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Abstract

Human impacts on the natural environment have resulted in a steady decline in biodiversity and associated ecosystem services. A major policy and management challenge is to efficiently allocate limited resources for nature conservation to maximize biodiversity benefits. Spatial assessment and mapping of biodiversity value plays a vital role in identifying key areas for conservation and establishing conservation priorities. This study measured biodiversity value using readily available data and tools in order to identify conservation priority sites in a heavily modified and fragmented production landscape. The study also assessed trade-offs among biodiversity and other ecosystem services. We used spatial tools for assessing and mapping biodiversity such as Patch Analyst in ArcGIS 10.2 to assess landscape alteration states, and the Integrated Valuation of Ecosystem Services and Tradeoffs to identify habitat quality. Results indicated that areas of high biodiversity conservation value were concentrated in less modified land-cover types. Substantially modified land-cover types (generally associated with agriculture and irrigated pastures) had lower habitat quality and biodiversity value. The analysis revealed that assessments based solely on habitat condition may not be the most suitable basis for conservation planning because this does not include associated adjacent land uses, roads or other threats to biodiversity. Spatially targeted environmental plantings and less intensive agroforestry that reconnect native remnants in heavily fragmented landscapes can provide significant potential conservation outcomes. Planned landscape reconfiguration based on readily available spatial data can yield net positive benefits to biodiversity by halting degradation of remnant native vegetation and increasing total habitat area.

Keywords: Land-use change, ecosystem services, spatial approach, biodiversity, Australia

1. Introduction

In recent years, the importance of biodiversity to global economies, human welfare and survival has been well documented and widely recognised (Butchart et al., 2010; Duffy, 2009; Rands et al., 2010; Steffen et al., 2009; TEEB, 2009). In Australia, biodiversity continues to decline in spite of Federal and state government efforts to manage threats (Bennett, 2003; DSE, 2010; NRMC, 2010; OECD, 2008; SoE, 2011; Steffen et al., 2009) with similar trends globally (Butchart et al., 2010; CBD, 2010; MEA, 2005; Steffen et al., 2009). Moreover, Australia has suffered the largest documented extinction of species of any continent over the last 200 years (DSEWPC, 2011). The main identified threats to biodiversity in Australia include loss, fragmentation and degradation of habitat or natural ecosystems, spread of invasive species, unsustainable use of natural resources, inappropriate fire regimes, and climate change (Bennett, 2003; NRMC, 2010; Steffen et al., 2009).

With significant expansion in production landscapes for agricultural activity around the world and a resultant ongoing decline of natural systems (FAO, 2005; World Bank, 2010), there is an increasing focus on the role of production landscapes in conserving biodiversity and providing a variety of ecosystem services (Bélair et al., 2010; Kandziora et al., 2013; Wilson et al., 2010). Securing biodiversity in the production landscape can enhance agricultural productivity through pollination and pest regulation, water quality and nutrient regulation, soil stabilisation, and carbon sequestration (Hopper et al., 2005; Kasel et al., 2011; Scherr and McNeely, 2008; Tscharntke et al., 2005). While there is ongoing debate about the relative merits of integrated versus partitioned conservation activity (Phalan et al., 2011; Tscharntke et al., 2012), conservation policy makers and land managers are giving strong support to conserving biodiversity in highly modified production landscapes (Wilson et al., 2010). Spatial assessment and mapping of conditions suitable for biodiversity conservation or restoration are also essential for the establishment of baseline biological data that will aid successful conservation planning and management in highly modified landscapes (Eigenbrod et al., 2009; Jones-Walters, 2008) and help identify priority sites for allocating limited resources (Brooks et al., 2006; Higgins, 2006).

Extent and quality of habitat conditions are often used as proxies of biodiversity (Nelson et al., 2011; Tallis et al., 2010) and remote sensing based techniques are being increasingly employed to generate biodiversity and ecosystem services indicators (García-Gómez and Maestre 2011; Lück-Vogel et al., 2013; Nagendra et al., 2013; Spanhove et al., 2012). Recent research has focused on linking current land use and vegetation types to biodiversity and associated ecosystem services (Burkhard et al., 2012; Falcucci et al., 2007; Foley et al., 2005; Hector and Bachi, 2007; Kandziora et al., 2013; Yapp et al., 2010). A variety of approaches have been used to identify conservation priority sites within production landscapes, each focused on a different aspect of biodiversity (e.g., Kandziora et al., 2013; Schneiders et al., 2012; Tallis et al., 2010) from global (Brooks et al., 2006; Jongman, 2013) to local scale (Higgins, 2006; Jongman, 2013). Given the imperative for expeditious implementation of conservation solutions (Watts and Handley, 2010), rapid assessment approaches that use readily available data and tools are highly desirable (Baral et al., 2013; Burkhard et al., 2012; Grantham et al., 2008, 2009).

The aim of this study is to spatially characterise a heavily modified and fragmented production landscape and assess biodiversity value using readily available data and tools in order to identify conservation priority sites. An additional aim is to assess the effect of land-use change on the provision of biodiversity and associated ecosystem services. To achieve these objectives we used spatial approaches and tools for biodiversity assessment and mapping such as Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) biodiversity models (Tallis et al., 2010) and patch analyst tool (Rempel et al., 1999, 2012). The resulting data and maps and subsequent analyses are used to consider the opportunities for re-configuring natural vegetation in cleared, modified and degraded landscapes to meet new sustainable landscape management objectives. Furthermore, we comment on the suitability of InVEST tools for habitat quality assessment and conservation planning.

2. Methods

2.1. Study site

The study site is located in north-central Victoria, Australia between Kerang and Lake Boga, approximately 320 km north-west of Melbourne (35.972º S, 143.228º E, Fig. 1). The total area spans about 30,000 ha, essentially defined by the boundaries of the Little Murray and Lower Loddon Rivers in the North, West and South and the Murray Valley Highway in the West. Within the study area lies the Winlaton and Reedy Lakes Future Farming Landscapes (FFL) projects managed by Kilter Pty Ltd. The terrain is generally flat and low-lying (70-80 m above sea level) despite being a considerable distance from the coast. Mean annual rainfall of 50 years average is approximately 370 mm and mean annual temperature ranges from a minimum of 9 ºC to a maximum of 23 ºC.

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Land and water use in the study area are dynamic. Irrigation water entitlements are being bought and sold, and there are ongoing changes in where and how farming takes place, and with people moving from rural properties to regional town centres (NCCMA, 2007). More recently, Kilter Pty Ltd (an asset management group servicing the superannuation sector), has been selecting land in north-central Victoria and managing it under Future Farming Landscapes (FFL), a long-term program that aims to restore landscapes to their most sustainable configurations. Through this program 25% or 7552 ha of the Reedy Lakes and Winlaton study area is currently being reconfigured and managed for both traditional and new income streams including agriculture, forestry, green energy, and water. This potential for future land-use change presented an ideal opportunity to assess the current status of biodiversity and associated ecosystem services provided by each land use-land cover type as a baseline for assessing the implications of future land management options.

The area has been subject to extensive vegetation clearing for agriculture and pastoral production, with native vegetation now highly fragmented and often degraded (NCCMA, 2005). Since European settlement in the mid 1800s, an estimated 70% of native vegetation (18,300 ha) has been cleared. Associated effects of this clearing include widespread declines in biodiversity, increased soil and stream salinity and soil erosion (NCCMA, 2011). Each of these land management problems is of national importance (Steffen et al., 2009) and for this reason this study area is reflective of the challenges affecting many parts of the region. Major land use-land cover types and the proportion of the area occupied by each land use in Reedy Lakes and Winlaton include: (i) irrigated farming, 28%; (ii) dryland cropping, 26%; (iii) native vegetation, 23%; (iv) degraded land undergoing rehabilitation, 10%; (v) water, 10%; and (vi) other, 3%.

Reedy Lakes and Winlaton covers less than 0.2 % of Victoria's land mass; however, it supports a relatively large number of threatened flora (50 species, 2.5% of the total threatened flora for Victoria) and fauna (81 species, 45% of the total threatened species) (DSE, 2008a, b). The high levels of biodiversity, along with the pressures on it, have resulted in Reedy Lakes and Winlaton being identified as an important site for conservation by the Victorian Government (DSE, 2010). Wetlands within the study area support a high diversity and abundance of waterfowl species (Lugg et al., 1989) and some are of international significance, including the 'Kerang Wetlands Ramsar Site' (Fig. 1).

2.2. GIS data, software and analytical tools

A number of datasets were compiled for the study site from a variety of sources and stored in Geographic Information System (GIS) database. Key datasets included: (i) a recent land use map based on the Australian Land Use and Management (ALUM) classification (BRS, 2006) (ii) native vegetation/Ecological Vegetation Classes (EVC) (DSE, 2011), (iii) threatened flora and fauna (DSE 2008a, b), (iv) Land Management Unit (LMU) data (Kilter Pty Ltd, 2011), (v) climate data, and (vi) topographical data such as roads, contours and watercourses. GIS raster datasets, with a land use-land cover code for each cell were produced by collating these datasets into ArcGIS 10.2 from ESRI Inc.

All datasets were projected into UTM54 South using a GDA1994 geographic coordinate system with the raster datasets additionally re-sampled to a common spatial resolution of a 50 m grid.

2.2.1 Patch Analyst tool

For this study, size and distribution of landscape patches were assessed for native vegetation including grasslands using the Patch Analyst extension for ArcGIS 10.2 (Rempel et al., 1999, 2012) and the output used to classify the landscape into alteration classes. The distribution of remnant native vegetation in Reedy Lakes and Winlaton was quantified using spatial metrics such as patch size and connectivity. Remnant native vegetation was categorised into three patch sizes based on area (Michaels et al. 2008): small patches (<10 ha), medium patches (10-50 ha) and large patches (>50 ha). We analysed core area (Rempel et al., 1999) with application of different buffers of 25 m, 50 m, and 100 m following Michaels et al. (2008) and evaluated the number of patches in each of three patch area categories relative to the initial patch analysis.

2.2.2 InVEST tool

The biodiversity model in InVEST tools generates two key sets of information useful in making an initial assessment of conservation needs: the relative extent and habitat quality in a region and its changes across time (Tallis et al., 2010). This tool assumes that large areas with a high habitat quality would support more flora and fauna species and individuals, and the areas that decrease in habitat extent and quality over time would contain reduced levels of biodiversity. More detailed description of input data for InVEST are outlined in Table 1 and a more detailed description of calculating a parcel's habitat-quality and rarity score is outlined by Bai et al. (2011), Leh et al. (2013), Nelson et al. (2011), Polasky et al. (2011), and Tallis et al. (2010).

 # Table 1 approximately here#

2.3. Land cover

For this study we used current land use-land cover types for the InVEST analysis (Tallis et al. 2010; Table 1) and a possible future land use based on proposed land use reconfiguration by the Future Farming Landscapes program to assess the impact of land-use change on biodiversity and various ecosystem services. The planned future land use reconfiguration covers 25% of the study area and includes: (i) irrigated cropping, 37%; (ii) biodiversity and environmental planting, 26%; (iii) grazing, 20%; (iv) perennial horticulture, 9%; and (v) agroforestry, 5%. A large number of native tree species are included under the environmental planting programme including Mallee Eucalypt (*Eucalyptus dumosa*), Black Box (*Eucalyptus largiflorens*), Red Gum (*Eucalyptus camaldulensis*) and a variety of *Acacia* species (Kilter Pty Ltd, 2011).

2.4. Conservation priority sites

Conservation priority sites were identified according to a number of criteria including: (i) extant vegetation types and their bioregional conservation status within the region, (ii) biodiversity goals and resource condition targets of the study region, and (iii) and relative abundance of threatened fauna and flora.

2.5. Land-use changes and impact on biodiversity and associated ecosystem services

Key ecosystem services associated with biodiversity in the study area are listed in Table 2 (DSE 2004, 2010; Parks Victoria, 2000; Steffen et al., 2009). A rapid qualitative assessment of ecosystem services provides an understanding of land use-land cover change and associated impacts on various ecosystem services. For this study we used peer reviewed papers, published reports and expert opinion for qualitative assessment and ranking (Baral et al., *in press,* Bullock et al., 2007, 2011; Cao et al., 2009; Dowson and Smith, 2007; de Groot and van der Meer, 2010; MEA, 2005; Ostle et al., 2009; Shelton et al., 2001;). In addition, feedback from other stakeholders and agencies has also been incorporated.

 # Table 2 approximately here#

To assess the impacts of land use-land cover changes we used three temporal reference points – (i) pre-European condition from modelled historical vegetation data: it was assumed that the study area was intact native vegetation until European settlement and vegetation modification in the early 1850s, (ii) current or intensive agricultural focus: the large proportion of native vegetation converted to agriculture since the 1850s, and (iii) future farming landscape: proposed landscape reconfiguration through the FFL program.

3. Results

3.1. Spatial characterisation of the landscape – Patch Analyst tool

Twenty two percent of the study area (6,800 ha) supported native vegetation. This vegetation was highly fragmented, in more than 4,000 irregularly shaped patches. Of these patches 98.5% were small sized patches (<10 ha), 1.2% were medium sized (10-50 ha) and only 0.3% were large sized (>50 ha). Although there was one large block of approximately 1,800 ha intact native vegetation (Fig. 2), the small sized patches of native vegetation dominated the landscape with mean patch size of 1.8 ha and median patch size of 0.06 ha. Small sized patches of native vegetation were distributed predominantly (82%) on privately owned land subject to agricultural and pastoral land uses. However, 40% of medium and larger patches were located on public land, often within conservation and habitat protection areas. Other metrics associated with native vegetation patch analysis such as, edge, shape and diversity and interspersion metrics are presented in Table 3.

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The extent to which patches are at risk of depletion is dependent on the size of patches and the area of edge. This was assessed by measurement of various sized buffers (25 m, 50 m, and 100 m) around the patch. Increasing buffer size substantially decreased the number of patches of remnant vegetation. For example using a 25 m buffer reduced the number of vegetation patches by more than 50% (4,098 to 1,804) and a 100 m buffer, reduced the number of isolated patches by over 95%.

3.2. Relative habitat quality across the landscape – InVEST tool

The InVEST tool indicated that a very small proportion of the landscape currently provides high habitat quality and associated biodiversity values. Larger vegetation patches usually support greater habitat quality (Fig. 3), although this depended on surrounding land use-land cover and their associated threats. Two wildlife reserves and part of a large water body i.e., Lake Boga are classified as relatively high quality habitats. Interestingly the eastern study area boundary along the Little Murray River shows a higher habitat quality which is due to reduced intensity of threats and larger areas of extant native vegetation.

 # Fig 3 approximately here#

3.3. Conservation priority sites

Based on the North Central CMA's regional biodiversity goals and resource condition target and the bioregional conservation status of remnant native vegetation, the study area is classified into three categories of remnant native vegetation patches – high (44%), moderate (49%) and low (7%). The most cleared and underrepresented EVCs in the study bioregion, and therefore the high priority for conservation or restoration, are Plains Savannah, Plains Woodland, Chenopod Grassland and Semi-arid Chenopod Woodland. Moderate priority sites are represented by various EVCs such as, Lignum Swamp, Lignum Swampy Woodland, and Woorinen Mallee. Other EVCs such as Riverine Chenopod Woodland, Grassy Riverine Swamp and Lake Bed Herbland are reasonably well represented and classified under low priority sites. The sites with recorded threatened fauna and threatened flora are further classified as very high priority conservation sites (Fig. 4).

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3.4. Land-use change and impact on biodiversity and other ecosystem services

A qualitative assessment of past and future land-use changes and their impact on biodiversity and various ecosystem services (Fig. 5), indicates that prior to the 1850s the study area was covered with intact native vegetation that supported biodiversity and supplied a wide range of ecosystem services except agricultural commodities (Fig. 5a). After European settlement the majority of the landscape was cleared (over 70%), resulting in increased agriculture production at the expense of other ecosystem services (Fig. 5b). Under the FFL program the reconfigured landscape includes a combination of biodiversity, agriculture, and grazing (Fig. 5c). The main land-use changes from FFL's planned reconfiguration and associated impacts on a number of ecosystem services (Table 2) is summarised in Table 4 which indicates an overall positive impact on a number of ecosystem services for environmental planting, agroforestry and extensive grazing. However, there is strong trade-off between forage and food production in the case of conversion to agriculture.

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 # Table 4 approximately here#

4. Discussion

This study demonstrates that readily available spatial datasets and tools can be used to assess habitat quality and biodiversity values in human-dominated landscapes and can be useful for initial assessment and conservation planning. Our analysis also indicates that there is a high potential for protecting and enlarging small remnant patches for reducing fragmentation and increasing connectivity and associated biodiversity at the landscape scale.

4.1. Spatial characterisation of the landscape – Patch Analyst tool

Results from native vegetation patch analysis provided a wide range of indices relevant to landscape alteration state and opportunities for reconnecting landscapes for biodiversity enhancement in the study area. Michaels et al. (2008) assessed the level of landscape modification in north-west Tasmania based on the extent and distribution of remnant native vegetation. Similar to this study, their results suggest that conserving small remnants patches and revegetating around them can enhance landscape connectivity by reducing fragmentation at the landscape scale. However, parts of the study area were in a relictual state with limited capacity to be restored (McIntyre and Hobbs, 1999). In many cases, fragmented remnant vegetation may contribute some biodiversity value, including their role as stepping stones for biodiversity to move to larger patches and as dispersal sources (Lindenmayer and Fischer, 2006; Michaels et al., 2008; Rubio and Saura, 2012). Hilty et al. (2006) proposed planting corridors of native vegetation as a solution to habitat fragmentation allowing species to move between isolated fragments. Others have suggested that such appropriately located biodiversity corridors may be important in allowing plant and animal species to migrate due to climate change (Baranyi et al., 2011). Such corridor plantings need to start with the protection and connection of relatively high value biodiversity patches (CEF, 2012). If remnant native vegetation is to be managed sustainably on heavily modified agricultural land, its role in providing other ecosystem services, such as carbon storage or water quality, needs to be assessed, and in turn can support, and provide funding for conservation (CEF, 2012; Crossman et al., 2011; Foley et al., 2005).

4.2. Relative habitat quality across the landscape – InVEST tool

Vegetation condition assessment and mapping has become a major priority for Australian agencies and organizations responsible for natural resource management (Pert et al., 2012). However current approaches used in various Australian states , the ‘habitat hectares approach’ in Victoria (Parkes et al., 2003), ‘biometric approach’ in New South Wales (Gibbons et al., 2008), and ‘bio-condition mapping’ in Queensland (Eyre et al., 2011) focus mainly on vegetation condition with limited consideration of surrounding landscape and potential threats, and may not lead to the best biodiversity conservation decisions. The results of the InVEST tool differ to those of the Victorian government Department of Sustainability of Environment for the same area (Newell et al., 2006), and indicates that a focus solely on vegetation condition without considering surrounding landscape context and potential threats may not lead to the best biodiversity conservation decisions. Patterns in biodiversity habitat quality are inherently spatial and should be analysed in conjunction with the surrounding threats (Paukert et al., 2011) and their relative impact, the sensitivity of habitat to each threat, and distances between the habitats and sources of threats (Pert et al., 2012; Tallis et al., 2010).

Our results indicate that different assessment approaches might yield quite different results, impacting on conservation and restoration investment choices. However, there is a positive relationship between the size of native vegetation patch and habitat quality – that was consistent with many other studies (Fischer et al., 2006; Munro et al., 2007; Newell et al., 2006). This is especially true in fragmented production landscapes where a number of threatening processes surround remnant native vegetation and where smaller patches are more susceptible than larger patches (Munro et al., 2007). To this end, conservation measures should focus on consolidating smaller vegetation patches in to larger blocks. Landscape scale biodiversity assessments need to include the whole mosaic of land cover and land uses, including small fragments or individuals in areas used for pastoral production or agriculture outside patches of native vegetation.

4.3. Conservation priority sites

In recent years, there has been some progress towards biodiversity conservation, with an additional 2,000 ha of habitat improved for biodiversity conservation and the risk of extinction reduced for threatened flora and fauna at priority sites (NCCMA, 2011). However the study area still has a low cover of native vegetation (<30% of pre-European) and is therefore a high priority for protection of remaining EVCs based on the regional biodiversity goal and resource condition targets (NCCMA, 2003, Table S1). The location of biodiversity and associated threats are distributed unevenly therefore it is essential to prioritise the area for conservation to minimise the loss (Brooks et al., 2006; Higgins, 2006). Conservation priority maps generated in this study (Fig. 4) provide an indicative guide to natural resource managers and investors of where to allocate the limited resources available for nature conservation in order to maximize biodiversity benefits (Higgins, 2006). However, distribution of records of threatened fauna and flora are concentrated near water-bodies and accessible sites. This is mainly due to issues surrounding accessibility and the use of water bodies for recreational purposes by those people reporting species occurrences. Consequently, they may present a biased picture of habitat requirements, particularly for fauna.

In areas of high priority sites, conservation organisations can partner with other stakeholders interested in a variety of services to effect outcomes, effectively increasing the resources available for conservation (Goldman et al., 2008) and maximise the return on conservation investment (Underwood et al., 2008).

4.4. Land-use changes and provision of biodiversity and ecosystem services

The relationship between biodiversity values and the provision of ecosystem services has been extensively discussed (Hectar and Bagchi, 2007; Kandziora et al., 2013; Kareiva et al., 2011; Leadely et al., 2010; Turner et al., 2007). Ecosystems functions affected by loss of biodiversity include pollination, seed dispersal, climate regulation, carbon sequestration, and agricultural pest and disease control (MEA, 2005). This is particularly important in this study area, where ecosystem services such as water quality, soil conservation and pollination are economically important. Provision of ecosystem services further justifies conservation and restoration of native vegetation (CEF, 2012; Nelson et al., 2008). Conservation purely for the sake of biodiversity is difficult to justify without first demonstrating direct benefits to human beings (Chen et al., 2010).

Land management has a major impact on biodiversity and the provision of ecosystem services. In many parts of the world, land-use change has altered most of the landscape and resulted in substantial ecological consequences such as decline in biodiversity and ecosystem services (Zhao et al., 2006). Our study landscape has undergone considerable habitat loss and fragmentation in a relatively short history of European occupation. We found that the proposed land-use changes in this study landscape could result in a net positive gain to biodiversity, mainly due to conversion of intensively-managed agriculture and pasture land to environmental plantings, low intensity grazing and agroforestry activities. The InVEST results inferred that smaller, fragmented patches that are exposed to threats are generally of low conservation value. Smaller patches may sustain smaller populations which increases the probability of extinction resulting from environmental and demographic pressures (Fischer and Lindenmayer, 2007). Therefore biodiversity plantings and other revegetation work will be more effective if they are consolidated to existing remnant vegetation patches in order to create larger habitat patches that have a higher probability of being randomly occupied by a given individual or species than smaller patches (Connor and McCoy, 1979). This confirms the view of McIntyre and Hobbs (1999) that relictual landscapes are of lower priority for conservation investments. The data from this study provides a basis for reconfiguring and consolidating the current biodiversity investment program for greater conservation benefits.

Limitations of applying geo-spatial and remote sensing techniques including InVEST tools for biodiversity assessments include the lack of assessment of small-scale characteristics and finer details (Spanhove et al., 2012) and field verification is required in many cases (Hernández-Stefanoni et al., 2011; Lück-Vogel et al. 2013). Furthermore, the value of a patch of habitat for species or ecosystem will depend on size, quality, functional condition, surrounding land uses and suitability for rare or threatened species. While the basic biodiversity model of the InVEST tool takes surrounding land uses into consideration, the habitat value of a patch is limited to its size.

5. Conclusions

Conservation of biodiversity and associated ecosystem services in highly modified and fragmented production landscapes is a crucial natural resource management issue in Australia and elsewhere. Availability of data and appropriate tools are often identified as issues in assessment of biodiversity and ecosystem services. Here we successfully demonstrate spatial approaches to classifying the landscape for habitat quality, based on the size, density, distribution and condition of native remnant vegetation in the landscape scale. Our findings indicate that simple and readily available spatial data, tools and models can be useful for conservation assessment, planning and management and, as observed by Polasky et al.

(2008), higher levels of both biodiversity conservation and the provision of ecosystem services can be achieved by appropriate spatial patterns of restoration activities. Conservation organisations, or catchment management bodies, businesses and individual landowners can use these tools to align their strategies and locate their restoration activities on priority sites to maximize the outcomes of their conservation investment (Kareiva, 2010; Underwood et al., 2008).

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Appendix A Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi [information to be provided]

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Table 1 Input data for InVEST biodiversity model

Data	Description
Current LULC map	A GIS raster dataset with a numeric LULC code for each cell, 1 Native vegetation, 2 Agriculture, 3 Pasture, 4 Water bodies, 5 Built up areas.
Threat data and sources	A table of threats considered for this analysis e.g., agriculture, built up areas and sealed and unsealed roads and GIS raster file of the distribution and intensity of each threat. GIS shape files of polygons with data on the relative degree of proximity to potential threats (roads, built-up areas and agriculture) were used to assess the impact on biodiversity.
Accessibility to sources of degradation	A GIS polygon shape file containing data on the relative protection which provides barriers against threats. Formal conservation areas and protected lands were considered sites with minimum accessibility and were assigned a threat level of 0, while polygons with maximum accessibility (e.g. poorly enforced ownership, extractive reserves) were assigned 1. Polygons under intermediate levels of protection were assigned values between 0 and 1 (Polasky et al., 2011; Tallis et al., 2010).
Sensitivity of habitat types to each threats	A table of LULC types whether or not they are considered habit and for LULC types that are habitat, their specific sensitivity to each threat. Sensitivity values range from 0 to 1 where 0 represents no sensitivity to a threat and 1 represents the greatest sensitivity (Polasky et al., 2011). Sensitivity scores are determined from the literature and expert knowledge (Bai et al., 2010; Polasky et al., 2011; Tallis et al., 2010).
Half-saturation constant	The numeric value indicating the half saturation constant. InVEST model uses a half-saturation curve is used to convert habitat degradation scores to habitat quality scores (Tallis et al., 2010). An inverse relationship between the degradation score and its habitat quality score is determined by this half-saturation constant. The half-saturation constant used was equal to the grid cell degradation score that returns a pixel habitat quality score of 0.5. That is, if the half-saturation constant is 10 then any pixel with a degradation score of 10 will have a habitat quality score of 0.5 (Tallis et al., 2010).

LULC, Land use-land cover

Table 2 Key ecosystem services associated with biodiversity in the Reedy Lakes and Winlaton study area. Letters in brackets represent Millennium Ecosystem Assessment categories: provisioning (P), Regulating (R), Cultural (C) and Supporting (S) services.

Ecosystem services	Description
Forage production (P)	Production of forage for domestic livestock mainly from pasture and grazing land
Water supply (P)	Provision of water for consumptive use, includes both quality and quantity
Carbon stock (R)	Storage of carbon in wood, other biomass and soil
Carbon sequestration (R)	Capture atmospheric carbon dioxide in trees, shrubs and other vegetation
Water regulation (R)	Regulation of hydrological flows by vegetation and microorganisms
Salinity water disposal (R)	Storage of saline water
Flood control (R)	Control of floods
Nutrient regulation (R)	Internal cycling, processing and acquisition of nutrients by vegetation and microorganisms
Pollination (R)	Pollination of wild plant species and harvested crops
Aesthetic beauty (C)	Attractive landscape features helps enjoyments of scenery
Recreation (C)	Travel to natural ecosystems for eco-tourism, outdoor sport etc
Soil protection (S)	Promotes agricultural productivity and the integrity of natural ecosystems
Wildlife habitat (S)	Landscapes capacity to hold naturally functioning ecosystems support a diversity of plants and animal life

Table 3 Summary of native vegetation patch analysis in the Reedy Lakes and Winlaton study area.

Metric	Value
Patch Density and Size Metrics	
Number of Patches	4098
Mean Patch Size (ha)	1.8
Median Patch Size (ha)	0.06
Patch Size Coefficient of Variance	2036.4
Patch Size Standard deviation	35.6
Edge Metrics	
Total Edge (km)	1931
Edge Density	269.4
Mean Patch Edge (m)	471.2
Shape Metrics	
Mean Shape Index	1.4
Area Weighted Mean Shape Index	9.4
Mean Perimeter-Area Ratio	3008.2
Mean Patch Fractional Dimension	1.5
Area Weighted Mean Patch Fractal Dimension	1.4
Diversity and Interspersion Metrics	
Shannon’s Diversity Index	4.0
Shannon’s Evenness Index	0.5

Table 4 Potential effect of land-use change (conversion of irrigated and dryland farming to future land uses under the Future Farming Landscapes program) on various ecosystem services. Qualitative scale based on that used by others (Bullock et al., 2007, 2011; Cao et al., 2009; de Groot and van der Meer, 2010; Dowson and Smith, 2007; MEA, 2005; Ostle et al., 2009; Shelton et al., 2001): '+' positive, '++' strongly positive, '0' neutral or no change, '-' negative, '- -' strongly negative, '?' not known. Letters in brackets represent Millennium Ecosystem Assessment categories: provisioning (P), Regulating (R), Cultural (C) and Supporting (S) services.

	Future Land Use			
Ecosystem Services	Environmental planting (native species)	Agroforestry (exotic species)	Grazing (extensive)	Agriculture (intensive)
Forage production (P)	--	--	+	--
Water supply (P)	--	--	+	0
Food production (P)	0	0	0	++
Wood production (P)	0	++	0	0
Carbon stock (R)	++	++	+	0
Carbon sequestration (R)	++	++	+	0
Water regulation (R)	++	+	+	0
Salinity water disposal(R)	+	+	+	0
Flood control (R)	++	+	+	0
Nutrient regulation (R)	++	+	+	0
Pollination (R)	+	?	+	0
Aesthetic beauty (C)	?	?	?	0
Recreation (C)	+	+	?	0
Soil protection (S)	++	+	+	0
Wildlife habitat (S)	++	+	+	0

Figure Captions

Fig. 1 Location of the Reedy Lakes, Winlaton study area and major land use-land cover types in north central Victoria, Australia.

Fig. 2. Distribution of native vegetation patches in Reedy Lakes and Winlaton according to patch size. Areas currently being converted to biodiversity planting as a part of Future Farming Landscapes are highlighted as are examples of landscape alteration states (a1) intact, (a2) variegated, (a3) fragmented, and (a4) relictual (after McIntyre and Hobbs, 1999), (b) extant native vegetation, (c) pre-European (1750) vegetation distribution (colours represent simplified native vegetation groups, see Table S2).

Fig. 3 The InVEST model of relative habitat quality.

Fig. 4 Conservation priority sites based on bioregional conservation status and north-central regional biodiversity goal and resource condition target, and sites with recorded threatened fauna and flora.

Fig. 5 Typical land-use transition in the Reedy Lakes and Winlaton study area and potential trade-offs among multiple ecosystem services: (a) pre-1850s, (b) 1850s to current, and (c) future landscape under the Future Farming Landscapes (FFL) program. The provision of ecosystem services is applicable to particular transitions and indicative only (figure inspired by Foley et al., 2005).

Fig 1

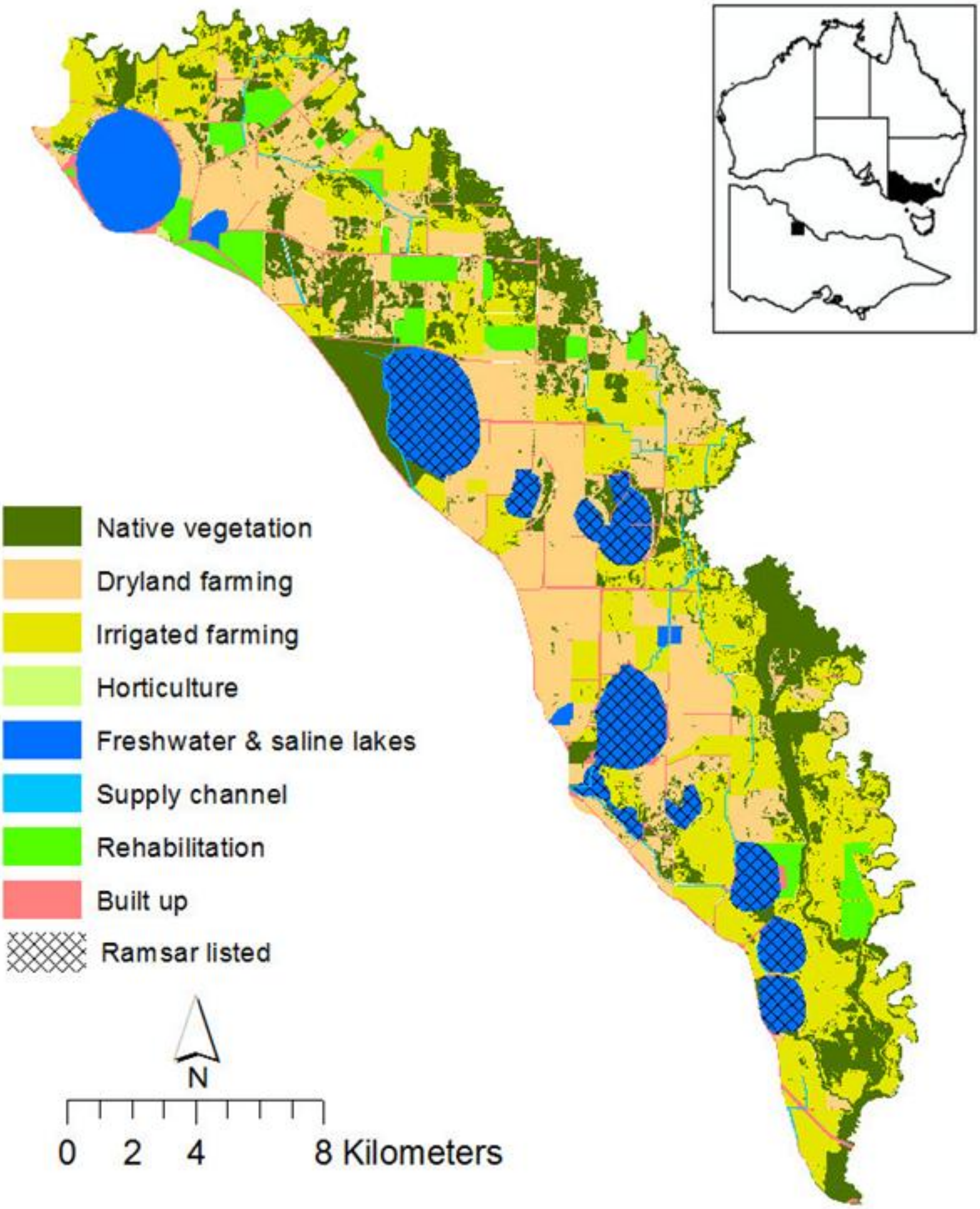

Native vegetation
Dryland farming
Irrigated farming
Horticulture
Freshwater & saline lakes
Supply channel
Rehabilitation
Built up
Ramsar listed
N
0
2
4
8 Kilometers

Fig 2

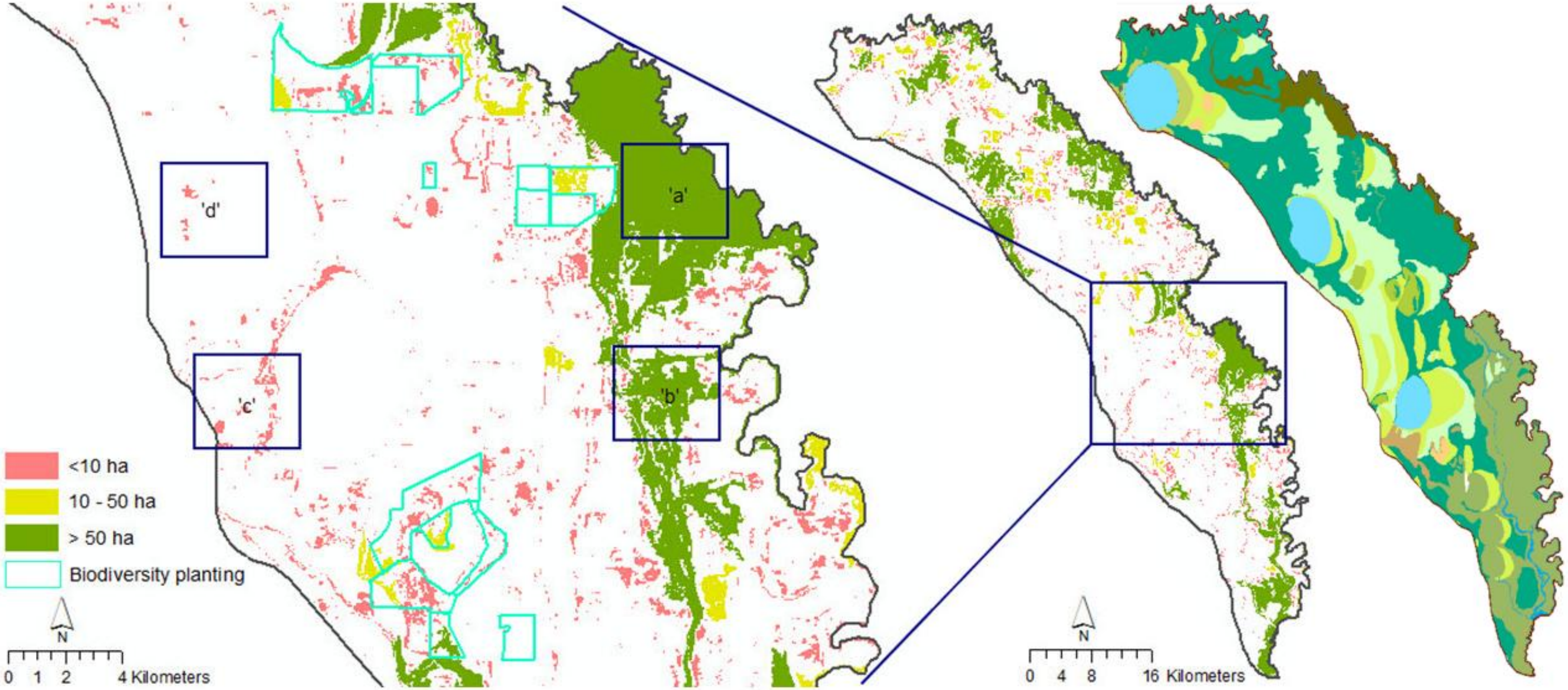

'a'
'b'
'c'
'd'
<10 ha
10 - 50 ha
> 50 ha
Biodiversity planting
N
0 1 2 4 Kilometers
N
0 4 8 16 Kilometers

Fig 3

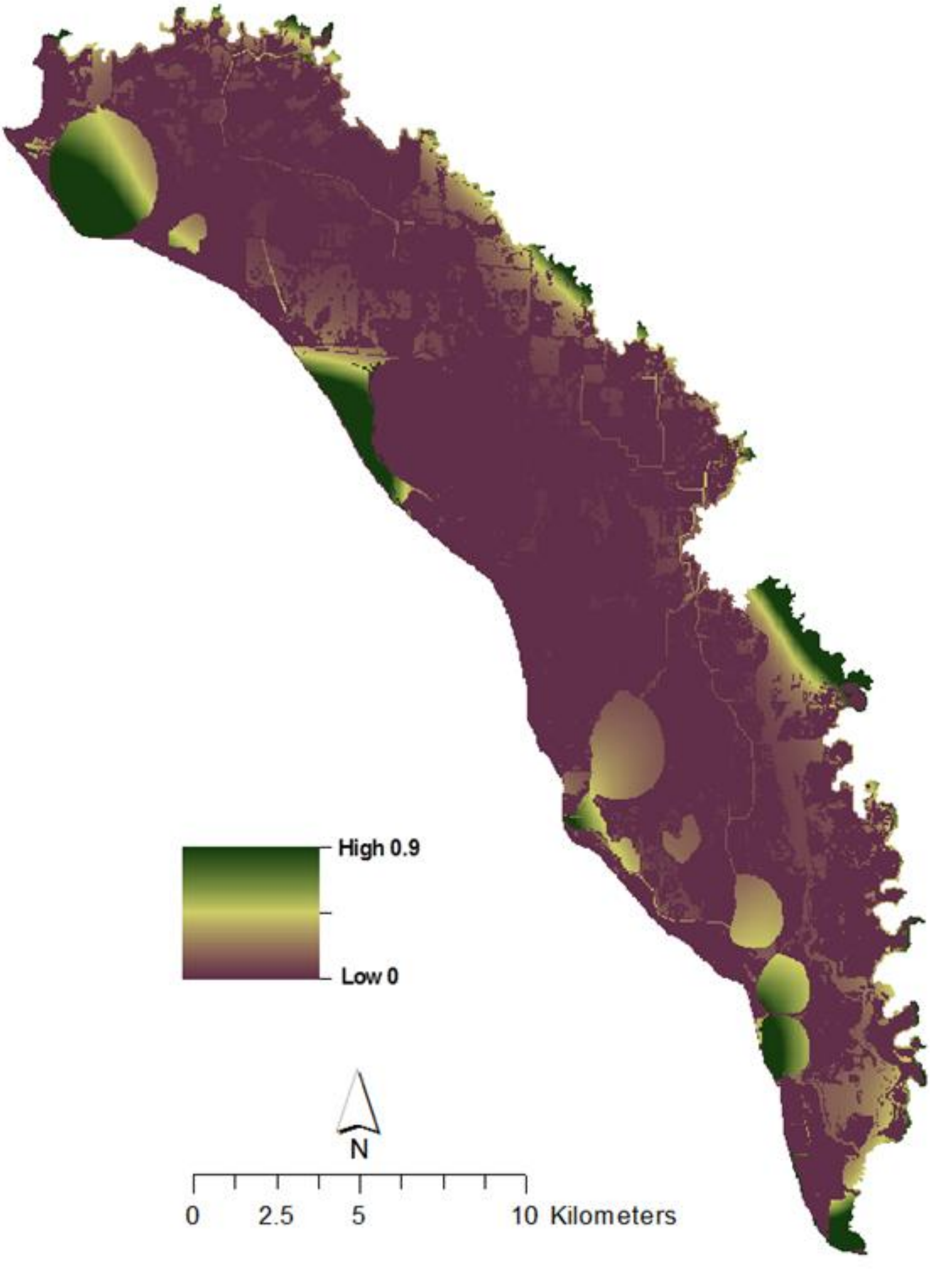


Fig 4

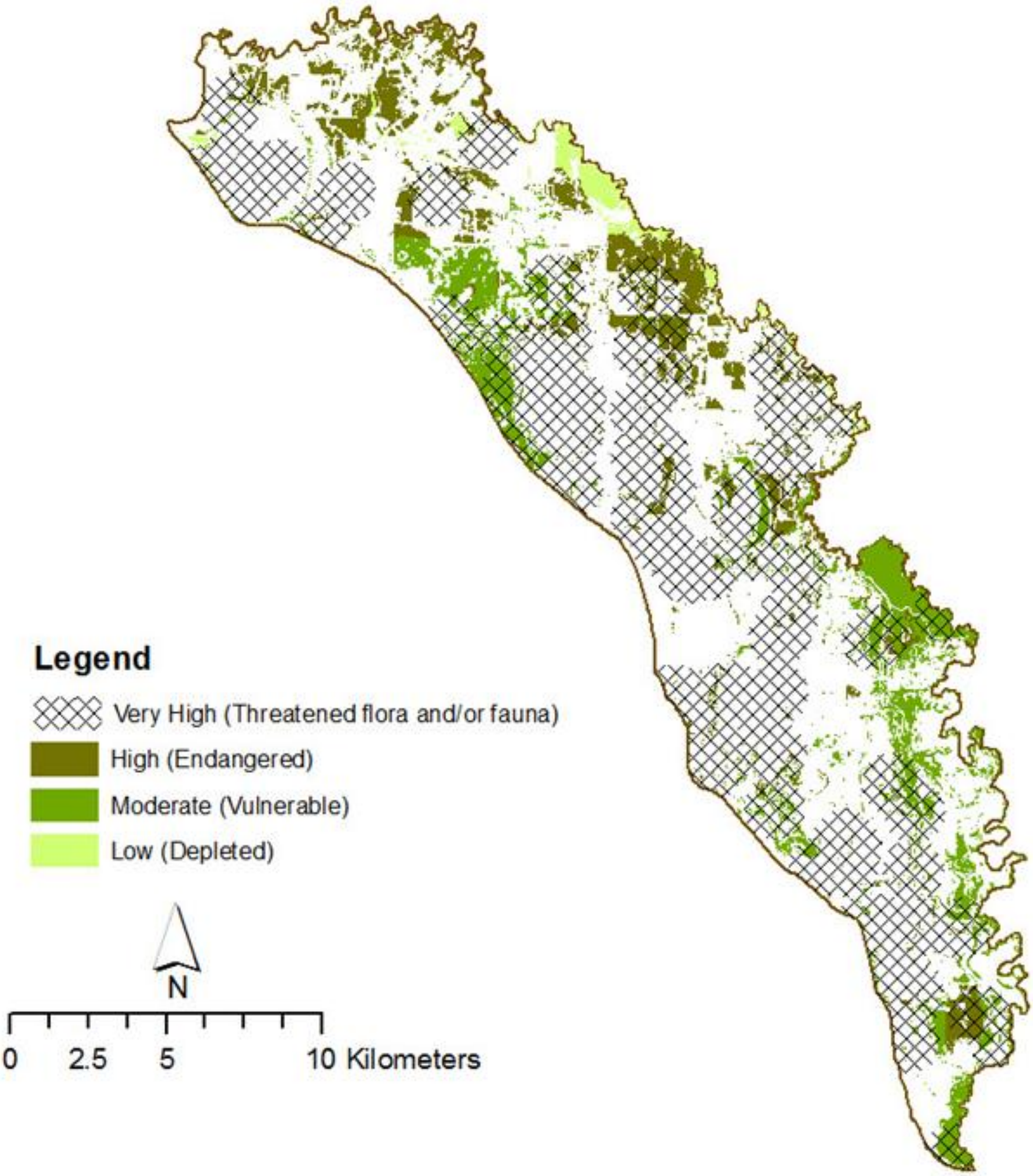
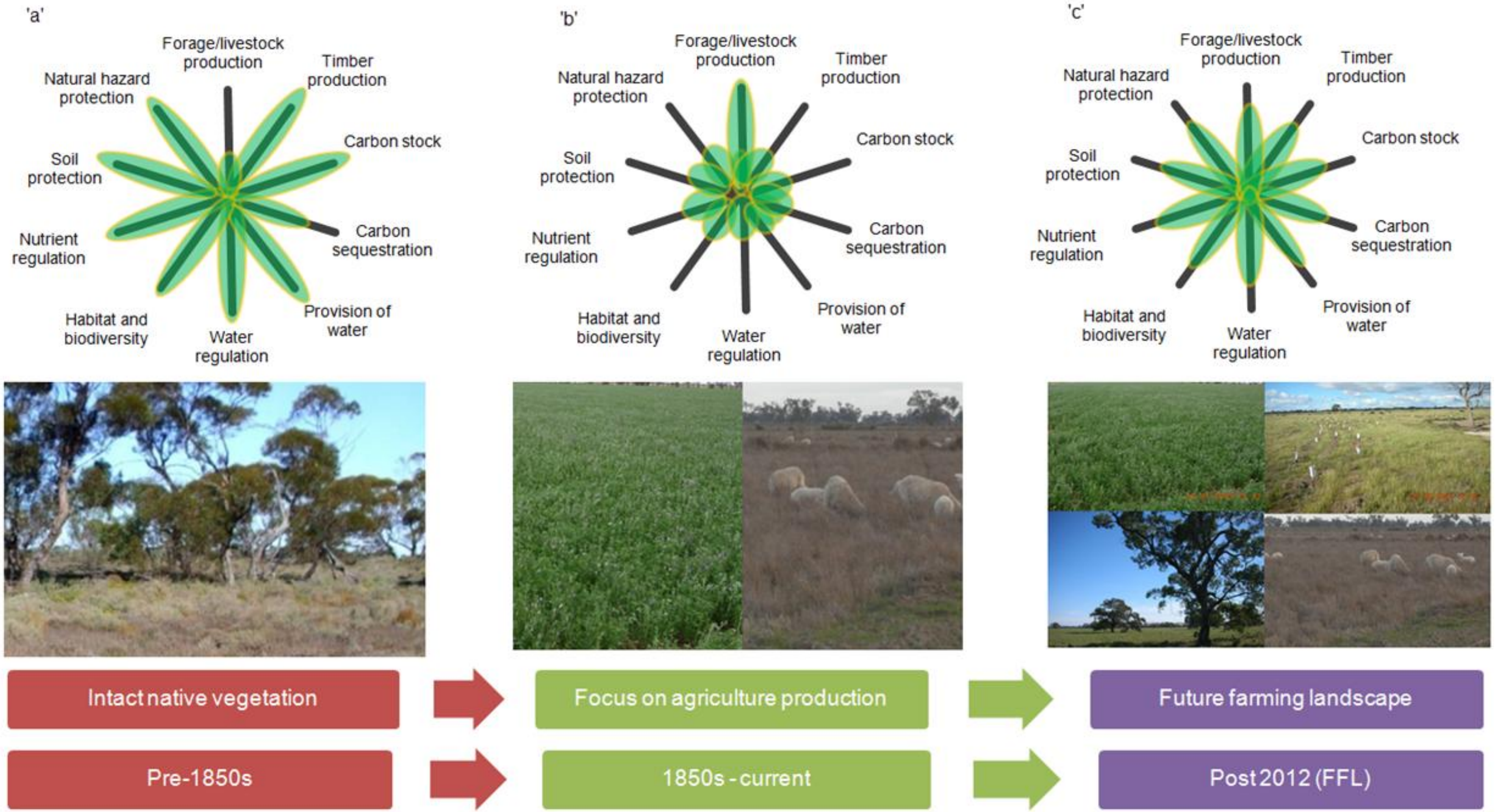

Legend
Very High (Threatened flora and/or fauna)
High (Endangered)
Moderate (Vulnerable)
Low (Depleted)
N
0
2.5
5
10 Kilometers

Fig 5


'a'
Forage/livestock production
Timber production
Natural hazard protection
Carbon stock
Soil protection
Carbon sequestration
Nutrient regulation
Provision of water
Habitat and biodiversity
Water regulation
'b'
Forage/livestock production
Timber production
Natural hazard protection
Carbon stock
Soil protection
Carbon sequestration
Nutrient regulation
Provision of water
Habitat and biodiversity
Water regulation
'c'
Forage/livestock production
Timber production
Natural hazard protection
Carbon stock
Soil protection
Carbon sequestration
Nutrient regulation
Provision of water
Habitat and biodiversity
Water regulation
Intact native vegetation
Focus on agriculture production
Future farming landscape
Pre-1850s
1850s - current
Post 2012 (FFL)

Appendix A

Supporting material for: "Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in north-central Victoria, Australia" by Himlal Baral, Rodney J. Keenan, Sunil K Sharma, Nigel E. Stork and Sabine Kasel

Table S1 Biodiversity goals and resource condition targets of the study region (NCCMA, 2003).

Goal	Resource condition targets
The ecological function of indigenous vegetation communities will be maintained and, where possible native plant and animal species will be restored to viable levels	*Target 1*: Improve the quality and coverage of all vulnerable or endangered Ecological Vegetation Classes and any others with less than 15% (as measured by habitat hectares, Parkes et al., 2003) by 2013
Threatened vegetation communities will increase in extent and improve in quality to achieve net gain by: • increasing the native vegetation cover of the region to 30% • increasing the cover of all Ecological Vegetation Classes to at least 15% of their pre-1750 distribution	*Target 2*: Increase native vegetation coverage to 20% of the region by 2030 *Target 3*: Maintain and improve existing viable population of significant threatened species from 2003 *Target 4:* No further bioregional extinctions from 2003

Table S2 Original and recent (2006) extent of Ecological Vegetation Classes in the Reedy Lakes and Winlaton study area and their bioregional conservation status (DSE, 2011).

Ecological Vegetation Class	Pre-1750 (ha)	Present 2006 (ha)	% Remaining	Bioregional Conservation Status
Riverine Grassy Woodland	41	32	77	Vulnerable
Lake Bed Herbland	185	121	65	Depleted
Lignum Swamp	340	202	60	Vulnerable
Grassy Riverine Forest	9	5	56	Depleted
Lignum Swampy Woodland	5457	2387	44	Vulnerable
Grassy Riverine/Swamp Complex	1111	460	41	Depleted
Riverine Chenopod Woodland	11323	3279	29	Depleted
Woorinen Mallee	34	9	26	Vulnerable
Chenopod Grassland	4567	787	17	Endangered
Plains Savannah	27	4	15	Endangered
Semi-arid Woodland	358	37	10	Endangered
Semi-arid Chenopod Woodland	3547	348	10	Endangered
Plains Woodland	1	0	14	Endangered
Ridged Plains Mallee	6	0	7	Endangered
Total	27005	7671	34	

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