Agricultural intensification and loss of matrix habitat over 23 years in the West Wimmera, south-eastern Australia

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Abstract

The global trend toward more intensive forms of agriculture is changing the nature of matrix habitat in agricultural areas. Removal of components of matrix habitat can affect native biota at the paddock and the landscape scale, particularly where intensification occurs over large areas. We identify the loss of paddock trees due to the proliferation of centre pivot irrigation in dryland farming areas as a potentially serious threat to the remnant biota of these areas. We used a region of south-eastern Australia as a case study to quantify land use change from grazing and dryland cropping to centre pivot irrigation over a 23-year period. We also estimated rates of paddock tree loss in 5 representative landscapes within the region over the same period. The total area affected by centre pivots increased from 0 ha in 1980 to nearly 9000 ha by 2005. Pivots were more likely to be established in areas which had originally been plains savannah and woodlands containing buloke (*Allocasuarina luehmannii*), a food source for an endangered bird. On average, 42% of paddock buloke trees present in 1982 were lost by 2005. In the two landscapes containing several centre pivots, the loss was 54% and 70%. This accelerated loss of important components of matrix habitat is likely to result in species declines and local extinctions. We recommend that measures to alleviate the likely negative impacts of matrix habitat loss on native biota be considered as part of regional planning strategies.

Keywords

Paddock trees, matrix habitat loss, centre pivot irrigation, agricultural intensification.

1. Introduction

In many areas that have long been cleared of most native vegetation for agriculture, relatively recent trends towards declines in biodiversity are becoming evident. Large-scale shifts to intensive land uses in regions long used for traditional, more extensive agriculture have been implicated in such declines, particularly in Europe (Fuller et al., 1995; Chamberlain et al., 2000; Newton, 2004; Eggleton et al., 2005). The ever-increasing pressure for greater production efficiency in farming systems is continuing to drive the trend toward more intensive agricultural practices (Mansergh et al.).

At the scale of the individual paddock, agricultural intensification involves a simplification of the agroecosystem through reduced biodiversity, and increased inputs in the form of pesticides, fertilisers, or water (Tscharntke et al., 2005). Such intensification results in the removal of structural elements of the matrix, for example the removal of paddock trees (Maron, 2005), as well as resulting in direct mortality for species susceptible to chemical inputs. The impacts of such loss and alteration of matrix habitat are evident at both the paddock and the landscape scale (Eggleton et al., 2005; Tscharntke et al., 2005). Simulation studies have demonstrated that matrix quality can affect the ability of species to traverse the landscape by influencing the effectiveness of stepping stones and corridors (Baum et al., 2004), and paddock trees in particular have been shown to provide nesting and feeding habitat (Law et al., 2000; Lumsden et al., 2002; Manning et al., 2004; Lumsden and Bennett, 2005) and act as stepping stones between native vegetation remnants (Fischer and Lindenmayer, 2002). Furthermore, they directly and indirectly fulfil important ecological functions in influencing soil nutrient and moisture levels and harbouring beneficial species such as predatory invertebrates (Wilson, 2002; Oliver et al., 2006).

As climate becomes increasingly variable and rainfall in many temperate and semiarid agricultural regions becomes less reliable, reliance on irrigation of crops, even in dryland farming regions, is likely to increase. Centre pivot and lateral move irrigation systems, which pump water through a spray arm that can be over 600 m long, require the removal of all tall native vegetation within the reach of the arm. Despite only becoming widely used in many countries within the past 15-20 years, it is now one of the major forms of irrigation in suitable regions and its use is rapidly increasing. For example, in Mauritius the area under centre pivots reached 3000 ha within six years of the introduction of centre pivot technology (Teeluk, 1997). Where this proliferation of centre pivot irrigation replaces less intensive dryland farming practices, the nature of the matrix habitat is significantly affected, and there is potential for a large-scale impact on regional biodiversity.

We used an agricultural region of south-eastern Australia as a case study to investigate the extent of agricultural intensification, namely, introduction of centre pivot irrigation systems over a 23-year period. The proliferation of centre pivot irrigation circles is of concern in this region as the matrix areas still being farmed using less intensive grazing or dryland cropping support paddock trees which are an important food resource of an endangered taxon, the south-eastern red-tailed black-cockatoo (*Calyptorhynchus banksii graptogyne*), and habitat for several other threatened species (Maron, 2005; Maron et al., 2005). The rate of loss of these trees to

2005, previously only reported for a period early in the history of centre pivot use in the region (Maron, 2005), is also assessed.

2. Methods

2.1. Study area

An area of 163,200 ha in the western part of the Wimmera bioregion in Victoria was selected as a case study for this research (Fig. 1). The soils of the study area are primarily fertile grey clays interspersed with low-fertility sandy ridges, with native vegetation on the former soil types substantially modified or removed (Land Conservation Council, 1985). Within this study area, five focal landscapes were chosen to determine loss of scattered buloke (*Allocasuarina luehmannii*) trees (Maron, 2005), which are of particular interest due to their importance to the endangered red-tailed black-cockatoo (Maron and Lill, 2004) (Fig. 1).

2.2. Increase in centre pivots

The number and area of centre pivot irrigation areas (centre pivots) was determined from analysis of satellite imagery and aerial photography for the years 1980, 1993, 1995, 2000, 2001 and 2005. Landsat MSS imagery was used for the 1980 analysis (50 m pixels), Landsat TM imagery (30 m pixels) was used for 1993 and 1995 analysis, Landsat 7 EMR+ imagery (30 m pixels) was used for the 2000 analysis, SPOT Panochromatic/Monochromatic imagery (10 m pixels) was used for the 2001 analysis and ortho-rectified aerial photographs (0.6 m pixels) for the 2005 analysis. All active pivots and evidence of previous pivots were first calculated from the 2005 images as they provided the best resolution. The mapped areas were then compared to images from the previous years and any pivots that were not evident at an earlier time deleted. Due to the lower resolution of images earlier than 2001 it was not possible to determine which pivot areas were in use at the time. Thus the calculations are cumulative and represent the total area that had been used for centre pivots over the period. Although the satellite imagery and aerial photography were gathered at different times of the year and often over a time-frame of up to 12 months, for the purposes of calculating annual increase in pivot numbers and area the data were treated as though they were collected at the same time of the year. The area affected by centre pivots in 2005 in relation to the modelled pre-1750 distribution of ecological vegetation classes was calculated within ArcView GIS 3.3.

2.3. Loss of paddock trees

Rates of loss of paddock buloke trees between 1997-2005 were determined using the five focal landscapes. Following the methods of Maron (2005), all buloke paddock trees evident in each focal landscape were counted in the 2005 images and compared with the number present in 1997. However, although both sets of images used in this previous study were captured during summer, when grass residue was pale resulting in a high contrast between trees and pasture/crop stubbles, the 2005 images were captured at a time when the pasture grasses and crops were still green. This led to increased difficulty in distinguishing the trees in some images, particularly that depicting the Patyah landscape. In order to reduce error caused by omitting trees that were present but poorly visible, transparencies used to mark all trees in the 1997 image were overlain on the 2005 images and each location where a tree was present in 1997 was individually checked for the presence of a tree in 2005. If there was uncertainty about whether a particular tree was present in 2005, it was considered to be present; thus, a conservative estimate of loss was made. Rates of loss from each landscape were compared with those recorded between 1982/82 and 1997 (Maron, 2005).

3. Results

3.1. Changes in land use

No evidence of centre pivots was visible on the 1980 images. However, several pivots were present in the area in 1993 and the number of and area affected by centre pivots increased steadily from 1993 to 2005 (Figs. 1 and 2). On average, 11.75 pivots totalling 617 ha were established per year from 1993 to 2005, although between 2000 and 2005 13 new pivots at 651 ha were being established per year. Pivot areas proliferated in the north of the study area, particularly in the region between the Tallageira Nature Conservation Reserve and Little Desert National Park (Fig. 1). Few were established in the south. The average size of pivots increased slightly from 41.7 ha in 1993 to 50.5 ha in 2005. By 2005, 8734 ha of the study area had been affected by centre pivots, representing 5.5% of the area and up to 25% of the area between Tallageira Nature Conservation Reserve and Little Desert National Park.

Areas which formerly supported the Plains Woodland ecological vegetation class were the most heavily utilised for centre pivots, making up almost 75% of the total area affected by pivots, while Plains Woodland, Plains Savannah and Shallow Sands Woodland ecological vegetation classes combined made up almost 94% (Table 1). All of these ecological vegetation classes have buloke as a dominant or co-dominant overstorey species (Commonwealth and Victorian Regional Forest Agreement Steering Committee, 2000; White et al., 2003).

3.2. Overall rates of tree loss

In the 15 years between 1981/82 and 1997, the average rate of loss of buloke trees from paddocks in the five landscapes analysed had been 26% (Maron, 2005). In the 23 years to 2005, this figure was 42%. In the most affected landscape, 70% of trees that were present in paddocks in 1981/82 had been lost by 2005 (Table 2).

The per annum rate of loss of paddock buloke trees, expressed as a percentage of trees present in 1981/82, was higher when calculated over the 23 years to 2005 than over the 15 years to 1997 (Table 3). While Maron (2005) found an average annual rate of loss of 1.7%, the rate of loss per annum since 1997 (calculated as a percentage of 1997 trees) was 3.0% (Table 3). This indicates that although the number of trees remaining in the landscape is decreasing, the number being removed annually is not, and therefore the annual percentage loss has more than doubled in comparison with the period 1981/82-1997.

3.3. Impact of land use on tree loss

New centre pivot irrigation systems that had not been present in 1997 were evident in three of the five landscapes in 2005. These developments contributed disproportionately to the loss of paddock buloke trees. Although these new pivots affected an average of 7.6% of these three landscapes, they accounted for an average 22% of the bulokes lost since 1997 (Table 4).

Due to the time of year at which the images were taken (spring) pasture could not always be reliably distinguished from cropland. However, the Neuarpurr and Neuarpurr North landscapes were predominantly cropland in 1997 and personal observations in the study area confirm that this remained the case in the five years to

2005. The Benayeo landscape in the five years to 2005 was observed to have become predominated by dryland cropping. The Patyah landscape consists of pasture with very little cropping, while the Bringalbert landscape hosts a mix of cropping and pasture. The mean overall loss of trees from the three cropping landscapes, at 56.8%, is substantially higher than the Bringalbert (mixed cropping and grazing) landscape (28%) and the Patyah (grazing only) landscape (11.7%) (Table 2).

4. Discussion

Agricultural intensification, rather than the conversion of new areas to agriculture, has been responsible for most of the increase in food production over the past 30 years (United Nations Food and Agriculture Organization, 2006). Such intensification has resulted in substantial landscape change, and the resultant negative impacts on native biota are more recently becoming evident (Donald et al., 2001; Soderstrom et al., 2003). Continuing growth of centre pivot irrigation is likely to result in markedly changed landscapes, with the removal of the majority of woody native vegetation from the agricultural matrix. In the current study, the area affected by centre pivots increased linearly to cover 5.5% of the study area over the 23 years to 2005. At a more localised scale, centre pivots occupied as much as 25% of the area between the Tallageira Nature Conservation Reserve and the Little Desert National Park. This trend appears to be more widespread, as similar increases in centre pivots were evident in adjoining parts of the Wimmera bioregion in South Australia.

Although the groundwater accessed in the study area has been fully allocated since 1996 there has been no reduction in the rate of increase in area affected by centre pivots because the pivot arms are frequently moved to new paddocks with the original site used for the centre pivot returned, temporarily or permanently, to dryland cropping or grazing (C. Guest, personal communication, 2006). Agricultural practices such as grazing and tillage prevent the regeneration of native vegetation on sites cleared for centre pivot irrigators. Therefore, although tree removal at one pivot site might involve only a few dozen trees, the cumulative impact as centre pivots are moved represents a substantial loss of matrix habitat on a regional scale.

This alteration in matrix habitat is likely to have had a substantial impact on the biodiversity of the region. Manning et al. (2006) refer to scattered paddock trees as 'keystone structures' due to their disproportionately large contribution to ecosystem function. In the Wimmera, the scattered buloke trees provide a critical food resource to an endangered specialist granivore, the south-eastern red-tailed black-cockatoo, which feeds only on the seeds of three tree species (Joseph, 1982; Maron and Lill, 2004). Scattered trees in agricultural land also act as focal foraging sites for microchiropteran bats (Lumsden and Bennett, 2005) and their role as host to mistletoes (including, in the case of buloke, the vulnerable buloke mistletoe *Amyema linophylla*) makes them likely nesting sites for a suite of declining bird species and sources of high-nutrient litter fall (Watson, 2001; Cooney et al., 2006). They also often represent the remnants of threatened vegetation communities (Gibbons and Boak, 2002).

In addition to local-scale habitat alteration, changes in the agricultural matrix can influence landscape-scale processes. The loss of paddock trees and other forms of matrix homogenisation, such as conversion from native perennial pastures to introduced annuals, results in an increase in patch/matrix contrast, potentially influencing use of remnant patches and decreasing the ability of some organisms to traverse the landscape. Lower genetic diversity in skink populations has been attributed to attributes of the matrix surrounding habitat patches, suggesting that skink dispersal through a homogeneous exotic pasture matrix is reduced compared with a matrix of native tussock grassland (Berry et al., 2005). Castellon and Sieving (2005) recorded reduced dispersal of an understorey rainforest bird from wooded patches surrounded by open habitat than those surrounded by shrubby vegetation. Measures that manage matrix permeability may reduce the influence of fragmentation (Antongiovanni and Metzger, 2005). Improvements in matrix quality may be similarly effective at providing landscape connectivity as creation or retention of vegetation corridors (Castellon and Sieving, 2005).

The introduction of irrigation can itself have a negative effect on birds, especially those of open grassy habitats (Brotons et al., 2004). Irrigation and intensive management of areas previously subject to dryland agriculture results in changes to the spatial and temporal distribution of resources, through reduced prey habitat in the form of pasture or crop stubbles (McCracken and Tallowin, 2004). In Australia, bird species such as spotted harrier (*Circus assimilis*), little button-quail (*Turnix velox*), and plains-wanderer (*Pedionomus torquatus*), which are listed as threatened or near threatened at national or state levels (Department of Sustainability & Environment, 2003), are likely to be negatively affected by habitat change from previously open grassy woodland with extensive grazing and cereal cropping to intensive irrigated cropping.

The increase in centre pivot irrigation is effectively accelerating habitat loss in a region where tree decline through stubble burning, nutrification and natural senescence with little regeneration already are occurring (Maron, 2005). In an earlier study of the five focal areas, Maron (2005) recorded substantially lower annual rates of tree loss for the fifteen-year period to 1997 than we found in the eight years to 2005, despite native vegetation clearing controls being in place since 1989 with more recent policy intended to provide some protection for paddock trees introduced in 2002 (State of Victoria, 2002). The rates of tree loss recorded in this study are also higher than those recorded in other recent studies of agricultural regions (Ozolins et al., 2001; Carruthers, 2005). For example, Carruthers (2005) reported an annual rate of loss of 0.5% compared to the average 1.8% over the 23 years of this study. If the 3.0% annual rate of loss detected over the eight years to 2005 continues, paddock bulokes will be all but absent from the area within approximately 25 years, although it is likely that trees in some landscapes (such as those in which the predominant land use is sheep grazing) will be retained longer.

The loss of paddock trees and other matrix habitat has not often been quantified in the past, with the focus mainly on broadscale clearing of intact native vegetation. Australian native vegetation legislation does not adequately provide for the loss of matrix habitat through intensification of land use, yet this is a major threat to biodiversity. The buloke grassy woodlands of the Wimmera are part of a vegetation community listed as threatened under the Commonwealth and State legislation. However, as this once widespread community is now restricted primarily to paddock trees within a matrix of pastoral and irrigated land with predominantly non-native understorey, the trees themselves are not afforded the level of protection they would receive if they occurred within a remnant patch.

In Europe and the United States, agri-environment schemes have been widely used in attempts to mitigate the negative impacts of agricultural intensification and restore matrix habitat (Donald and Evans, 2006). Primary producers are paid to employ more environmentally-friendly practices, which often include maintaining a more heterogeneous matrix through restoring field margins and reducing herbicide use. Should such schemes be introduced in Australia, compensation of land managers for extending matrix management to the protection of scattered paddock trees has the potential to create benefits for native wildlife on a landscape scale.

We recommend that consideration be given to the impacts of agricultural intensification on biodiversity in Australia. Although legislation to cease broad-scale clearing has been introduced in most states and territories, Australia potentially faces a second wave of local extinctions and species declines due to the continuing loss of matrix habitat. While centre pivot irrigation is preferable in terms of water efficiency compared with practices such as flood irrigation, the potential impacts on native biota of introducing it to previously non-irrigated areas warrant attention. Landscape planners in affected regions should consider activities to mitigate and offset the effects of matrix habitat change, potentially through retaining and replanting paddock trees wherever possible, and utilising the corners of centre pivot paddocks for revegetation.

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Fig. 1. a) Location of study area and focal landscapes and distribution of areas affected by centre pivot irrigation in the west Wimmera in b) 1993, c) 2000 and d) 2005 (note 2001 SPOT satellite imagery used as background). Pivot areas are represented as black circles. Black squares = focal landscapes.

Fig. 2. Increase in centre pivot irrigation areas by total area and number in the West Wimmera.

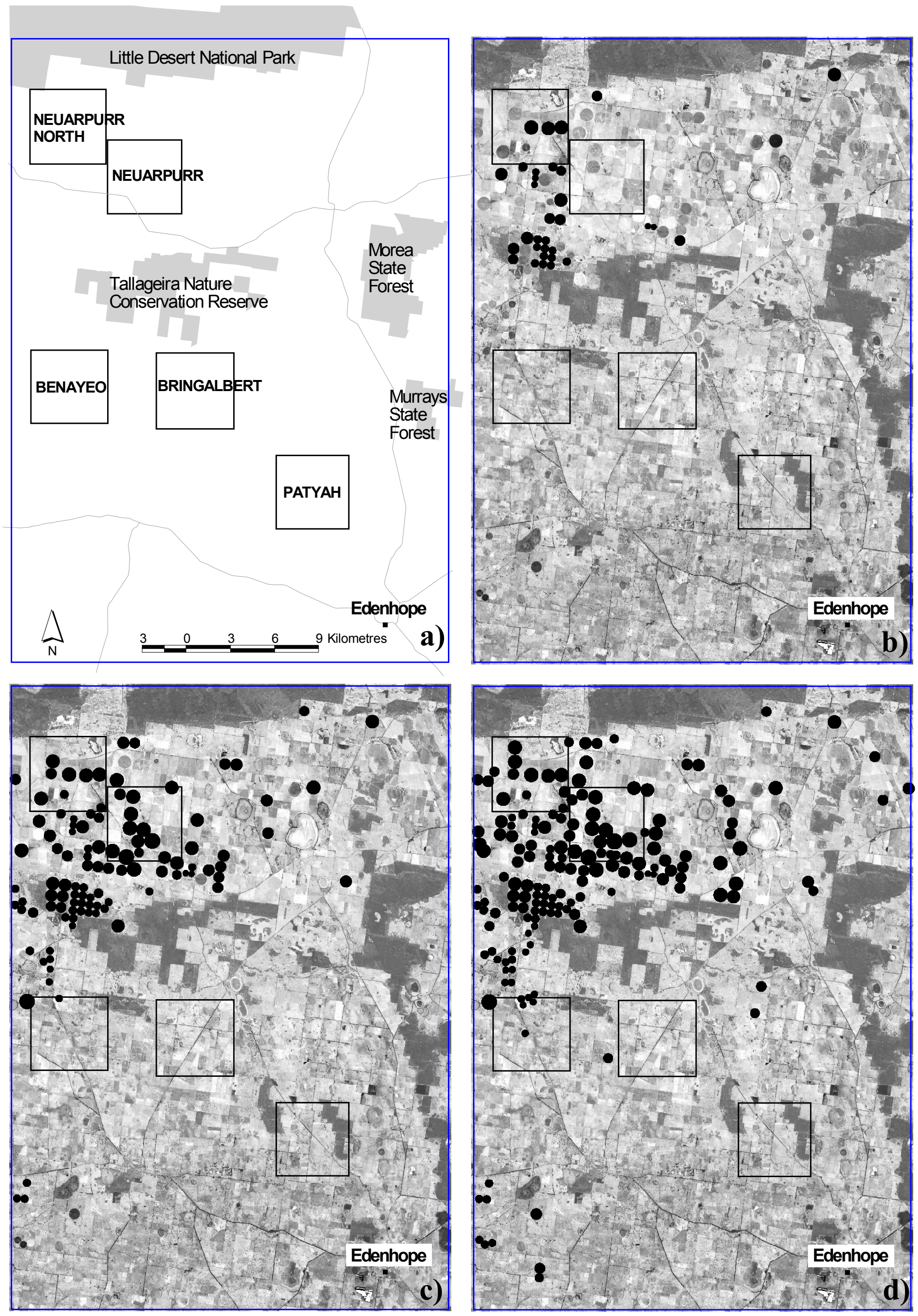
Little Desert National Park
NEUARPURR NORTH
NEUARPURR
Tallageira Nature Conservation Reserve
Morea State Forest
BENAYEO
BRINGALBERT
Murrays State Forest
PATYAH
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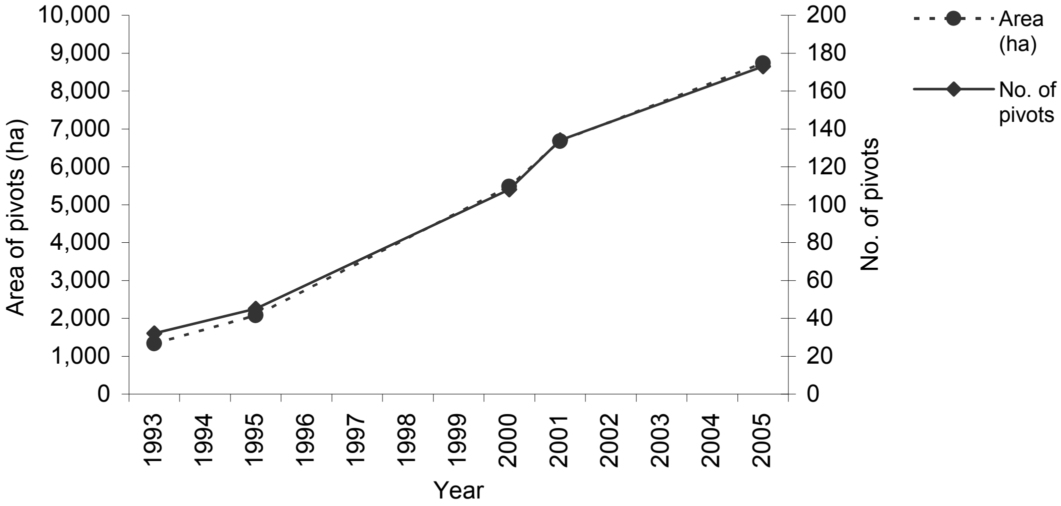
Fig. 1.



10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Area of pivots (ha)
200
180
160
140
120
100
80
60
40
20
0
No. of pivots
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Year
Area (ha)
No. of pivots

Fig. 2.

Table 1. Area (ha) of pre-1750 ecological vegetation classes (EVC) affected by centre pivot irrigation areas within the study area.

Pre-1750 EVC	Total area under pivots in 2005	% of pre-1750 extent under pivots
Damp Sands Herb-rich Woodland	97.6	2.4
Heathy Woodland	5.8	0.2
Low Rises Woodland	12.0	1.1
Lowan Sands Mallee	53.2	0.7
Dunefield Heathland	0.4	1.0
Sandstone Ridge Shrubland	15.1	2.0
Heathy Herb-rich Woodland	4.6	0.1
Seasonally Inundated Shrubby Woodland	2.3	0.7
Red Gum Swamp	49.5	0.6
Drainage-line Woodland	4.6	0.6
Shallow Sands Woodland/Plains Sedgy Woodland/Seasonally Inundated Shrubby Woodland/Damp Sands Herb-rich Woodland Mosaic	1.7	0.1
Damp Sands Herb-rich Woodland/Shallow Sands Woodland Mosaic	284.0	14.2
Plains Woodland	6419.6	6.4
Plains Savannah	838.1	14.6
Shallow Sands Woodland	803.6	6.3

Table 2. Loss of paddock buloke trees since 1981/82 in the five focal landscapes

* after Maron (2005)

		No. buloke trees			
Focal area name	Area (ha)	1981/82*	2005	No. lost	% loss since 1981/82
Neuarpurr	2320	1586	476	1110	70.0
Neuarpurr North	2060	1662	759	903	54.3
Bringalbert	1440	4257	3064	1193	28.0
Benayeo	1500	1554	837	717	46.1
Patyah	530	411	363	48	11.7
Mean±SD					42.0±10.2
Total	7850	9470	5499	2503	

Table 3. Rate of loss of buloke paddock trees per annum. *see Maron (2005)

	% of 1981/82 trees lost per annum		% of 1997 trees lost per annum
Focal area name	**Calculated over 15 years to 1997***	**Calculated over 23 years to 2005**	**Calculated over 8 years to 2005**
Neuarpurr	2.6	3.0	6.4
Neuarpurr North	2.2	2.4	4.0
Bringalbert	1.2	1.2	1.5
Benayeo	2.3	2.0	2.2
Patyah	0.3	0.5	1.0
Mean	**1.7**	**1.8**	**3.0**

Table 4. Loss of buloke trees from new centre pivot areas between 1997-2005 in landscapes where centre pivots were present.

Focal area name	No. buloke trees lost 1997-2005	% lost from new centre pivot areas	% total area under new pivots
Neuarpurr	493	25	14.3
Neuarpurr North	357	34	7.0
Benayeo	179	7	1.6