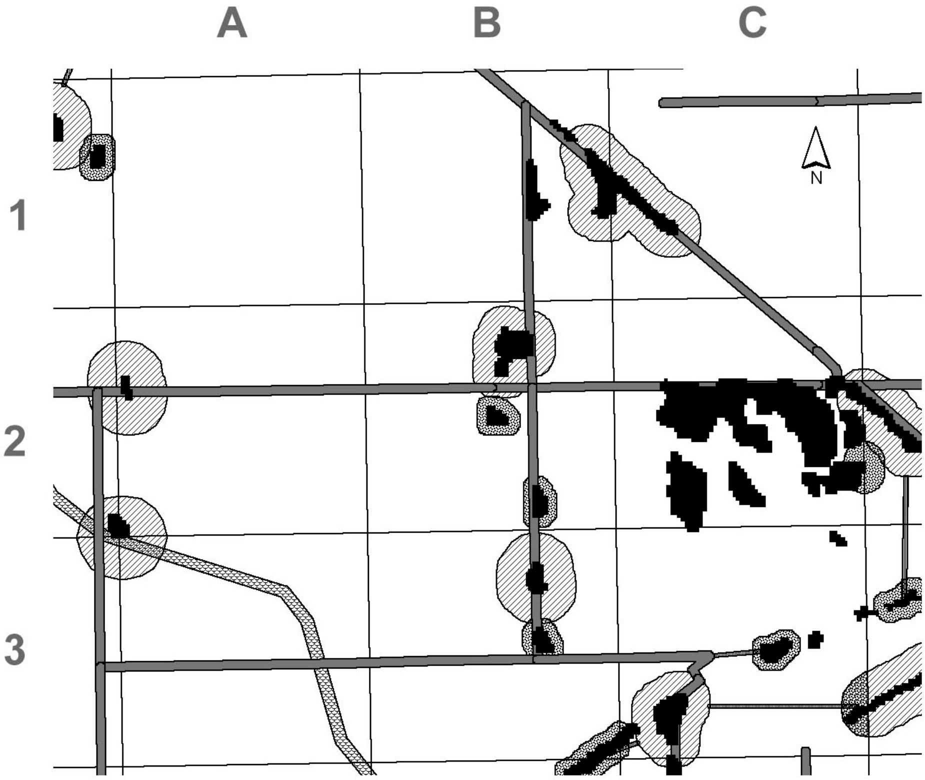

Figure 2 A small section of the Goulburn Broken Catchment (Riverina Bioregion) showing existing vegetation and the 'vegetation' added by each of the six rules. For an explanation of the rules see text.

Rule 1, the buffering of remnants to 40 ha, resulted in an increase in the number of large remnants across the catchment, but not all landscape units could be modelled to include at least one 40 ha remnant. This was because some landscape units did not contain extant vegetation (at the scale of 1 : 100 000) (e.g. A1, Figure 2). The number of 40 ha remnants created varied between bioregions in the catchment. For example, in the Victorian Alps no 40 ha remnants were created because all landscape units contained large blocks of vegetation. In the Riverina Plains, by contrast, many landscape units contained no remnants and so no buffering occurred. In the 5839 landscape units in the Goulburn Broken Catchment, 2111 'extra' 40 ha remnants were created (36% of cells, 1 : 100 000 map grid).

Not all landscape units had two remnants buffered to 10 ha (Rule 3) (e.g. A2, Figure 2). This occurred when there were no remnants to buffer (e.g. A1, Figure 2), when there was only one existing remnant (and so was buffered to 40 ha) (e.g. A2 Figure 2) or when there was only one remnant to buffer (e.g. B3, Figure 2). Similarly, for the 10 ha remnants there were often no existing remnants to buffer or large areas of vegetation were present, or there was only one remnant to buffer. In the entire Goulburn Broken Catchment 2160 ten-hectare remnants were created, a success rate of 32% of landscape units.

Rule 2 aimed to link each 40 ha remnant with other remnants using a 40 m corridor. Corridors were often not created because the remnants were along existing roadsides and streams and so a ‘new’ corridor was not necessary.

Secondary and tertiary roads were buffered to 40 m either side (e.g. A2, Figure 2). Not all landscape units contained buffered roads (e.g. A1, Figure 2). Streams were buffered to 50 m either side (e.g. A3, Figure 2).

Vegetation extent

Vegetation extent increased after the rules were modelled for all bioregions, but the relative increases varied between bioregions. The bioregions with the least extant vegetation displayed the greatest change in vegetation extent after the rules had been modelled. The Central Victorian Uplands increased by one third (from 21% to 31%), as did the Goldfields (from 29% to 39%), and for the Northern Inland Slopes, vegetation cover doubled (from 9% to 21%) and tripled for the Victorian Riverina (from 7% to 21%). In contrast there was little difference in vegetation coverage between pre-and post-rule models for the bioregions that had high percentages of existing vegetation cover (Highlands – Northern Fall, Highlands – Southern Fall, and Victorian Alps).

When the finer scale of EVCs within bioregions is examined, the preferential clearing of particular EVCs is evident. For example within the fertile Riverina 53 of the 70 EVCs (76%) have less than 15% vegetation cover. This compares to the Victorian Alps and Highlands Southern Fall, where no EVCs have been depleted below 15%. The Northern Inland Slopes, Goldfields and Central Victorian Uplands have also been largely and selectively cleared, with over 65% of EVCs having less than 15% cover. After the rules were modelled there was a marked reduction in the number of EVCs with less than 15% vegetation coverage in each bioregion within the Goulburn Broken Catchment. All EVCs increased in coverage, including several EVCs that are now considered to be extinct.

However, some EVCs had less than 15% vegetation cover after the rules were modelled (e.g. 13 EVCs within the Victorian Riverina) (Table 1). It can be seen that, while not reaching 15%, there were substantial increases to each EVC after the rules were modelled. Many of the EVCs that remained with less than 15% cover were complexes or mosaics (Table 1). At this stage, these types of EVCs are not represented accurately and are ill-defined.

Discussion

This project employed a literature-based approach to develop a set of rules with the aim of progressing towards the conservation of the majority of species within the Goulburn Broken Catchment. The rules built on the existing pattern of vegetation resulting in a model that increased the integrity and habitat value of existing remnants. The cover of most endangered and vulnerable Ecological Vegetation Communities (EVCs) were increased to at least 15% of their pre-European cover, however there were a few exceptions and further work is required to address this deficiency. The connectivity of landscapes was improved through the creation of ‘stepping stones’ and corridors through enhancement of existing remnants and corridors (roadsides and waterways). The rules were based upon generally accepted scientific principles and robust scientific studies collected over a range of ecosystems, the resultant model is likely to identify elements that need to be present in a landscape to conserve the majority of species.

Table 1 Ecological vegetation classes with less than 15% vegetation cover after the general enhancement rules were modelled, for each bioregion in the Goulburn Broken Catchment.

Bioregion and EVC	**% coverage pre rules**	**% coverage post rules**
Central Victorian Uplands		
Grassy Woodland	2.2	11.2
Grassy Woodland / Valley Grassy Forest Complex	0.05	9.0
Plains Grassy Woodland	0.9	11.6
Riverine Escarpment Scrub	0.9	11.7
Unclassified Foothill Forest	2.9	8.9
Goldfields		
Damp Sands Herb-rich Woodland	0	13.6
Low-rises Grassy Woodland/Alluvial Terraces Herb-rich Woodland Mosaic	3.7	12.1
Plains Grassy Woodland/Plains Grassland/Plains Grassy Wetland Mosaic	0.4	14.5
Riverina Plains Grassy Woodland/Plains Grassland/Gilgai Wetland Mosaic	0.2	8.2
Sedge-rich Woodland	0.3	1.0
Shrubby Granitic-outwash Grassy Woodland/Plains Grassy Woodland Complex	2.4	10.6
Valley Grass Forest/Creekline Grassy Woodland Mosaic	4.1	8.7
Valley Grassy Forest/Plains Grassy Woodland Complex	0.4	14.0
Highlands – Northern Fall		
Granitic Hills Woodland/Rocky Outcrop Shrubland-Herbland Mosaic	6.4	6.4
Plains Grassy Woodland	1.9	12.8
Northern Inland Slopes		
Alluvial Terraces Herb-rich Woodland	0.7	9.8
Cane Grass Wetland Complex	0	7.7
Grassy Woodland	1.7	13.8
Plains Grassy Woodland	0.6	13.4
Plains Grassy Woodland/Gilgai Plain Woodland/Wetland Mosaic	0.05	10.8
Victorian Riverina		
Alluvial Terraces Herb-rich Woodland/Creekline Grassy Woodland Mosaic	0.9	3.6
Alluvial Terraces Herb-rich Woodland/Plains Grassy	1.6	13.2
Brackish Lakes Mosaic	0.04	6.8
Cane Grass Wetland Complex	0	6.0
Granitic Hills Woodland/Rocky Outcrop Shrubland-Herbland Mosaic	0	7.8
Low-rises Grassy Woodland / Alluvial Terraces Herb-rich Woodland Complex	3.8	14.7
Low-rises Grassy Woodland/Alluvial Terraces Herb-rich Woodland Mosaic	3.1	9.4
Plains Grassland	0.3	12.8
Plains Grassy Woodland/Creekline Grassy Woodland Mosaic	0	11.0
Plains Grassy Woodland/Gilgai Wetland Mosaic	2.3	6.8
Riverina Plains Grassy Woodland/Plains Grassland/Gilgai Wetland Mosaic	0.03	6.8
Riverine Grassy Woodland/Riverina Plains Grassy Woodland Complex	1.4	6.0
Wetland Formation	6.0	11.6

The large scale of the project resulted in a vision for how future planning for the catchment might occur. It was not meant to be prescriptive, but rather be a tool for discussion and assessment for planning land use change, along with other considerations. For example, the ‘biodiversity layer’ produced here can be overlain with revegetation activities in areas that control salinity, and overlapping areas could be targeted. In turn, the economic cost of changes to land use can be assessed (e.g. the number of hectares that need to be revegetated or length of fencing). This is the future work of the Catchment Analysis Tool.

The majority of EVCs were increased to the target of 15% in each bioregion. However, some EVCs remained below this target, and further planning is required to address this deficit. Although EVCs are based upon floristic elements, they may also be useful surrogates for the distribution of fauna (MacNally et al. 2002). This makes them efficient tools for assessing likely biodiversity outcomes. An increase in the vegetation cover of all EVCs is likely to be a positive step towards the conservation of biodiversity.

Geographic information system: benefits and limitations

GIS (Arcview) is a powerful tool that was used to display, query and manipulate spatially explicit data. It allowed rapid modelling and assessment of the rules.

Further data layers would add value to the modelling process. Although existing data layers were useful in providing a basis for a land use change scenario, there were some limitations. The tree cover layer was limited to a tree density greater than 10%. This ignores other important biodiversity elements, such as native grasses and woodlands that have a tree density less than 10%. However, in the list of EVCs that did not reach 15% vegetation cover (Table 1) all EVCs increased greatly in cover, including grasslands and grassy woodlands. Another limitation was that land uses surrounding remnants are not currently mapped. This would be an important layer to incorporate into any model, as the surrounding land uses are critical for species richness. The surrounding land use also affects the ability to assess the likely cost and time involved in revegetation activities. For example, revegetation is likely to be cheaper and more effective in native pasture where natural regeneration can occur, compared to cropped land where large amounts of time and money would be required to begin revegetation. The quality of existing remnants, which would also be important in the selection of remnants to buffer, is also not known.

Project applications

Overlaying biodiversity rules with other models

This project was devised to be incorporated into the Catchment Analysis Tool to assess the effects of revegetating landscapes for the conservation of biodiversity on hydrological outcomes. The CAT is currently being prepared.

Assessment of landscape change

The output map of vegetation extent after the rules were modelled can be assessed at any scale, from whole-of-catchment to individual farms. This has benefits at each scale. First, vegetation targets for the catchment, bioregions and EVCs can be readily assessed. Mapping at finer resolutions can be used as a tool to begin discussions with stakeholders about visions for landscape change.

Project limitations

The limitations of this project need to be recognised. First, it is unlikely that ‘one size fits all’. For example, there may be some regions where 40 m corridors are not wide enough to mitigate threatening processes. In other regions, or for some species, narrower corridors or stepping stones may be sufficient. This type of detail can be determined when examining the data layers at smaller scales, such as regions or landscapes. The model’s general principles can be adapted to smaller-scale landscapes. For example, there may be waterways which this modelling did not capture, but the 50 metre rule could still be applied to the targeted waterway.

The 40 ha threshold for remnant size does not consider the habitat requirements of all species. Some species require remnants greater than 40 ha to survive (e.g. Hooded Robins require 100 ha blocks) (Freudenberger 1999). Larger blocks (>40 ha) of revegetation should also be considered in revegetation projects.

The configuration of remnants within a landscape was not explicit in the rules because of the lack of data. However this is an important aspect in the conservation of biodiversity. There was some consideration of landscape configuration in the preferential selection of remnants near streams. The rules do not consider other aspects of landscape pattern, such as surrounding land use and distance to other remnants.

There were no data available that could distinguish habitat quality. A surrogate measure of habitat quality was applied by selecting the largest remnants for enhancement (buffering). These remnants are more likely to contain a diversity of habitat elements, or at least have the potential to do so. In addition, larger remnants require less revegetation to reach targets of 10 ha and 40 ha, so revegetation is more likely to be achievable than for smaller remnants. The first imperative of conservation is to conserve existing remnants, and this was the basis for the rules.

While a catchment-scale approach to planning for the conservation of biodiversity is useful, there is also a need to recognise that ecological processes operate at several spatial and temporal scales. For example, for some reptiles, amphibians and invertebrates, species abundance and richness can be related more to microhabitat features than to remnant size (Hadden and Westbrooke 1996). Additionally, the movement of animals can occur at the micro level (e.g. centipedes foraging among leaf litter) and at the global level (e.g. migratory birds flying from Siberia to Victoria). Monitoring ecological processes and particular faunal groups at finer and coarser scales must necessarily be considered for biodiversity outcomes to be achieved.

This project was useful in identifying gaps in our knowledge about how best to revegetate landscapes to conserve the majority of species. Several questions arise:

- How many large blocks (40 ha or larger) are required in a given landscape unit to conserve biodiversity and ecosystem functioning?
- What landscape configuration best conserves the majority of species for the least habitat area? For example, does a series of small, linked blocks have the same effect as one large block?
- Is there a minimum width for corridors? Is there a threshold width for which corridors do not provide enough resources for dispersing animals to allow them to move through the landscape? Is there a 'best width' for corridors that can be applied to different landscapes?
- Is there a minimum length for corridors before they become too long and 'edgy'?
- When are stepping stones rather than continuous links of vegetation more appropriate — for example, to mitigate the possible detrimental effects of corridors, such as acting as weed or fire conduits?
- How wide is an effective buffer around existing remnants, roadsides and streams to reduce edge effects? Is this width appropriate for different landscape elements?

Future applications

Future work will include generating a range of land use change scenarios based on the rules given here. For example, the number of remnants to be enhanced (buffered) can be reduced or increased in each landscape unit. Similarly, streamside and roadside buffers can be increased or decreased to provide a range of scenarios. It is envisaged that alternative scenarios will result in vegetation extents of at least 10%, 20% and 30% for bioregions within catchments.

A range of scenarios will be assessed using the Catchment Analysis Tool (CAT) to ensure the efficient and effective use of funds for implementing land use change. Because a range of options and benefits can be assessed, this is more likely to result in positive outcomes that are accepted by a wide range of stakeholders.

Conclusions

Biophysical modelling at large scales should result in more strategic revegetation activities. There is a need to move away from *ad hoc* revegetation projects that are unlikely to meet objectives (e.g. biodiversity conservation and salinity control). Computers enable rapid modelling and assessment of land use change scenarios. The use of models to plan and assess land use change scenarios, coupled with on-ground revegetation activities to validate predicted outcomes, would result in better planning for the conservation of biodiversity.

Although we do not have all the answers about the best ways in which to conserve biodiversity and restore ecosystem functions, uncertainty is not an excuse for inaction. What we do know is that, given current vegetation extent and connectivity, we will lose many species if we do not begin to reverse habitat loss and fragmentation.

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References

Arnold, G.W., Steven, D. W., Weeldenburg, J.R. and Smith, E.A. (1993) Influences of remnant size, spacing pattern and connectivity on population boundaries and demography in Euros *Macropus robustus* living in a fragmented landscape. *Biological Conservation* **64**: 219–230.

Barrett, S. (2000) *Birds on Farms — Ecological Management for Agricultural Sustainability*. Birds Australia, Melbourne.

Bennett, A.F. (1987) Conservation of mammals within a fragmented forest environment: the contributions of insular biogeography and autoecology. **In** Saunders, D.A., Arnold, G.W., Burbidge, A.A. and Hopkins, A.J.M. (eds) *Nature Conservation: The Role of Remnants of Native Vegetation.* Surrey Beatty & Sons: Chipping Norton, NSW (pp 41–52).

Bennett, A.F. (1990) Land use, forest fragmentation and the mammalian fauna at Naringal, south-western Victoria. *Australian Wildlife Research* **17**: 325–347.

Bennett, A.F. (1991) Roads, roadsides and wildlife conservation; a review. **In** Saunders, D.A. and Hobbs, R.J. (eds) *Nature Conservation 2: The Role of Corridors.* Surrey Beatty & Sons, Chipping Norton: NSW (pp 99–118).

Bennett, A.F. (1999) *Linkages in the Landscape. The Role of Corridors and Connectivity in Wildlife Conservation.* IUCN: Gland, Switzerland.

Bennett A. F. and Ford L.A. (1997) Land use, habitat change and the conservation of birds in fragmented rural environments: a landscape perspective from the Northern Plains, Victoria, Australia. *Pacific Conservation Biology* **3**: 244–261.

Bennett, A. F. and van der Ree, R. (2001). Roadside vegetation in Australia: conservation values and function of a linear habitat network in rural environments. Proceedings of the International Association of Landscape Ecology Conference: UK.

Bennett, A., Kimber, S. and Ryan, P. (2000) *Revegetation and Wildlife. A Guide to Enhancing Revegetated Habitats for Wildlife Conservation in Rural Environments.* Bushcare National Research and Development Program: Melbourne.

Berwick, S. (2001) The Goulburn Broken Catchment and its vegetation types. **In** Earl, G., Stelling, F. Titcumb, M. and Berwick, S. (eds) *Revegetation Guide for the Goulburn Broken Catchment* Department of Natural Resources and Environment: Melbourne (pp 5–15).

Caughley, J. and Gall, B. (1985) Relevance of zoogeographical transition to conservation of fauna: amphibians and reptiles in the south-western slopes of New South Wales. *Australian Zoologist* **21**: 513–529.

Deacon, J.N. and MacNally, R. (1998) Local extinction and nestedness of small-mammal faunas in fragmented forest of central Victoria, Australia. *Pacific Conservation Biology* **4**: 122–131.

Downes, S.J., Handasyde, K.A. and Elgar, M.A. (1997) The use of corridors by mammals in fragmeneted Australian eucalypt forests. *Conservation Biology* **11**: 718–726.

Forman, R.T.T. (1995) *Land Mosaics: The Ecology of Landscapes and Regions.* Cambridge University Press: Cambridge, UK.

Freudenberger, D. (1999). *Guidelines for Enhancing Grassy Woodlands for the Vegetation Investment Project.* Greening Australia, Canberra.

Garnett, S.T. and Crowley, G.M. (2000) *The Action Plan for Australian Birds.* Commonwealth of Australia: Canberra.

GBCMA (2000). *Goulburn Broken Native Vegetation Plan.* Goulburn Broken Catchment Management Authority: Shepparton.

Gilpin, M.E. and Hanski, I. (1991) *Metapopulation Dynamics: Empirical and Theoretical Investigations.* Academic Press: London.

Hadden, S.A. and Westbrooke, M.E. (1996) Habitat relationships of the herpetofauna of remnant buloke woodlands of the Wimmera Plains, Victoria. *Wildlife Research* **23**: 363–372.

Hargis, C.D., Bissionette, J.A. and David, J.L. (1998) The behaviour of landscape metrics commonly used in the study of habitat fragmentation. *Landscape Ecology* **13**: 176–186.

Honeyman, R. (1997) Corporate Geospatial Data Library. Department of Natural Resources and Environment: East Melbourne (unpublished).

Howe, R.W. (1984) Local dynamics of bird assemblages in small forest habitat islands in Australia and North America. *Ecology* **65**: 1585–1601.

Kitchener, D.J., Dell, J. Muir, B.G. and Palmer, M.J. (1982) Birds in Western Australian wheatbelt reserves — implications for conservation. *Biological Conservation* **22**: 127–163.

Knopf, F.L. and Sampson, F.B. (1994) Scale perspectives on avian diversity in western riparian ecosystems. *Conservation Biology* **8**: 669–676.

Leck, C.F. (1979) Avian extinctions in an isolated tropical wet-forest preserve, Ecuador. *Auk* 96: 343–352.

Loyn, R.H. (1987) Effects of patch area and habitat on bird abundance, species numbers and tree health in fragmented Victorian forests. **In** Saunders, D.A., Arnold, G.W., Burbidge, A.A. and Hopkins, A.J.M. (eds) *Nature Conservation: The Role of Remnants of Native Vegetation.* Surrey Beatty & Sons: Chipping Norton, NSW (pp 65–77).

Lynch, J.F. and Saunders, D.A. (1991). Responses of bird species to habitat fragmentation in the wheatlbelt of Western Australia: interiors, edges and corridors. **In** D.A. and Hobbs, R.J. (eds) *Nature Conservation 2: The Role of Corridors.* Surrey Beatty & Sons: Chipping Norton, NSW (pp 143–158).

MacNally, R. (1999) Habitat fragmentation and habitat loss: secondary, cascading effects and predictability. *Australian Biology* **12**: 138–151.

MacNally, R. and Horrocks, G. (2002). Proportionate spatial sampling and equal-time sampling of mobile animals: A dilemma for inferring areal dependence. *Austral Ecology* **27**: 405–415.

MacNally, R., Bennett, A.F., Brown, G.W., Lumsden, L.F., Yen, A., Hinkley, S., Lillywhite, P. and Ward, D. (2002). How well do ecosystem-based planning units represent different components of biodiversity? *Ecological Applications* **12**(3): 900–912.

Mann, S. and Davidson, I. (1993) The Mollyullah to Glenrowan District Regent Honeyeater Project. Preliminary Report for the Department of Conservation and Natural Resources. Department of Natural Resources and Environment: Benalla.

Margules, C.R. and Pressey, R.L. (2000). Systematic conservation planning. *Nature* **405**: 243–253.

Muir, A., Edwards, S. and Dickins, J. (1995) Description and conservation status of the vegetation of the box–ironbark ecosystem in Victoria. Arthur Rylah Institute for Enviornmental Research Flora and Fauna Report No. 136. Department of Conservation and Natural Resources, Melbourne.

NRE (1997) Victoria's Biodiversity: Directions in Management. Department of Natural Resources and Environment Melbourne.

NRE (2000) *Restoring our Catchments. Victoria's Draft Native Vegetation Management Framework.* Department of Natural Resources and Environment: East Melbourne.

NRE (2002) *Victoria's Native Vegetation Management: A Framework for Action.* Department of Natural Resources and Environment: East Melbourne.

Platt, S.J. and Lowe, K.W. (2002) *Biodiversity Action Planning: Action Planning for Native Biodiversity At Multiple Scales – Catchment, Bioregional, Landscape, Local.* Department of Natural Resources and Environment, Melbourne.

Reid, J.R.W. (2000) Threatened And Declining Bird in The New South Wales Sheep-Wheat Belt: II Landscape Relationships - Modelling Bird Atlas Data Against Vegetation Cover. CSIRO Sustainable Ecosystems, Canberra.

Recher, H.F. and Serventy, D.L. (1991) Long-term changes in the relative abundance of birds in Kings Park, Perth, Western Australia. Conservation Biology **5**: 90–102.

Robinson, D. (1998) Lowering the goals? Habitat requirements of vertebrates and other wildlife groups in Victoria's Northern Plains and how well they match up. **In** *Down to Grass Roots: Proceedings of a Conference on Management of Grassy Ecosystems.* Victoria University: St Albans.

Robinson, D. and Traill, B.J. (1996) *Conserving Woodland Birds in the Wheat and Sheep Belts of Southern Australia.* RAOU: Melbourne.

Saunders, D.A. (1989) Changes in the avifauna of a region, district and remnant as a result of fragmentation of native vegetation: the wheatbelt of Western Australia. A case study. *Biological Conservation* **50**: 99–135.

Saunders, D.A. (1996) Does our lack of vision threaten the viability of the reconstruction of disturbed ecosystems? *Pacific Conservation Biology* **2**: 321–326.

Saunders, D.A., Hobbs, R.J. and Margules, C.R. (1991) Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* **5**: 18–32.

Saunders, D.A. and Hobbs, R.J. (1995) Habitat reconstruction: the revegetation imperative. **In** Bradstock, R.A., Auld, T.D., Kingsford, D.A.K., Lunney, R.T. and Siverston, D. (eds) *Conserving Biodiversity: Threats and Solutions.* Surrey Beatty & Sons: Chipping Norton, NSW (pp 104–112).

Taws, N. (2001). *Bringing Birds Back.* Greening Australia: Canberra.

Wilson, A. and Lindenmayer, D.B. (1995) *Wildlife Corridors and the Conservation of Biodiversity: A Review.* Greening Australia: Canberra.

Woinarski, J.C.Z., Whitehead, P.J., Bowman, D.J.M. and Russell-Smith, J. (1992). Conservation of mobile species in a variable environment: the problem of reserve design in the Northern Territory, Australia. *Global Ecology and Biogeography Letters* **2**: 1–10.

Yates, C.J. and Hobbs, R.J. (1997) Temperate Eucalypt woodlands: a review of their status, processes threatening their persistence and techniques for restoration. *Australian Journal of Botany* **45**: 949–973.