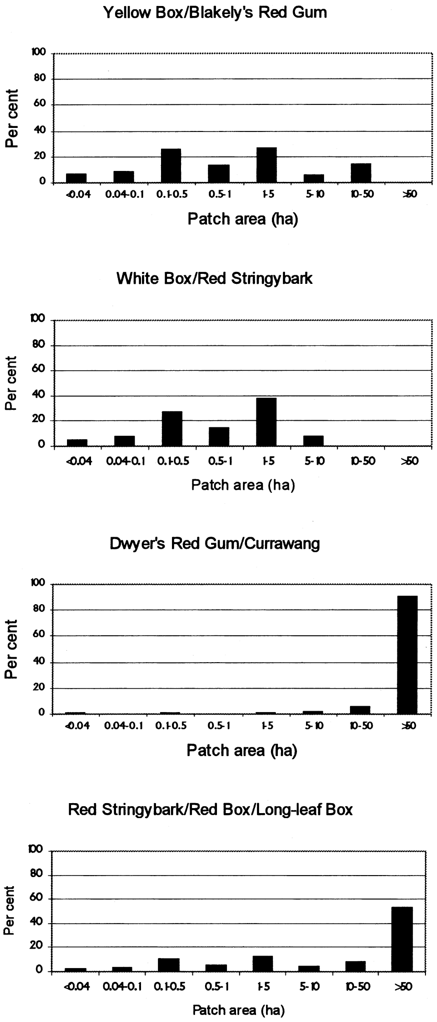

Figure 4. The contribution of different patch sizes to the total cover of different woodland communities in the study area.

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

Woodland type	% of predicted pre-1750 extent				
	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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References

Banks J. C. G. (1997) Tree ages and ageing in Yellow Box. In: *The Coming of Age. Forest Age and Heritage Values* (ed. J. Dargavel) pp. 17–28. Environment Australia, Canberra.

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

Bennett A. F., Lumsden L. F. and Nicholls A. O. (1994) Tree hollows as a resource for wildlife in remnant woodlands: spatial and temporal patterns across the northern plains of Victoria, Australia. *Pacific Conservation Biology* **1**, 222–235.

Benson J. (1999) Setting the Scene. The Native Vegetation of New South Wales. Native Vegetation Advisory Council, Sydney.

Commonwealth of Australia (1997) Nationally Agreed Criteria for the Establishment of a Comprehensive, Adequate and Representative Reserve System for Forests in Australia. A Report by the Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-Committee. Commonwealth of Australia, Canberra, Australia.

Davey C. (1997) Observations on the Superb Parrot within the Canberra district. *Canberra Bird Notes* **22**, 1–14.

Fischer J. (2000) The value of paddock trees for birds in a pastoral landscape in southern New South Wales. Bachelor of Science (Honours) Thesis, Department of Geography, The Australian National University, Canberra.

Freudenberger D. and Ozolins A. (2000) Isolated trees under threat from farming. *Farming Ahead* **104**, 38–39.

Gibbons P. and Lindenmayer D. B. (2002) *Tree Hollows and Wildlife Conservation in Australia.* CSIRO Publishing, Melbourne.

Gibbons P., Lindenmayer D. B., Barry S. C. and Tanton M. T. (2000) Hollow formation in eucalypts from temperate forests. *Pacific Conservation Biology* **6**, 218–228.

Hanski I. and Gilpin M. (1991) Metapopulation dynamics: brief history and conceptual domain. *Biological Journal of the Linnaean Society* **42**, 3–16.

Higgins P. J. (1999) *Handbook of Australian, New Zealand and Antarctic Birds*, Vol. 4**.** *Parrots to Dollarbird.* Oxford University Press, Melbourne.

Kimber P. C. (1981) Eucalypt diebacks in the south west of Western Australia. In: *Eucalypt Dieback in Forests and Woodlands* (eds K. M. Old, G. A. Kile and C. P. Ohmart) pp. 37–43. CSIRO, Melbourne.

Landsberg J., Morse J. and Khanna P. (1990) Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proceedings of the Ecological Society of Australia* **16**, 149–165.

Law B. S., Anderson J. and Chidel M. (1999) Bat communities in a fragmented forest landscape on the south-west slopes of New South Wales, Australia. *Biological Conservation* **88**, 333–345.

Law B., Chidel M. and Turner G. (2000) The use by wildlife of paddock trees. *Pacific Conservation Biology* **6**, 130–143.

Littleboy M., Piscopo G., Beecham R., Barnett P., Newman L. and Alwood N. (2001) Dryland salinity extent and impacts, New South Wales. Technical report for the National Land and Water Resources Audit. NSW Department of Land and Water Conservation, Sydney.

Lumsden L. (1993) Bats. Nature's nocturnal insect controllers. *Trees and Natural Resources* **December**, 8–11.

Lumsden, L.F. and Bennett, A.F. (1995) Bats of a semi-arid environment in south-eastern Australia: biogeography, ecology and conservation. *Wildlife Research* **22**, 217–40.

McDonald T. (2000) Strategies for the ecological restoration of woodland plant communities: harnessing natural resilence. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. J. Yates) pp. 286–297. Surrey Beatty and Sons, Chipping Norton.

Maguire O., Thomas V. and Hunter S. (2000) *Southern CRA/Riverina Highlands Vegetation Mapping Extension.* A Report Undertaken by the National Parks and Wildlife Service Southern Comprehensive Regional Assessment Unit for the Riverina Highlands Regional Vegetation Management Committee. New South Wales National Parks and Wildlife Service, Hurstville, NSW.

Parnaby H. and Cherry K. (1992) A Trapping Study of the Bat Fauna of Mountain Ash Plantations and Old Growth Forests of the Strzelecki Ranges, Victoria. Department of Conservation and Natural Resources, Melbourne.

Pressey R. L., Hager T. C., Ryan K. M. *et al.* (2000) Using abiotic data for conservation assessments over extensive regions: quantitative methods applied across New South Wales, Australia. *Biological Conservation* **96**, 55–82.

Reid J. W. (1999) Threatened and Declining Birds in the NSW Sheep-Wheat Belt: 1. Diagnosis, Characteristics and Management. Consultancy Report to NSW National Parks and Wildlife Service. CSIRO Wildlife and Ecology, Canberra.

Reid N. and Landsberg J. (2000) Tree decline in agricultural landscapes: what we stand to lose. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. J. Yates) pp. 127–166. Surrey Beatty and Sons, Chipping Norton.

Stoneman G. L., Rayner M. E. and Bradshaw F. J. (1997) Size and age parameters of nest trees used by four species of parrot and one species of cockatoo in south-west Australia. *Emu* **97**, 94–96.

Thackway R. and Cresswell I. D. (1995) *An Interim Biogeographic Regionalisation for Australia: A Framework for Setting Priorities in the National Reserves System Cooperative Program.* Australian Nature Conservation Agency, Canberra.

Thomas V., Gellie N. and Harrison T. (2000) *Forest Ecosystem Classification and Mapping for the Southern CRA Region.* Resource and Conservation Division, Department of Urban Affairs and Planning and Forests Taskforce, Department of Prime Minister and Cabinet, Canberra.

Windsor D. M. (2000) A review of factors affecting regeneration of box woodlands in the Central Tablelands of New South Wales. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. J. Yates) pp. 271–285. Surrey Beatty and Sons, Chipping Norton.

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.