

# Contribution of paddock trees to the conservation of terrestrial invertebrate biodiversity within grazed native pastures

IAN OLIVER,<sup>1\*</sup> SARINA PEARCE,<sup>1†</sup> PENELOPE J. M. GREENSLADE<sup>2</sup> AND DAVID R. BRITTON<sup>3</sup>

<sup>1</sup>Key Centre for Biodiversity and Bioresources, Department of Biological Sciences, Macquarie University, Sydney, New South Wales, <sup>2</sup>School of Botany and Zoology, Australian National University, Canberra, ACT and <sup>3</sup>Australian Museum, 6 College St Sydney, New South Wales, Australia

**Abstract:** Paddock trees are a common feature in the agricultural landscapes of Australia. Recent studies have demonstrated the value of scattered paddock trees for soil fertility, native pasture plants and arboreal faunas; however, the degree to which scattered paddock trees contribute to the conservation of terrestrial invertebrate biodiversity within grazed landscapes remains unknown. We ask three questions: (i) Is there a difference between the terrestrial invertebrate assemblages found under paddock trees compared with surrounding grazed native pastures? (ii) Can gradients in soil and litter variables from the base of trees explain patterns in invertebrate assemblages? and (iii) Does the presence of scattered paddock trees have implications for the conservation of terrestrial invertebrate biodiversity within grazed native pastures? We used pitfall trapping and extraction from soil cores to sample the invertebrate assemblages under six New England Peppermint trees (*Eucalyptus nova-anglica* Deane and Maiden) and compared them with assemblages sampled from the open paddock. Formicidae and Collembola univariate and multivariate data were analysed along with a range of soil and litter variables. We found (i) significant differences in the assemblages of invertebrates under trees compared with surrounding grazed pastures; (ii) that most soil and litter variables revealed gradients away from tree bases and these variables explained significant variation in invertebrate assemblages; and (iii) more native invertebrates and more species of invertebrates were found under trees compared with the surrounding pastures. We discuss the relationships between paddock trees, the ground and soil environments and the invertebrate communities that inhabit these environments, and conclude with a discussion of the future for paddock trees and the biota supported by them.

**Key words:** conservation, invertebrate, paddock tree, tree decline.

## INTRODUCTION

Single trees or small patches of trees are a common feature within Australian agricultural landscapes. In some regions they represent the majority of the remaining native vegetation. For example, in the south-west slopes region of New South Wales, more than 50% of the remaining tree cover on the fertile foothills and plains comprises scattered trees and tree patches less than 1 ha in size (Gibbons & Boak 2002; Carruthers *et al.* 2004). However, at current rates of decline, paddock trees and tree patches could be lost from some regions of Australia in as little as 40

years (Ozolin *et al.* 2001; Gibbons & Boak 2002; Carruthers *et al.* 2004). Understanding their value is clearly an important and urgent task.

Paddock trees and tree patches have been shown to increase agricultural productivity by providing shelter to pastures, crops and stock from wind, heat and cold (Reid & Bird 1990; Walpole 1999; Anonymous 2001). Paddock trees reduce erosion, control water table height, thus reducing the effects of salinity (Zhang *et al.* 1999), and provide important associations with ectomycorrhizal fungi which aid in the uptake of nutrients from the generally nutrient-poor Australian soils (Tommerup & Bougher 2000). They can even play a role in the biological control of agricultural pests by providing habitat for invertebrate and vertebrate faunas that feed on pest species (Lumsden 1993; Majer & Delabie 1999; Anonymous 2001).

Paddock trees also provide resources for native species that feed on pollen, nectar, seed and invertebrates (Carruthers *et al.* 2004). They provide important habitat for hollow dependant fauna (Law *et al.* 2000; Reid

\*Corresponding author. Present address: Department of Infrastructure, Planning and Natural Resources, PO Box U245, University of New England, Armidale, NSW 2351, Australia (Email: ian.oliver@dipnr.nsw.gov.au).

†Present address: School Biological Sciences, University of Bristol, Woodland Road, Bristol BS8 1UG, UK.

Accepted for publication June 2005.

& Landsberg 2000; Gibbons & Boak 2002; Gibbons & Lindenmayer 2002) and provide stepping stones which facilitate bird and arboreal mammal movement and dispersal across the fragmented agricultural landscape (Fischer & Lindenmayer 2002a,b; van der Ree *et al.* 2003). The retention of paddock trees in grazed landscapes has also been shown to contribute to native plant conservation by maintaining indigenous herbs, forbs and mistletoes (Chilcott *et al.* 1997; Reid *et al.* 1997; Reid & Landsberg 2000). However, the degree to which paddock trees provide habitat for native terrestrial invertebrate faunas is largely unknown (but see Majer & Delabie 1999; Majer & Recher 2000).

In agricultural landscapes, management impacts might reasonably be expected to be greatest on terrestrial biota, because of cultivation, herbicide or fertilizer application, as well as biomass removal, soil compaction and nutrient concentration by domestic grazing stock (King *et al.* 1976, 1985; King & Hutchinson 1980, 1983; Heisler 1995; Bromham *et al.* 1999; Oliver *et al.* 2005). In this study we ask the general question of whether paddock trees contribute to the conservation of terrestrial invertebrate biodiversity in grazed native pastures, and address three specific questions: (i) Is there a difference between terrestrial invertebrate assemblages found under paddock trees compared with the surrounding grazed native pastures? (ii) Can gradients in soil and litter variables from the base of trees explain patterns in invertebrate assemblages? and (iii) Does the presence of paddock trees have implications for the conservation of terrestrial invertebrate biodiversity within grazed native pastures?

## METHODS

### Study site

The study was conducted at the 'Newholme' field laboratory situated on the Northern Tablelands of New South Wales approximately 580 km north from Sydney. 'Newholme' is located in grazing country that has been largely cleared of native woody vegetation to promote the establishment of grazing pastures (Brouwer & Crijns 1994). The area has a cool temperate climate, with a mean annual rainfall of 870 mm, with on average, 65% of rain falling within summer (King & Hutchinson 1976).

The study site was located within a single paddock ('Corn' 66 ha, altitude 1020 m) which contained scattered trees of several *Eucalyptus* spp. and a ground cover dominated by native perennial plant species, including *Microlaena stipoides*, *Aristida ramosa*, *Sporobolus creber* and *Eragrostis* spp. The paddock had been fertilized with aerial applications of superphosphate (125 kg ha<sup>-1</sup>) in 1983, 1985, 1997 and 1998,

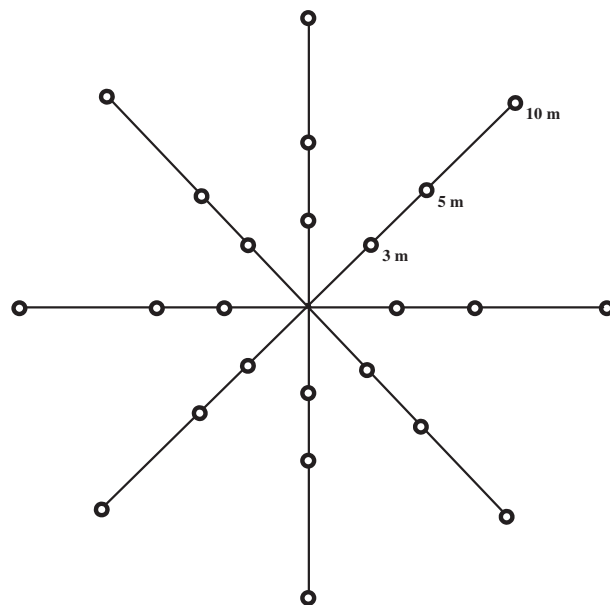
and a single aerial application of white clover (*Trifolium repens*) in 1983. The paddock supported both sheep and cattle at 6–8 dry sheep equivalents per hectare per year (Brouwer & Crijns 1994).

### Study design

Within the 'Corn' paddock, six New England Peppermint trees (*Eucalyptus nova-anglica* Deane and Maiden) that were separated from other woody vegetation by a minimum distance of 30 m were selected for study. *Eucalyptus nova-anglica* was selected because the required number of trees of similar size and of sufficient distance from other vegetation could be found (mean: height = 16 m, d.b.h. = 0.57 m, canopy diameter = 13 m). At each of the six trees, random compass bearings and random distances between 50 m and 100 m were generated to locate an open paddock study site at least 30 m from other trees. To test the first question, sampling took place at each of the 12 sites (six trees, six open paddocks) at 24 points located using a star sampling design (Fig. 1). To test the second question, the north axis of the star sampling design at each tree was extended to 30 m and sampling points located every metre.

### Sampling methods

Ground-active invertebrates were sampled using glass pitfall traps (length = 10 cm, diameter = 2.5 cm) two-



**Fig. 1.** Star sampling design used at each of the six trees and six open paddock sites. Circles indicate pitfall trap locations.

thirds filled with 100% ethanol and placed in the ground at each of the 24 sampling points at each of the 12 star design sites. Similarly, 30 pitfall traps were installed along each transect extending north from the six trees. Traps were active immediately after installation and left in place for 6 days in August 1998. A second session of pitfall-trapping occurred over 6 days for the 30-m transects in the following summer (January 1999). All 1998 samples were sorted with the aid of a dissection microscope into major groups (mainly orders). Formicidae from the 1998 star design samples, and the 1999 transect samples were further sorted to genus then morphospecies by D. Britton following the protocols of Oliver and Beattie (1993, 1996). Morphospecies identifications were verified and identified to named species where possible by D. Smith (Australian Museum, Sydney). Voucher specimens have been lodged in the Australian Museum, Sydney.

Soil invertebrates were sampled by soil coring in August 1998 at every metre along the 30-m transects. Soil cores were 10 cm in diameter, included the litter layer and sampled the soil to a depth of 5 cm. Invertebrates were extracted at the University of New England over a period of 6 days from the inverted cores in tullgren funnels heated by a 15-W pilot light. All samples were sorted into major groups (mainly orders). Collembola were further sorted to genus, then morphospecies by P. Greenslade and, where possible, identified to named species. Species level identification provided an assessment of exotic *versus* native taxa. Vouchers have been lodged with the South Australian Museum, Adelaide.

Every second metre along the 30-m transects the litter (leaves, twigs, etc.) in a 25 × 25 cm quadrat was collected. These samples were allowed to air dry at room temperature for 1 week before weighing. The percentage of the litter sample by weight that was derived from the pasture (grasses) and from the tree (leaves and twigs) was calculated for each sample. At the same points, samples of soil (approximately 0.5 kg) from the surface of mineral soil down to 10 cm were taken. These samples were analysed for total nitrogen with the Kjeldahl method (Bremner 1965); organic carbon, determined by potassium dichromate oxidation plus titration with iron(II)sulphate using a potentiometric auto-titrator (Allison 1965); extractable phosphorus, using Bray no. 1 (0.025 N HCL, 0.03 N NH<sub>4</sub>F, Bray & Kurtz 1945); electrical conductivity, measured with a conductivity cell with internal temperature compensation (Raymont & Higginson 1992); and pH, measured in a 1 : 5 solution of soil : 0.01 M CaCl<sub>2</sub> (Raymont & Higginson 1992). A separate soil core (depth = 10 cm, diameter = 4 cm) was also taken every second metre after all leaf litter had been cleared for analysis of bulk density. All soil analyses were conducted by personnel at the

Gunnedah Research Centre, Department of Land and Water Conservation, New South Wales, Australia.

### Data analysis

*Is there a difference between the invertebrate assemblages found under paddock trees compared with the surrounding grazed native pastures?*

Multi-response permutation procedures tested for statistical difference between the assemblages from the two habitats using PC-ORD (McCune & Mefford 1999) and the Bray–Curtis association measure. Differences were examined at coarse (orders) and fine (ant morphospecies) taxonomic levels. Data were transformed ( $x^{0.5}$ ) prior to statistical analysis so that results were not dominated by the few superabundant taxa. Rank-abundance distributions were also generated to compare graphically the ground-active invertebrate assemblages associated with the scattered trees and the open paddock. Prior to plotting, data from all 24 pitfall traps on the star design at each of 12 sites were pooled, and the abundances of each major group and ant morphospecies were tallied.

*Can gradients in soil and litter variables from the base of trees explain the patterns in invertebrate assemblages?*

Simple correlation was used to test the degree to which the presence of trees resulted in gradients in soil and litter variables and the degree to which these gradients explained change in invertebrate abundance and richness.

To test the degree to which gradients in soil and litter variables explained change in invertebrate assemblages (species composition and abundance at sampling points), the direct gradient analysis technique canonical correspondence analysis (CCA) was used (CANOCO for Windows, version 4, Ter Braak & Smilauer 1998). Canonical correspondence analysis constructs axes of variation in the invertebrate assemblages, and these axes are constrained to be linear combinations of the environmental variables (Ter Braak & Prentice 1988). Monte Carlo permutations ( $n = 9999$ ) were then used to test for statistically significant explanatory variables. Permutations were restricted by block (tree identification), which takes into account sampling at a number of different locations (trees) and provides a test for common within-location variation (Ter Braak & Smilauer 1998). Permutations were further restricted to linear transects, which takes into account the spatial autocorrelation structure of the regular linear sampling design at each tree (Ter Braak & Smilauer 1998).

We first tested the significance of the variance explained by each environmental variable (and dis-

tance from the tree bases) individually (the marginal effect). We then used the forward selection procedure to build minimum models which explained the maximum variation in the invertebrate assemblages (the conditional effect, Ter Braak & Verdonschot 1995). The variable 'metres from tree bases' was not included in these latter analyses as relationships between this variable and change in invertebrate assemblages were purely correlative, and we were most interested in building models that included potential causative variables. Because soil and vegetation variables were only assessed every 2 m, only those invertebrate data recorded from the same 15 sample points on each transect were submitted for analyses by CCA. Analyses were performed on raw data, where very abundant taxa had large influence over results, and on transformed data ( $x^{0.5}$ ) where the influence of very abundant taxa was reduced.

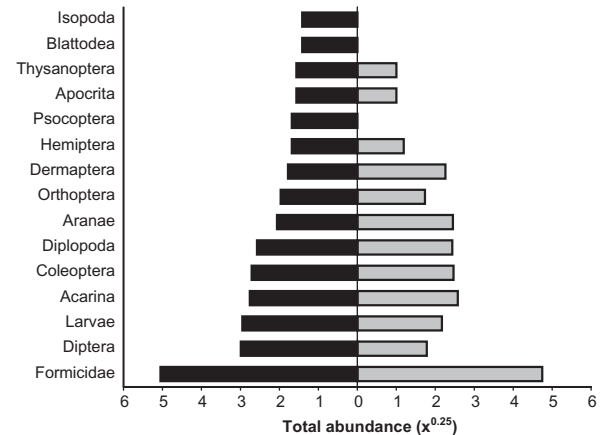
*Does the presence of paddock trees have implications for the conservation of terrestrial invertebrate biodiversity in grazed native systems?*

To begin to answer this question we first investigated the pooled richness among transects. That is, we pooled the data from each tree at each metre and tallied the total number of different Formicidae and Collembolan taxa sampled at each metre along all transects. We calculated moving averages along the 30 m transects and plotted the resultant curve to show how many different taxa were represented at different distances across all trees. We then used the information on origin of Collembolan taxa to determine whether there was a decline in the relative abundance of native compared with exotic Collembolan specimens with increasing distance from the tree base.

## RESULTS

### Is there a difference between the invertebrate assemblages found under paddock trees compared with the surrounding grazed native pastures?

Rank-abundance distributions of data at the coarse taxonomic level revealed that Formicidae (ants) dominated the pitfall trap samples (Fig. 2). Overall, the rank-abundance distributions were dissimilar, with fewer specimens and fewer major groups in the open paddock. Isopoda (slaters), Blattodea (cockroaches) and Psocoptera (booklice) were only recorded under the trees. The same trends were revealed at the fine taxonomic level, with numbers of Formicidae and numbers of morphospecies lower in the open paddock (Fig. 3). Multi-response permutation procedures revealed these differences between assemblages in the



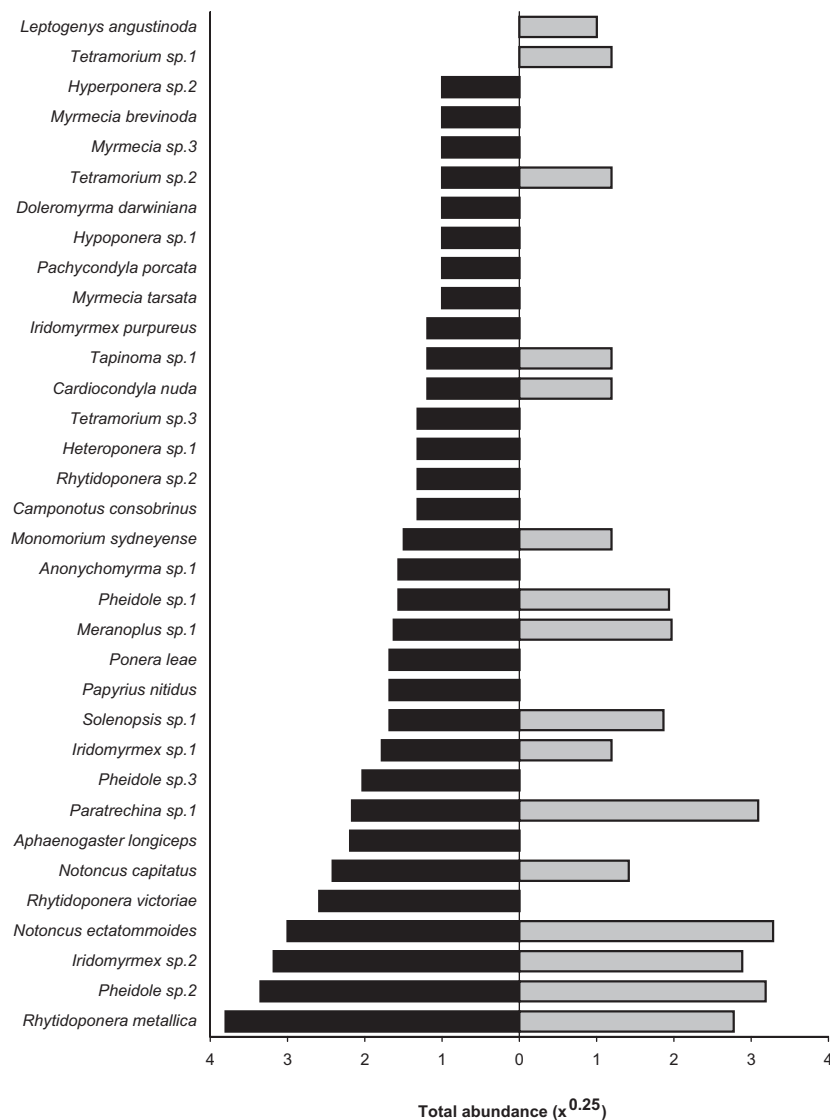
**Fig. 2.** Rank-abundance plots of arthropod major groups sampled in 1998 by pitfall traps under trees and in the (□) open paddock ( $n = 729$ ). Collembola were excluded because of flooding of some traps. (■) refers to scattered trees,  $n = 1042$ .

two habitats to be significant at both the coarse ( $P = 0.004$ ) and the fine-taxonomic levels ( $P = 0.014$ ).

### Can gradients in soil and vegetation variables from the base of trees explain the patterns in invertebrate assemblages?

Simple linear correlations revealed significant negative correlations between distance from the trees and total litter, percentage of tree litter, percentage of organic carbon, percentage of total nitrogen, carbon : nitrogen ratio and electrical conductivity, and significant positive correlations between distance from the trees and pH, and bulk density (Table 1). Plots of these gradients showed that the percentage of organic carbon, total nitrogen and electrical conductivity declined rapidly with increasing distance from tree bases and reached minimum levels at a distance equal to the average extent of the canopy (Fig. 4). Although no significant correlation was found between distance and extractable phosphorus over the 30-m transect, it also reached minimum levels near the extent of the canopy. The two litter parameters declined rapidly over the 30 m transects (Fig. 5). These gradients in soil and litter parameters explained significant amounts of variation in the abundance and richness of Collembola and Formicidae (Table 1). Abundance of Collembola and Formicidae declined significantly with the natural logarithm of distance from the tree bases (d.f. = 178,  $r = -0.22$ ,  $P < 0.01$  and  $r = -0.15$ ,  $P < 0.05$ , respectively), as did the richness of Formicidae ( $r = -0.27$ ,  $P < 0.001$ ; Fig. 5).

Direct gradient analysis (CCA) revealed that results were very similar regardless of whether data were raw or transformed. All variables, with the exception of pH for Collembola, individually explained significant vari-

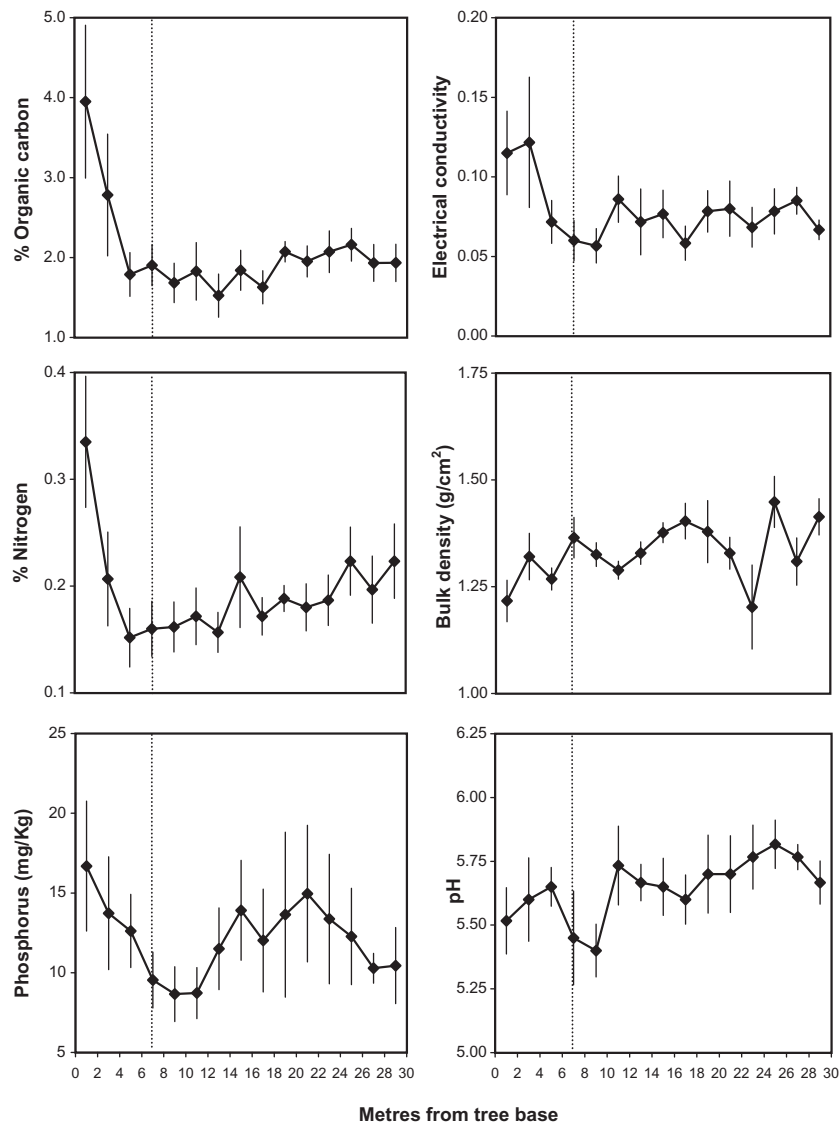


**Fig. 3.** Rank-abundance plots of Formicidae morphospecies sampled by pitfall traps in 1998 under trees and in the (□) open paddock (*n* = 496). (■) refers to scattered trees, *n* = 744.

**Table 1.** Simple correlations between vegetation and soil variables, and the natural logarithm of distance from tree bases and the abundance and richness of Collembola and Formicidae assemblages

	Distance from tree (In metre)	Collembola Abundance	Richness	Formicidae Abundance	Richness
Total litter	-0.75***	0.42***	ns	ns	ns
Tree litter (%)	-0.87***	0.21*	ns	ns	0.26*
Carbon (%)	-0.40***	0.70***	0.24*	ns	ns
Nitrogen (%)	-0.24*	0.61***	ns	ns	ns
Carbon : nitrogen ratio	-0.25*	ns	ns	ns	ns
Phosphorus	ns	0.45**	0.31*	ns	ns
pH	0.23*	ns	ns	ns	-0.27**
Electrical conductivity	-0.25*	0.59***	0.32*	-0.23*	ns
Bulk density	0.26*	ns	ns	ns	ns

ns *P* > 0.05, \**P* < 0.05, \*\**P* < 0.01, \*\*\**P* < 0.001. Data for all six trees were pooled prior to analysis (*n* = 90).



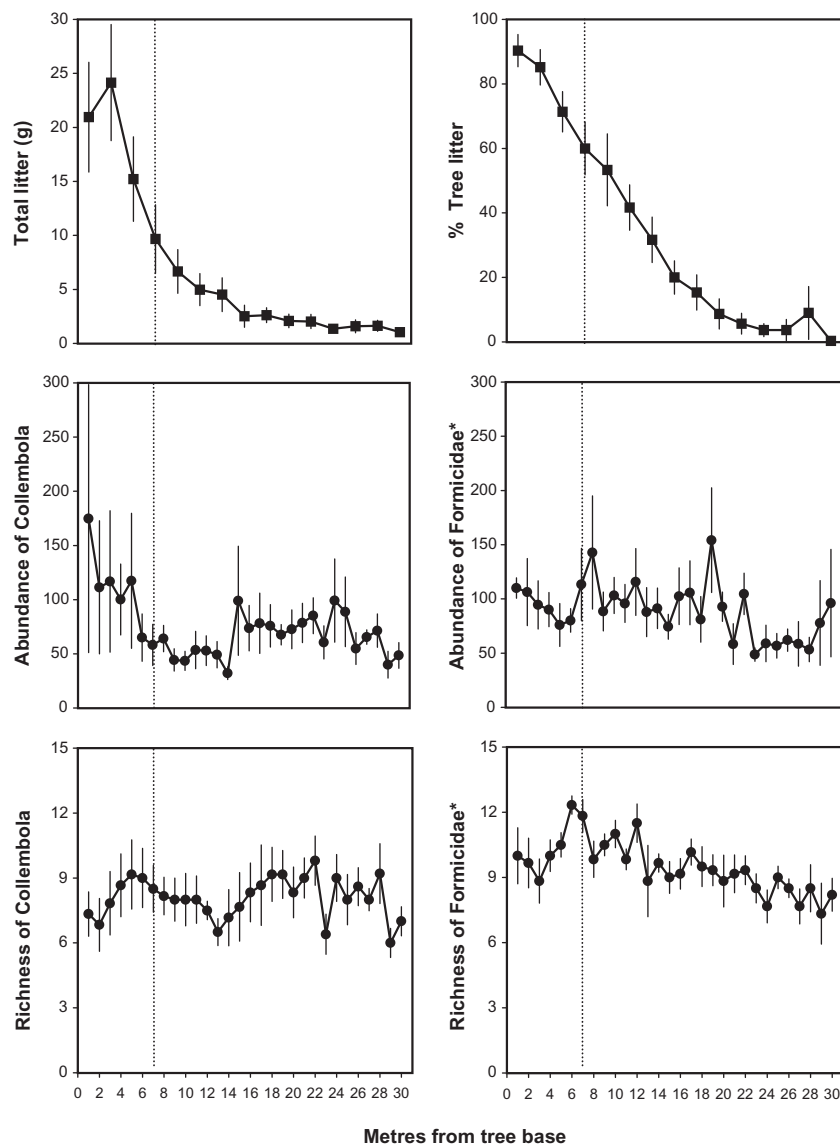
**Fig. 4.** Gradients in soil variables from the tree bases into the open paddock. Vertical dotted line indicates the average distance of the canopy edge from the tree bases. Error bars show one standard error about the mean.

ation in the assemblages (Table 2, marginal results). The Collembola minimum model excluded electrical conductivity and bulk density but included pH, whereas the Formicidae minimum model contained only five of the nine variables (Table 2, conditional results). Minimum models explained up to 29% and 22% of the variation in Collembola and Formicidae assemblages, respectively, with litter variables explaining the most variation for both assemblages.

**Does the presence of paddock trees have implications for the conservation of terrestrial invertebrate biodiversity in grazed native pastures?**

Fifty-eight Formicidae morphospecies were sampled by pitfall traps in both sampling periods and 34 Col-

lembolan taxa were identified from the 1998 soil cores. Pooling data among trees at each distance from the tree base revealed the trees to be an important contributor to the conservation of Formicidae within grazed native pastures, with nearly twice as many morphospecies recorded at any distance under the canopy compared with any distance beyond 20 m (Fig. 6). Combining these data into distance classes showed that 48 out of a total of 53 morphospecies (sampled in 1999) were recorded from the six transects in the first 7 m from the tree bases. In comparison, only 23 morphospecies were recorded from the last 7 m of the transects. Samples in the 8- to 14-m distance class added three morphospecies (to those recorded in the 1- to 7-m samples), and all remaining samples (15-30 m) added the final two morphospecies.



**Fig. 5.** Gradients in litter and invertebrate variables from the tree bases into the open paddock. Vertical dotted line indicates the average distance of the canopy edge from the tree bases. Error bars show one standard error about the mean. \*Formicidae from the 1999 samples.

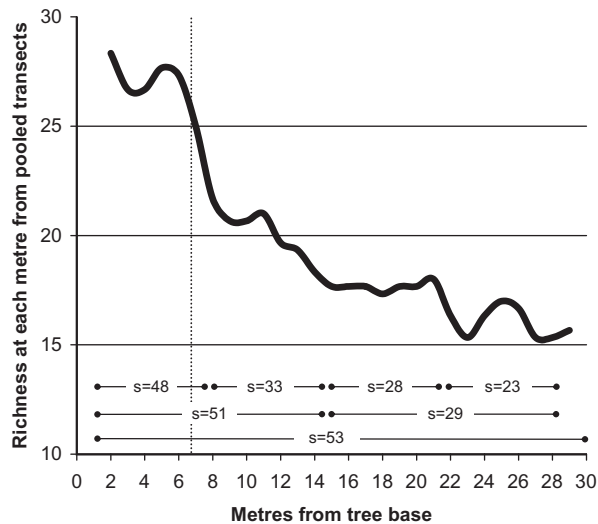
The pooled data did not reveal the same trends for Collembola with similar numbers of species sampled under and outside the canopy (Fig. 7). However, further analyses of the Collembolan data using information on the origin of the taxa revealed a similar trend. Nine Collembola were exotic species, 17 were known or probable native species, five were undetermined and four were immatures that could not be identified lower than family. The immatures and undetermined taxa were excluded from the following analyses. Similar trends in the relative abundance of native Collembolan individuals with increasing distance from the tree base were detected for five of the six trees (Fig. 8). With the exception of Tree V, which had experienced local flooding, smoothed relative abundance of native

Collembola peaked around the canopy edge between 5 m and 11 m and dropped rapidly thereafter. Averaging these data among the five trees (Fig. 9, excluding Tree V) revealed that the relative abundance of native Collembola was around 50% within the first few metres from the tree base and rose to a maximum of 64% 2.5 m short of the average canopy edge. Outside the canopy, the average relative abundance of native Collembola fell rapidly to around 25% at 11 m from the tree base and continued to decline gradually to a minimum of around 20% at 29 m. The negative relationship between relative abundance of native Collembola and the natural logarithm of distance from tree bases was highly significant (d.f. = 148,  $r = -0.46$ ,  $P < 0.001$ ).

**Table 2.** Proportion of variation explained (marginal and conditional) in the Collembola and Formicidae assemblages using raw and transformed abundance data

	Collembola		Conditional		Formicidae		Conditional	
	Marginal Raw	$x^{0.5}$	Raw	$x^{0.5}$	Marginal Raw	$x^{0.5}$	Raw	$x^{0.5}$
Distance from tree	0.11***	0.08***	nt	nt	0.10***	0.09***	nt	nt
Total litter	0.11***	0.10***	0.11***	0.10***	0.04*	0.03*	ns	ns
Tree litter (%)	0.09***	0.08***	0.02*	0.03***	0.09***	0.08***	0.09***	0.08***
Organic carbon (%)	0.10***	0.07***	0.07***	0.02**	0.03*	0.03*	ns	ns
Nitrogen (%)	0.10***	0.07***	0.02*	0.05***	0.03*	0.03*	0.03*	0.02*
Carbon : nitrogen ratio	0.04*	0.03*	0.03***	0.02**	0.02*	ns	ns	ns
Phosphorus	0.06**	0.03**	0.02**	0.02**	0.03*	0.03**	0.02**	0.02*
pH	ns	ns	0.02*	ns	0.05**	0.07***	0.05***	0.05***
Electrical conductivity	0.08***	0.06***	ns	ns	0.03*	0.03*	ns	ns
Bulk density	0.03*	0.02*	ns	ns	0.06**	0.04*	0.03*	0.02*
Total explained	0.32	0.27	0.29	0.24	0.27	0.24	0.22	0.19

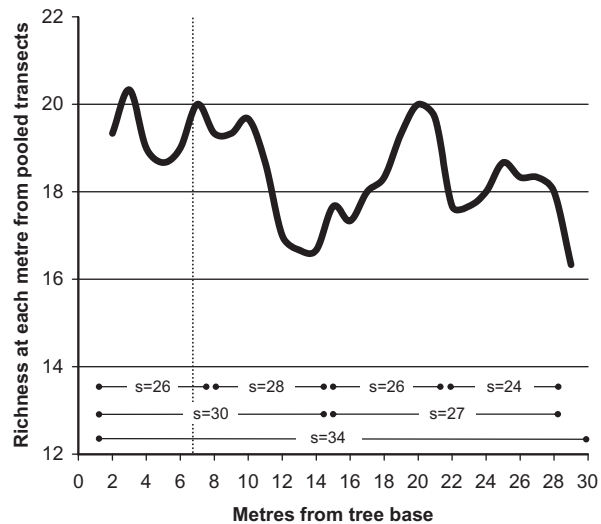
ns  $P > 0.05$ , \*  $P < 0.05$ , \*\*  $P < 0.01$ , \*\*\*  $P < 0.001$ . Variation explained: marginal – inertia attributed to variables considered individually divided by the sum of all unconstrained eigenvalues, conditional – inertia of each additional variable, in conjunction with the variable(s) already selected, divided by the sum of all unconstrained eigenvalues (see *Methods* section). Total explained: marginal – sum of all canonical eigenvalues divided by sum of all unconstrained eigenvalues when the model included all variables except distance from tree, conditional – sum of all canonical eigenvalues divided by sum of all unconstrained eigenvalues when the model included only those variables contained within the minimum model. Significance was tested by reduced model Monte Carlo permutation tests with 9999 permutations (see *Methods* section). nt, not tested.



**Fig. 6.** Richness of Formicidae\* at each metre using data pooled from six transects. Data plotted are moving averages of the datum recorded at the sample point and the data from 1 m either side of the sample point. Total richness\* of groups of traps in distance classes are also shown below the curve. Vertical dotted line indicates the average distance of the canopy edge from the tree bases. (\*Formicidae from the 1999 samples).

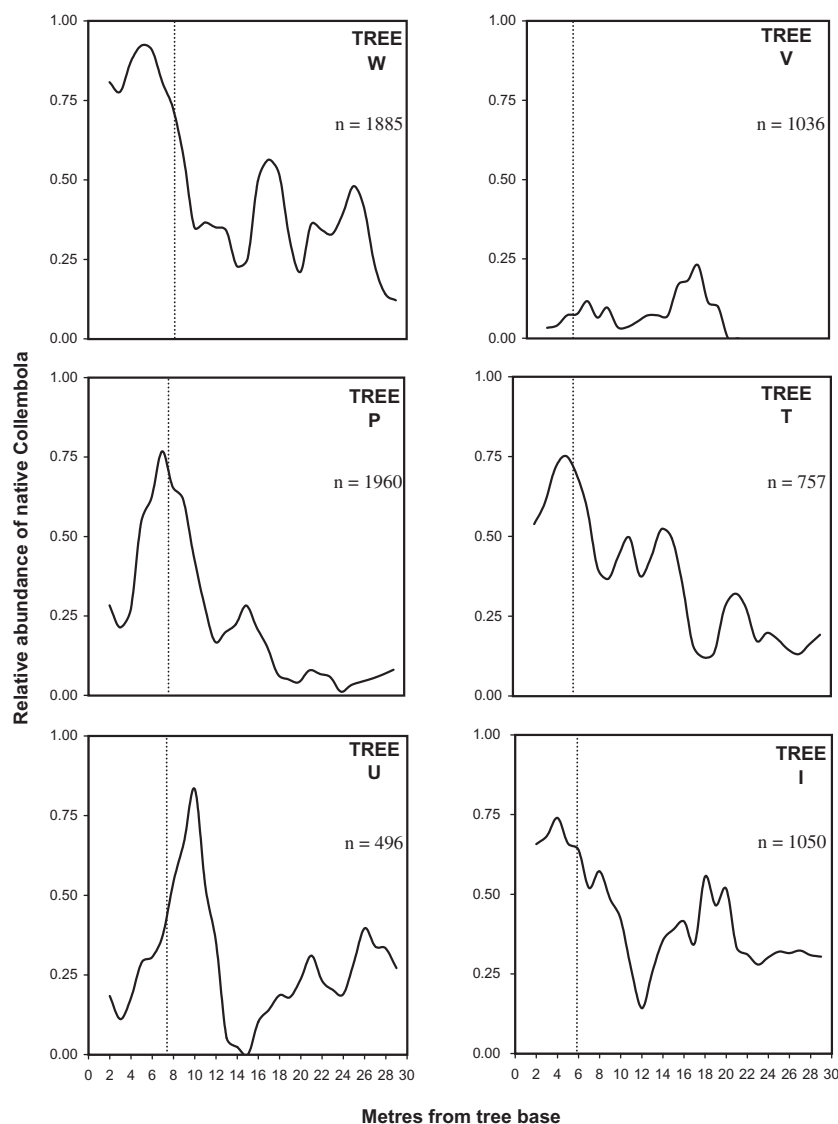
## DISCUSSION

Gradients in litter and soil variables were correlated with distance from tree bases and explained significant amounts of variation in invertebrate assemblages. Large changes with distance from tree bases were



**Fig. 7.** Richness of Collembola at each metre using data pooled from five transects (Tree V was excluded because of local flooding). Figure generated as for Figure 6.

observed for total litter and percentage of tree litter, variables that explained the largest amounts of variation in both Collembola and Formicidae assemblages. Litter depth and complexity is well known to be an important influence on ground-active and soil invertebrate assemblages (Huhta 1976; Uetz 1979; Oliver *et al.* 2000; York 2000). However, litter not only provides shelter and habitat for invertebrates and their prey, but also affects soil organic matter and soil nutrients.

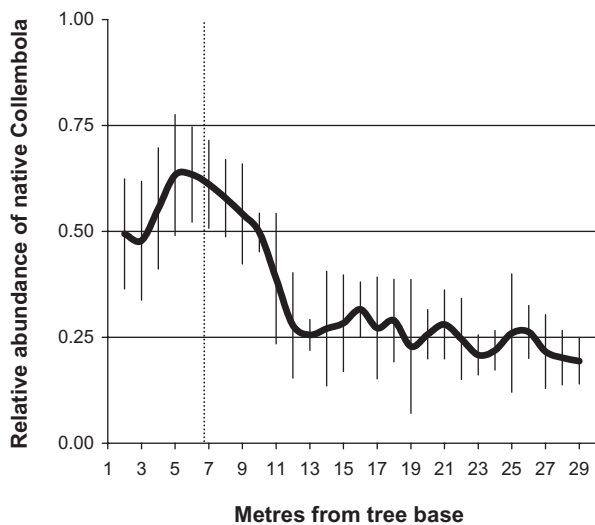


**Fig. 8.** Relative abundance of native Collembola for each of the six trees. Data presented are moving averages of the datum recorded at the sample point and the data from 1 m either side of the sample point. Vertical dotted lines indicate the distance of the canopy edge from each tree base. *n*, the total number of native and exotic Collembola recorded from the transect.

Soil nutrient concentrations (extractable phosphorus, total nitrogen and organic carbon) were also highest near the tree bases where total litter and percentage of tree litter were at their maximum. This pattern in soil nutrients is commonly found around trees and is believed to be the direct result of larger quantities of litter accumulation around trees at the soil surface and to root activity at depth (Ryan & McGarity 1983; Belsky *et al.* 1989; Wilson 2002; Graham *et al.* 2004). However, nutrient accumulation in the soils around trees will also result from the washing of windblown material from leaves and stems during rainfall and the deposition of nitrogen and phosphorus by the arboreal insects, birds and mammals that use the trees. A fur-

ther source of nutrients to the soils under trees comes from animals that shelter under them (Taylor & Hedges 1984; Taylor *et al.* 1984; Wilson 2002); however, our study did not find significantly higher quantities of sheep dung under the trees (Sarina Pearce 1998 unpubl. data). Consequently, it is well established that paddock trees, either directly through litter deposition or root activity, or indirectly by concentration of nutrients from elsewhere, affect the fertility and chemical composition of soils in their vicinity.

Our study has shown that ground-active and soil invertebrate assemblages are particularly sensitive to these spatial changes in litter and soil variables. Increases in total litter, percentage of tree litter, per-



**Fig. 9.** Relative abundance of native Collembola averaged across trees. Relative abundances of native Collembola at each sample point were first averaged among five trees (Tree V excluded). Error bars show one standard error about the mean. Moving averages were then calculated as for Figure 8. Vertical dotted line indicates the average distance of the canopy edge from the tree bases.

centage of organic carbon, percentage of total nitrogen and extractable phosphorus were significantly correlated with increases in the abundance of Collembola and, to a lesser extent, the richness of Collembola and Formicidae (univariate analyses), and the majority of the soil and litter variables explained significant variation in Collembola and Formicidae assemblages (multivariate analyses). Importantly, these tree-induced litter and soil changes were correlated with more native invertebrates, and more species of invertebrates under trees compared with the open paddock. Clearly, paddock trees make an important contribution to the conservation of terrestrial invertebrate biodiversity in native plant dominated grazing systems.

The extent to which paddock trees within native plant-dominated grazing systems complement terrestrial invertebrate biodiversity conservation in larger remnants, although beyond the scope of this study, is likely to be considerable in those landscapes where paddock trees represent a large proportion of the remaining remnant vegetation (Gibbons & Boak 2002; Carruthers *et al.* 2004). In these landscapes, reversing the decline of paddock trees is likely to be of major importance to the conservation of biodiversity.

Paddock trees are exposed to greater stresses from wind, insolation and herbivore attack compared with trees in patches. Fertilizers, pesticides, grazing stock and insect attack place additional stress on paddock trees in grazing systems, leading to accelerated rates of dieback (MacKay 1978; Heatwole & Lowman 1986; Landsberg *et al.* 1990; Reid & Landsberg 2000).

Similar pressures affect recruitment, and in one study in Western Australia not a single recruitment event was observed within a woodland patch since 1929 when the patch was isolated by clearing for agriculture, and domestic livestock were allowed to graze the patch. (Saunders *et al.* 2003). Consequently, paddock trees are declining at rates of between 0.54% and 2.5% per annum (Kile 1980; Landsberg & Gillieson 1995; Reid & Landsberg 2000; Gibbons & Boak 2002) and may be lost from some regions of Australia within as little as 40 years if no action is taken (Gibbons & Boak 2002).

We have shown that within these landscapes paddock trees and tree patches are logical foci upon which conservation-effective regeneration and revegetation efforts can concentrate (also see Abensperg-Traun 2000). They also present a salient reminder that many landscapes are variegated (McIntyre & Hobbs 1999) and that a single location within such a landscape has both production and biodiversity values. Managing these joint values as part of integrated natural resource management rather than viewing them as a production *versus* conservation dichotomy is a challenge for ecologists and land managers alike.

## ACKNOWLEDGEMENTS

We would like to thank Bob Crouch and Peter Smith from the former New South Wales Department of Land and Water Conservation and Andy Beattie from the Key Centre for Biodiversity and Bioresources for financial and intellectual support of this project in the early stages. Access to the 'Newholme' field station was provided and supported by Nick Reid and Jim Fittler from the University of New England. Field assistance was provided by Craig Angus, Caroline Gross, Chris Nadolny and Bill Upjohn. Sample processing was assisted by Kath King and David Dight. Many thanks are extended to Derek Smith from the Australian Museum, Sydney for taxonomic verification and identification of the Formicidae. This paper has benefited from comments provided at various times by Mike Bull, Mark Dangerfield, Phillip Norman, Mark Westoby, Brian Wilson and three anonymous reviewers.

## REFERENCES

- Abensperg-Traun M. (2000) In defence of small habitat islands: termites (Isoptera) in the Western Australian central wheat-belt, and the importance of dispersal power in species occurrence. *Pacific Conserv. Biol.* **6**, 31–9.
- Allison L. E. (1965) Organic carbon. In: *Methods of Soil Analysis* (eds C. A. Black, D. D. Evans, J. L. White, L. E. Ensminger & F. E. Clark) pp. 1372–8. American Society of Agronomy, Madison, WI.

- Anonymous (2001) *Paddock Trees: Who'll Miss Them When They're Gone*. New South Wales Land and Water Conservation, New South Wales National Parks and Wildlife Service and Greening Australia, Wagga Wagga.
- Belsky A. J., Amundson R. G., Duxbury J. M., Riha S. J., Ali A. R. & Mwonga M. (1989) The effects of trees on their physical, chemical, and biological environments in semi-arid savanna in Kenya. *J. Appl. Ecol.* **26**, 1005–24.
- Bray R. H. & Kurtz L. T. (1945) Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.* **59**, 39–45.
- Bremner J. M. (1965) Total nitrogen. In: *Methods of Soil Analysis* (eds C. A. Black, D. D. Evans, J. L. White, L. E. Enisminger & F. E. Clark) pp. 1149–76. American Society of Agronomy, Wisconsin.
- Bromham L., Cardillo M., Bennet A. F. & Elgar M. A. (1999) Effects of stock grazing on the ground invertebrate fauna of woodland remnants. *Aust. J. Ecol.* **24**, 199–207.
- Brouwer A. C. & Crijns D. M. H. (1994) *Property Management Plan for Newholme Field Laboratory*. Wageningen Agricultural University, Wageningen.
- Carruthers S., Bickerton H., Carpenter G., Brook A. & Hodder M. (2004) *A Landscape Approach to Determine the Ecological Value of Scattered Trees*. Summary Report Years 1 & 2. Biodiversity Assessment Services, South Australian Department of Water, Land and Biodiversity Conservation, Adelaide.
- Chilcott C., Reid N. & King K. (1997) Impact of trees on the diversity of pasture species and soil biota in grazed landscapes on the Northern Tablelands, NSW. In: *Conservation Outside Nature Reserves* (eds P. Hale & D. Lamb) pp. 378–86. Centre for Conservation Biology, the University of Queensland, Brisbane.
- Fischer J. & Lindenmayer D. B. (2002a) The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 1. Species composition and site occupancy patterns. *Biodivers. Conserv.* **11**, 807–32.
- Fischer J. & Lindenmayer D. B. (2002b) The conservation value of paddock trees for birds in a variegated landscape in southern New South Wales. 2. Paddock trees as stepping stones. *Biodivers. Conserv.* **11**, 833–49.
- Gibbons P. & Boak M. (2002) The value of paddock trees for regional conservation in an agricultural landscape. *Ecol. Manage. Restor.* **3**, 205–10.
- Gibbons P. & Lindenmayer D. B. (2002) *Tree Hollows and Wildlife Conservation in Australia*. CSIRO Publishing, Melbourne.
- Graham S., Wilson B. R. & Reid N. (2004) Scattered paddock trees, litter chemistry and surface soil properties in pastures on the New England Tablelands, NSW. *Aust. J. Soil Res.* **42**, 905–12.
- Heatwole H. & Lowman M. (1986) *Dieback: Death of an Australian Landscape*. Reed Books, Sydney.
- Heisler C. (1995) Collembola and Gamasina – bioindicators for soil compaction. *Acta Zool. Fennica* **196**, 229–31.
- Huhta V. (1976) Effects of clear-cutting on numbers, biomass and community respiration on soil invertebrates. *Ann. Zool. Fennica* **13**, 63–80.
- Kile G. A. (1980) An overview of eucalypt dieback in rural Australia. In: *Eucalypt Dieback in Forests and Woodlands* (eds K. M. Old, G. A. Kile & C. P. Ohmart) pp. 13–26. CSIRO, Melbourne.
- King K. L. & Hutchinson K. J. (1976) The effects of sheep stocking intensity on the abundance and distribution of mesofauna in pastures. *J. Appl. Ecol.* **13**, 41–55.
- King K. L. & Hutchinson K. J. (1980) Effects of superphosphate and stocking intensity on grassland microarthropods. *J. Appl. Ecol.* **17**, 581–91.
- King K. L. & Hutchinson K. J. (1983) The effects of sheep grazing on invertebrate numbers and biomass in unfertilised natural pastures of the New England Tablelands, NSW. *Aust. J. Ecol.* **8**, 245–55.
- King K. L., Hutchinson K. J. & Greenslade P. (1976) The effects of sheep numbers on associations of Collembola in sown pastures. *J. Appl. Ecol.* **13**, 731–9.
- King K. L., Greenslade P. & Hutchinson K. J. (1985) Collembolan associations in natural versus improved pastures of the New England Tablelands, NSW: distribution of native and introduced species. *Aust. J. Ecol.* **10**, 421–7.
- Landsberg J. & Gillieson D. S. (1995) Regional and local variation in insect herbivory, vegetation and soils of eucalypt associations in contrasted landscape positions along a climatic gradient. *Aust. J. Ecol.* **20**, 299–315.
- Landsberg J., Morse J. & Khanna P. (1990) Tree dieback and insect dynamics in remnants of native woodlands on farms. *Proc. Ecol. Soc. Aust.* **16**, 149–65.
- Law B. S., Chidel M. & Turner G. (2000) The use by wildlife of paddock trees in farmland. *Pacific Conserv. Biol.* **6**, 130–43.
- Lumsden L. (1993) Bats. Nature's nocturnal insect controllers. *Trees Nat. Res.* **December**, 8–11.
- McCune B. & Mefford M. J. (1999) *PC-ORD. Multivariate Analysis of Ecological Data*, Version 4. MjM Software Design, Gleneden Beach, OR.
- McIntyre S. & Hobbs R. (1999) A framework for conceptualizing human effects on landscapes and its relevance to management and research models. *Conserv. Biol.* **13**, 1282–92.
- MacKay S. (1978) Dying eucalypts of the New England Tablelands. *For. Timber* **14**, 18–20.
- Majer J. D. & Delabie J. H. C. (1999) Impact of tree isolation on arboreal and ground ant communities in cleared pasture in the Atlantic rain forest region of Bahia, Brazil. *Insectes Sociaux.* **46**, 281–90.
- Majer J. D. & Recher H. (2000) A tree alone. *Nat. Aust.* **26**, 58–65.
- Oliver I. & Beattie A. J. (1993) A possible method for the rapid assessment of biodiversity. *Conserv. Biol.* **7**, 562–8.
- Oliver I. & Beattie A. J. (1996) Invertebrate morphospecies as surrogates for species: a case study. *Conserv. Biol.* **10**, 99–109.
- Oliver I., MacNally R. & York A. (2000) Identifying performance indicators of the effects of forest management on ground-active arthropod biodiversity using hierarchical partitioning and partial canonical correspondence analysis. *For. Ecol. Manage.* **139**, 21–40.
- Oliver I., Garden D., Haller B., Greenslade P. J., Rodgers D. & Seeman O. (2005) Pasture improvement and grazing effects on the invertebrate biodiversity of native grasslands in south-east Australia. *Agric. Ecosyst. Environ.* **109**, 323–34.
- Ozolin A., Brack C. & Freudenberger D. (2001) Abundance and decline of isolated trees in the agricultural landscapes of Central New South Wales. *Pacific Conserv. Biol.* **7**, 195–203.
- Raymont G. E. & Higginson F. R. (1992) *Australian Laboratory Handbook of Soil and Chemical Methods*. Inkata Press, Melbourne.
- Reid R. & Bird P. R. (1990) Shade and shelter. In: *Trees for Rural Australia* (ed. K. W. Cremer) pp. 319–35. Inkata Press, Melbourne.

- Reid N. & 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 & C. J. Yates) pp. 127–66. Surrey, Beatty and Sons, Sydney.
- Reid N., Boulton A., Nott R. & Chilcott C. (1997) Ecological sustainability of grazed landscapes on the Northern Tablelands of New South Wales (Australia). In: *Frontiers in Ecology: Building the Links* (eds N. Klomp & I. Lunt) pp. 117–30. Elsevier Science, Oxford.
- Ryan P. J. & McGarity J. W. (1983) The nature and spatial variability of soil properties adjacent to large forest eucalypts. *J. Soil Sci. Soc. Am.* **47**, 286–93.
- Saunders D. A., Smith G. T., Ingram J. A. & Forrester R. I. (2003) Changes in a remnant of salmon gum *Eucalyptus salmonophloia* and York gum *E. loxophleba* woodland, 1978 to 1997. Implications for woodland conservation in the wheat-sheep regions of Australia. *Biol. Conserv.* **110**, 245–56.
- Taylor J. A. & Hedges D. A. (1984) Some characteristics of the trees used by sheep for diurnal camping and differences between the shade and nocturnal camping in a paddock on the Northern Tablelands of New South Wales. *Aust. Range. J.* **6**, 3–9.
- Taylor J. A., Hedges D. A. & Whalley W. (1984) The occurrence and distribution and characteristics of sheep camps on the Northern Tablelands of NSW. *Aust. Range. J.* **6**, 10–16.
- Ter Braak C. J. & Prentice I. C. (1988) A theory of gradient analysis. *Adv. Ecol. Res.* **18**, 271–317.
- Ter Braak C. J. & Smilauer P. (1998) *canoco Reference Manual and User's Guide to Canoco for Windows*. Centre for Biometry, Wageningen.
- Ter Braak C. J. & Verdonschot P. F. (1995) Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquat. Sci.* **57**, 255–73.
- Tommerup I. C. & Bougher N. L. (2000) The role of ectomycorrhizal fungi in nutrient cycling in temperate Australian woodland. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs & C. J. Yates) pp. 190–224. Surrey, Beatty and Sons, Sydney.
- Uetz G. W. (1979) The influence of variation in litter habitats on spider communities. *Oecologia* **40**, 29–42.
- van der Ree R., Bennett A. F. & Gilmore D. C. (2003) Gap-crossing by gliding marsupials: thresholds for use of isolated woodland patches in an agricultural landscape. *Biol. Conserv.* **115**, 241–9.
- Walpole S. C. (1999) Assessment of the economic and ecological impacts of remnant vegetation on pasture productivity. *Pacific Conser. Biol.* **5**, 28–35.
- Wilson B. (2002) Influence of scattered paddock trees on surface soil properties: a study of the Northern Tablelands of NSW. *Ecol. Manage. Restor.* **3**, 211–19.
- York A. (2000) Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests of southeastern Australia. *Austral Ecol.* **25**, 83–98.
- Zhang L., Dawes W. R., Hatton T. J., Reece P. H., Beale G. T. H. & Packer I. (1999) Estimation of soil moisture and groundwater recharge using the TOPOG\_IRM model. *Water Resour. Res.* **35**, 149–61.