The value of paddock trees for regional conservation in an agricultural landscape

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Summary **Isolated trees and small patches of trees – paddock trees – are a prominent feature of agricultural landscapes in Australia, but are declining in many areas due to natural senescence, clearing, dieback and the general absence of recruitment. We assessed the importance of paddock trees for woodland conservation in a 30 000 ha sample of the New South Wales (NSW) South-west Slopes using *Satellite Pour l'Observation de la Terre* (SPOT) panchromatic satellite imagery combined with models predicting the original distribution of vegetation communities. Tree-cover occurred over 12% of the study area. The patch-size distribution of vegetation in the study area varied between woodland types. For woodland communities that were confined to hills and ridges, most tree-cover occurred as few, large remnants. For woodland communities of the foothills and plains (Blakely's Red Gum, *Eucalyptus blakelyi* and Yellow Box, *Eucalyptus melliodora*, or White Box, *Eucalyptus albens* and Red Stringybark), 54% of remnant tree-cover occurred as patches < 1 ha. The loss of paddock trees will cause substantial reductions to some woodland communities. For example, the loss of patches < 1 ha in woodlands dominated by Blakely's Red Gum and Yellow Box would reduce this association from 7.4% to 3.4% of its predicted pre-1750 distribution. Mean distance to tree-cover across the study area increased almost fourfold if patches < 1 ha were removed from the landscape, which may have consequences for movements of some flora and fauna. Failure to protect and perpetuate paddock trees will diminish the likelihood of achieving the conservation objectives of comprehensiveness, adequacy and representativeness in agricultural landscapes.**

Key words ***Eucalyptus*, *isolated trees, landscape ecology, satellite imagery, sustainable agriculture*.**

Introduction

Paddock trees are a prominent feature of agricultural landscapes in Australia. Here, we define 'paddock trees' as isolated trees, small modified patches and woodland remnants up to 1 ha. In intensively managed agricultural landscapes, paddock trees predominantly occur on land that is grazed or cultivated and typically have a highly modified understorey.

Paddock trees are declining in much of the intensively managed agricultural zone of Australia. The rate of loss among isolated and scattered trees has been estimated at 0.54–2.5% per annum (Freudenberger & Ozolins 2000; reviewed by Reid & Landsberg 2000), suggesting their total loss could feasibly occur in 40–185 years. This is due to a number of reasons: (i) eucalypts have a maximum lifespan of around 400–500 years (Banks 1997; Stoneman *et al*. 1997; Gibbons *et al*. 2000), so trees retained during extensive clearing that occurred through the 1800s will progressively senesce; (ii) paddock trees are subject to a high rate of mortality due to the interaction between elevated nutrient loads and insect attack (Landsberg *et al*. 1990), salinity (Kimber 1981) and soil compaction (Yates & Hobbs 1997); (iii) clearing paddock trees on private land is permitted, without consent, under some legislation (e.g. the NSW *Native Vegetation Conservation Act 1997*); and (iv) eucalypts generally do not regenerate where they are grazed or cultivated (Bennett *et al*. 1994), so paddock trees in these areas are not replaced.

Although often highly modified examples of native vegetation communities, paddock trees perform a number of ecosystem functions:

- Paddock trees frequently contain habitat for species that feed on pollen, nectar, seed and invertebrates or nest in hollows. These include species listed as threatened, such as the Superb Parrot (*Polytelis swainsonii*) (Davey 1997), Squirrel Glider (*Petaurus norfolcensis*), Brush-tailed Phascogale (*Phascogale tapoatafa*) (Law et al. 2000) and a number of species of bats (Microchiroptera) (Parnaby & Cherry 1992; Lumsden & Bennett 1995; Law *et al*. 1999, 2000). Hollows suitable for fauna generally occur in trees > 120–150 years old (Gibbons & Lindenmayer 2002), so recruitment must be addressed well before the existing paddock tree resource is lost.
- Paddock trees enable some species (e.g. woodland birds) to move between larger remnants, thereby contributing to the viability of metapopulations (Fischer 2000).
- Isolated and widely spaced trees have a

- high root volume and potentially intercept and pump considerable volumes of subsurface water, thus helping to reduce salinity risk (Freudenberger & Ozolins 2000; Reid & Landsberg 2000).
- Invertebrate and vertebrate fauna supported by paddock trees can help control invertebrate populations (Lumsden 1993).
- Paddock trees can recycle nutrients leached beyond the pasture root zone (Reid & Landsberg 2000) and isolated trees can maintain neutral pH and improve soil friability within their root zone (B. Wilson, unpubl. data, 2000).
- Paddock trees are potential foci for restoration activities (McDonald 2000).

The contribution of paddock trees to regional woodland conservation has not been assessed. In NSW, woody vegetation below about 12–15% canopy cover is not generally mapped (Benson 1999). In the present paper we: (i) quantify the contribution of paddock trees to total tree-cover in an agricultural landscape; (ii) assess the relative importance of paddock trees for the regional conservation of different woodland communities; and (iii) examine some implications of losing paddock trees from an agricultural landscape.

Methods

We remotely sampled woody vegetation in 30 808 ha around the township of Holbrook, which lies on the Hume Highway north of Albury (Fig. 1). The boundary of the study area approximates the boundary of the Holbrook 1:25 000 mapsheet (8326-1-S). The coordinates of the northwest and southeast boundaries of the study area are 35°37'30"S, 147°15'00" and 35°47'00", 147°30'00".

The study area falls within the Southwest Slopes Bioregion in the Murray-Darling Basin (Thackway & Cresswell 1995). Approximately 16% of the Southwest Slopes contains native vegetation cover and formal conservation reserves cover 1.3% of this bioregion (Pressey *et al.* 2000). The dominant land uses in the study area are grazing and cultivation. Significant areas of Radiata Pine (*Pinus radiata*) plantations occur in the eastern part of the bioregion, but not within the study area.

Maguire *et al.* (2000) mapped eight woodland communities in the study area: (i) River Red Gum (*Eucalyptus camaldulensis*); (ii) Blakely's Red Gum (*Eucalyptus blakeleyi*) with Weeping Grass (*Microlaena stipoides*) and Stinking Pennywort (*Hydrocotyle laxiflora*); (iii) Blakely's Red Gum and Yellow-box (*Eucalyptus melliodora*) with Wallaby Grass (*Danthonia racemosa*) and Speargrass (*Austrostipa scabra* ssp. *falcata*); (iv) White-box (*Eucalyptus albens*) with Weeping Grass and Redgrass (*Bothriochloa macra*); (v) Red Stringybark (*Eucalyptus macrorhyncha*) and White Box with Stinking Pennywort and Weeping Grass; (vi) Red Stringybark and Red-box (*Eucalyptus polyanthemos*) with Grey Guinea Flower (*Hibbertia obtusifolia*) and Common Raspwort (*Gonocarpus tetragynus*); (vii) Red-box and Long-leaf Box (*Eucalyptus goniocalyx*) with Common Raspwort and Poa Tussock (*Poa sieberiana*); and (viii) Dwyer's Red Gum (*Eucalyptus dwyeri*) and Currawang (*Acacia doratoxylon*).

We identified tree-cover across the study area using a panchromatic *Satellite Pour l'Observation de la Terre* (SPOT, Centre National d'Etudes Spatiales, Paris, France) image taken in summer and a geographical information system (Arcview; ESRI, Redlands, CA, USA). The panchromatic image captures the visible spectral range (0.61–0.68 μm). We converted this image to a grid in Arcview, isolated the range of colours that corresponded with tree-cover and converted each continuous group of grid cells to a separate polygon. As the SPOT imagery has a pixel size of 10 m, even the crowns of isolated, mature trees were captured in the conversion. Thus, a patch was any tree crown or group of tree crowns with an area of at least 100 m^2. Non-tree vegetation, such as grasslands, was not captured using this technique. We placed a buffer on each polygon so a discrete patch was one in which the edge of the tree crowns was > 20 m from adjacent tree crowns.

As we only used the panchromatic image to classify woody vegetation (not multispectral imagery), the range of colours that characterized tree crowns sometimes represented areas without trees, such as the shaded portions of cleared hills. The error associated with this classification was calculating by comparing the area of tree-cover captured using Arcview with a manual classification over ten 1 km^2 randomly located sites within the sampled area.

The patch-size distribution of woody vegetation within the study area was calculated separately for each vegetation type by

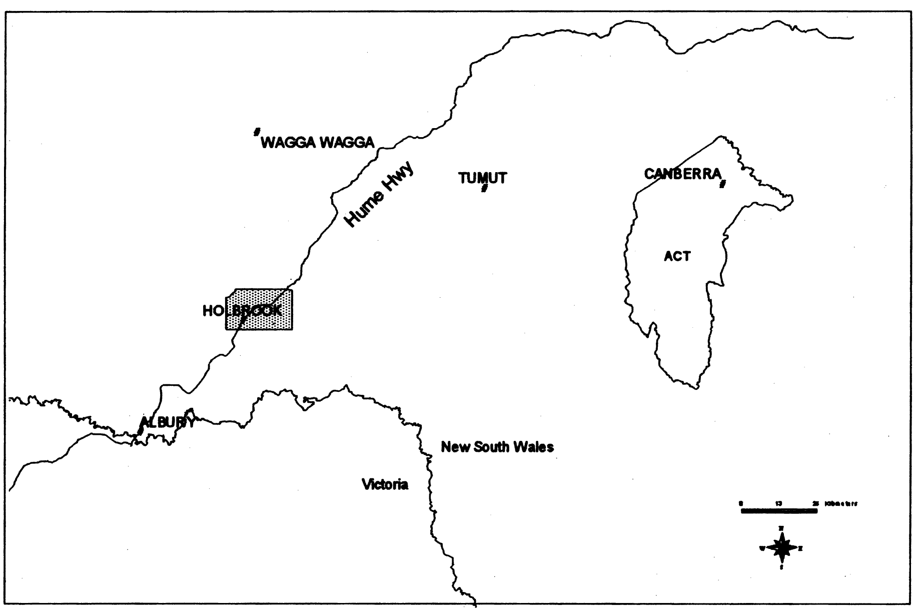

Figure 1. The study area.

overlaying the tree-cover layer derived from SPOT imagery with predicted distributions of each vegetation type prior to clearing. The 'pre-1750' distribution of each vegetation community was predicted by: (i) defining discrete vegetation types within the region from data obtained in full floristic plots located in remnant vegetation using a classification algorithm; and (ii) interpolating these across the entire landscape using climate, terrain and soils data as explanatory variables in a series of generalized additive models, which, in some cases, were modified using expert knowledge (Maguire *et al.* 2000). Further details of the methodology can be found in Thomas *et al.* (2000).

We simulated changes to the landscape with the removal of patches < 0.04 ha, < 0.1 ha, < 0.5 ha and < 1 ha because these are the patches likely to be lost over time for the reasons outlined above (i.e. senescence, dieback, clearing and an absence of recruitment). This was done by searching for and deleting these different patch sizes in the database and recalculating the per cent remaining of the different vegetation communities after each simulated removal. We used the mean distance to woodland patches as an index of connectivity. This was calculated by producing a 10-m grid in Arcview using the 'find distance' command. This command returns the minimum distance to woody vegetation for each 10 m grid cell across the study area. The mean and standard deviation of this figure for the entire study area was calculated separately upon the simulated removal of different-sized patches of woody vegetation.

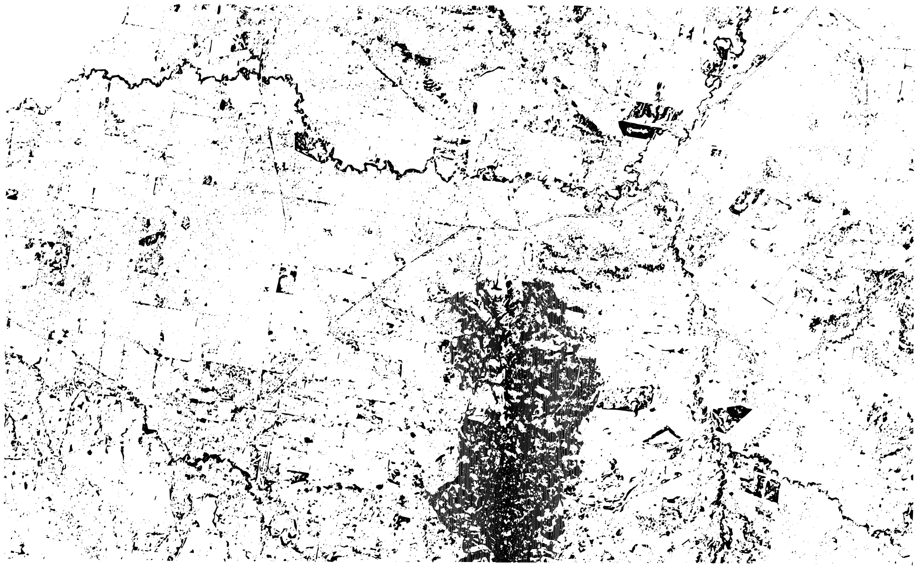

Figure 2. Woody vegetation across the study area derived from *Satellite Pour l'Observation de la Terre* (SPOT) satellite imagery. The township of Holbrook is in the southwest corner of the image, the Hume Highway is visible as a strip of vegetation running southwest to northeast.

Results

The estimated total cover of woody vegetation in the study area was 3765 ha. That is, 12% of the study area was estimated to contain woody vegetation (Fig. 2). For the purposes of analysis, some vegetation types defined by Maguire *et al.* (2000) occurred over a small, predicted area and were, therefore, amalgamated with the most similar floristic association. We based our analysis on four woodland types dominated by the following tree species: (i) Blakely's Red Gum and Yellow-box; (ii) Dwyer's Red Gum and Currawang; (iii) Red Stringybark, Red Box and Long-leaf Box; and (iv) White Box with Red Stringybark. We omitted the data for River Red Gum because there appeared to be frequent misclassification of cultivated paddocks as woody vegetation along the major creek line in the study area, where this vegetation type was predicted to occur.

Patch-size distribution of woody vegetation in the study area

Using our definition of a 'patch' (i.e. ≥ 10 m × 10 m and greater than 20 m from adjacent woody vegetation) there were an estimated 10 249 patches of woody vegetation in the study area ranging in size from individual mature trees (≥ 100 m^2) to a maximum patch size of 692 ha. The cumulative distribution of woody vegetation cover by patch size is summarized in Fig. 3. Patches of vegetation < 0.04 ha (1–2 mature trees), < 0.1 ha (around 1–5 mature trees), < 0.5 ha and < 1 ha represented 4%, 10%, 26% and 34% of all tree-cover, respectively. The balance (66%) occurred as patches > 1 ha.

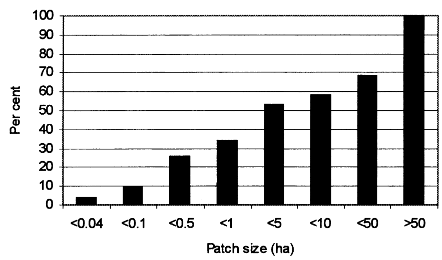

Figure 3. Cumulative per cent of total woody vegetation cover, by patch-size, in the study area.

Patch-size distribution of individual vegetation types

When the layer of woody vegetation produced from the SPOT image was overlayed with the predicted distribution of different vegetation communities in the study area, the estimated patch-size distribution of vegetation varied between the four woodland types (Fig. 4). For some vegetation types, most tree-cover occurred in large remnants (> 50 ha). The predicted area of vegetation dominated by Dwyer's Red Gum and Currawang was 540 ha. Most of this vegetation type (90%) occurred in one remnant and only 1.8% as isolated trees and patches < 1 ha (Fig. 4). The community dominated by Red Stringybark, Red Box and Long-leaf Box occurred over a predicted area of 1295 ha. Most of this vegetation type (53%) also occurred in one large remnant with 22% in patches < 1 ha (Fig. 4).

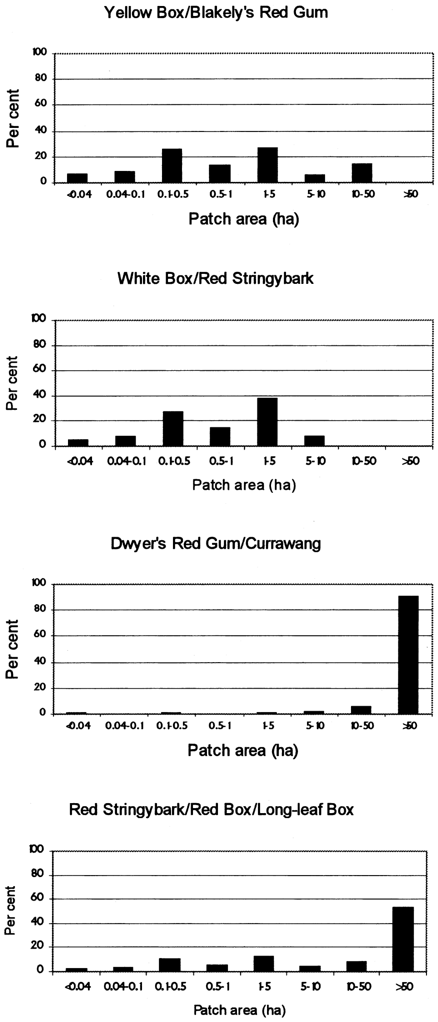

Figure 4. The contribution of different patch sizes to the total cover of different woodland communities in the study area.

For the other woodland communities, paddock trees (i.e. isolated trees, patches of trees and remnants < 1 ha) contributed substantially towards total vegetation cover (Fig. 4). For the communities dominated by Blakely's Red Gum and Yellow Box, which were predicted to occur over 1564 ha, 7% occurred in patches < 0.04 ha, 16% in patches < 0.1 ha, 41% in patches < 0.5 ha and 54% in patches < 1 ha. The balance (46%) occurred in patches > 1 ha. A similar pattern occurred for the community dominated by White Box and Red Stringybark, which was predicted to occur over 239 ha. Five per cent of this vegetation type occurred in patches < 0.04 ha, 13% in patches < 0.1 ha, 40% in patches < 0.5 ha and, 54% in patches < 1 ha. The remaining 46% occurred in patches > 1 ha.

Simulated removal of paddock trees

We calculated the percentage of each woodland community that would be lost with the removal from the study area of patches < 0.04 ha, < 0.1 ha, < 0.5 ha and < 1 ha, as these are the patches most likely to be lost for the reasons outlined above (i.e. senescence, mortality, clearing and lack of recruitment) (Table 1). There was relatively little change to the extent of woodland dominated by Dwyer's Red Gum and Currawang and woodland dominated by Red Stringybark, Red Box and Long-leaf Box with the removal of patches < 1 ha. There was greater impact on the other communities. For example, woodland dominated by Blakely's Red Gum and Yellow Box was reduced from 7.4% to 6.9% of its predicted pre-1750 distribution if patches < 0.04 ha were lost, to 6.3% of its pre-1750 distribution if patches < 0.1 ha were lost, to 4.4% of its pre-1750 distribution if patches < 0.5 ha were lost and to 3.4% of its pre-1750 distribution if patches < 1 ha were lost. The pattern was similar for the White Box and Red Stringybark communities, which were reduced from 15.5% to 7.1% of their predicted pre-1750 distribution in the study area if patches < 1 ha were lost.

We also simulated changes to connectivity across the study area with the removal of paddock trees. We used the mean distance to tree-cover as an index of connectivity. This mean was calculated with the removal of patches < 0.04 ha, < 0.1 ha, < 0.5 ha and < 1 ha. The mean distance to tree-cover increased substantially with the simulated removal of progressively larger patches of vegetation (Table 2). The simulated removal of patches < 1 ha increased the mean distance to tree-cover across the study area from 80 m to 358 m. There were wide ranges in distances between patches (as indicated by the standard deviations), so these figures should be viewed as indices of connectivity only.

Table 1. Predicted changes to the extent of different woodland types in the study area (compared with their predicted pre-1750 distribution as mapped by Maguire *et al.* 2000) after the loss of different-sized patches of vegetation

	% of predicted pre-1750 extent				
Woodland type	**All patches**	**If patches < 0.04 ha removed**	**If patches < 0.1 ha removed**	**If patches < 0.5 ha removed**	**If patches < 1 ha removed**
Dwyer's Red Gum, Currawang (540 ha)	65.9	65.6	65.4	64.7	64.7
Red Stringybark, Red Box, Long-leaf Box (1295 ha)	18.4	17.9	17.3	15.3	14.3
Blakely's Red Gum, Yellow Box (1564 ha)	7.4	6.9	6.3	4.4	3.4
White Box and Red Stringybark (239 ha)	15.5	14.7	13.5	9.3	7.1

Table 2. Changes in the mean distance (± 1 SD) to tree-cover in the landscape when we simulated the removal of patches < 0.04 ha, < 0.1 ha, < 0.5 ha and < 1 ha

	All woodland	**If patches < 0.04 ha removed**	**If patches < 0.1 ha removed**	**If patches < 0.5 ha removed**	**If patches < 1 ha removed**
Mean distance to tree-cover (m)	80 (± 138)	109 (± 156)	144 (± 182)	267 (± 273)	382 (± 358)

Error associated with the data

We manually checked the accuracy of our data by visually comparing woody vegetation on the SPOT image with the polygons of woody vegetation derived from the same image using Arcview. This was done for ten 1 km^2 plots located randomly in the study area. Overall, our data for the 10 km^2 sample indicated there to be 150 ha of tree-cover. After manually correcting polygons to tree crowns judged to be incorrectly classified, we estimated total tree-cover over this same area to be 134 ha. Therefore, this manual classification suggested that we overestimated tree-cover across the study area by 11%. The error varied in different parts of the landscape. In the continuous areas of native vegetation within the hilly parts of the study area, tree-cover was underestimated. On essentially cleared parts of the landscape the procedure overestimated tree-cover. Cropped paddocks in the flatter, well-watered parts of the landscape and the shaded sections of cleared hills were often misclassified as tree-cover. There would also be some error delineating the size of patches associated with the shade cast from trees, as the image is not taken from directly beneath the satellite (i.e. off nadir). A further source of error would be attributable to non-native tree-cover (e.g. around homesteads, in windbreaks and within the township of Holbrook). Our method was able to distinguish pine plantations from other tree-cover elsewhere in the landscape, although there were none within the study area. Field checking indicated that trees with small crowns were not detected, so this would add to any error. The vegetation models that were overlaid with the tree-cover layer also have a degree of uncertainty (Thomas *et al*. 2000). Our results should, therefore, be viewed as indicative of average patterns across the landscape only, and not an exact depiction of tree-cover at any particular site.

Discussion

Paddock trees represent a substantial proportion of tree-cover for some woodland communities. For example, we estimated that 54% of woodland dominated by Blakely's Red Gum, Yellow Box or White Box occurred in patches < 1 ha. These communities typically occur in agriculturally productive parts of the landscape. This pattern did not occur for woodland types situated in less productive parts of the landscape. For example, only 2% of the community dominated by Dwyer's Red Gum and Currawang occurred in patches < 1 ha.

As paddock trees represent a large proportion of the remnant vegetation in some woodland communities (e.g. Blakely's Red Gum and Yellow-box), this makes them important for achieving sound conservation outcomes within agricultural landscapes. The guiding principles used to assess forests in the Regional Forest Agreement (RFA) process throughout Australia were comprehensiveness, adequacy and representativeness (Commonwealth of Australia 1997). Among other things, these principles recognize that effective conservation requires the protection of sufficient examples of every vegetation community in every region. Our data indicate that the adequate protection of some vegetation communities relies on protection and management of paddock trees.

In the RFA process, one aim was to protect at least 15% of the predicted pre-1750 distribution of each vegetation association within each of the forested regions throughout the country (Commonwealth of Australia 1997). It has been argued that this figure should be higher in essentially cleared landscapes (Commonwealth of Australia 1997). For example, the NSW South-west Slopes (in which the study area occurs) contains 16% of its original vegetation cover, yet has many examples of species that have become extinct or are in serious decline (Reid 1999) and has the most extensive examples of dryland salinity in NSW (Littleboy *et al*. 2001), suggesting that a sustainable threshold of native vegetation cover has been exceeded.

Failure to arrest the decline of paddock trees from senescence, dieback, clearing and an absence of recruitment will contribute substantially to the further depletion of some vegetation communities. We predicted that the Blakely's Red Gum and Yellow Box communities would decline from 7.4% to 3.4% of their pre-1750 distribution in the study area if patches < 1 ha were lost from the landscape (Table 1). Thus, the continued loss of paddock trees may diminish the likelihood of achieving comprehensiveness, adequacy and representativeness in agricultural landscapes.

The loss of paddock trees from the landscape also reduces connectivity (Table 2). The mean distance to tree-cover increased from 80 m to 382 m with the loss of patches < 1 ha from the landscape, although high variation in the data can be seen (Table 2). Many species use the agricultural matrix as a conduit for movement (Bennett 1999; Fischer 2000). In the study area, this includes a number of fauna listed as threatened, such as the Regent Honeyeater (*Xanthomyza phrygia*) and Swift Parrot (*Lathamus discolor*) (Higgins 1999). Subpopulations of a metapopulation that are isolated face a higher risk of extinction relative to connected subpopulations (Hanski & Gilpin 1991). Movements by flora and fauna between subpopulations are important to enable genetic exchange and permit larger remnants to be repopulated in the event of a perturbation, such as fire or disease (Bennett 1999).

The loss of paddock trees will also impact upon the other ecosystem services provided by this resource, such as the interception and use of ground water, the cycling of nutrients and the control of invertebrates. However, we have no data to demonstrate the impacts of paddock-tree loss on these services.

The decline of paddock trees can be reduced by focusing on clearing, dieback and recruitment. When assessed for their conservation value in clearing applications, paddock trees must be considered in the regional context. Dieback among paddock trees can be reduced through a number of measures, such as limiting fertilizer use in their vicinity, avoiding prolonged camping by stock and minimizing herbicide drift (Reid & Landsberg 2000). However, these actions will ultimately be in vain unless measures are employed that encourage eucalypt regeneration in grazed and cultivated areas. Reid and Landsberg (2000) suggested that natural regeneration of eucalypts can be facilitated in grazed paddocks by disturbing the soil around paddock trees, temporarily fencing them and reintroducing grazing only after a period when seedlings are no longer likely to be damaged by stock, or giving newly established seedlings long periods of rest between short periods of grazing. There is anecdotal evidence that eucalypt regeneration can be achieved by manipulating grazing alone. However, eucalypt regeneration only occurs under the right set of conditions: the coincidence of sufficient seed-fall, bare soil, limited competition and adequate rainfall (reviewed by McDonald 2000; Windsor 2000). Greater understanding of the location and timing of these events and the economic implications for agricultural production is required if we are to integrate natural eucalypt regeneration to farming systems within Australia.

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