The Influence of Isolated Trees in Agro-ecosystems on Invertebrate Biodiversity

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Additional data are currently being produced and will be added as a supplement when they become available.

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Abstract

Isolated trees and clumps of trees are common features of the rural landscape of NSW. Past research has shown that isolated trees in agricultural landscapes influence many aspects of the biotic and abiotic environment. However, the contribution of isolated trees to invertebrate biodiversity conservation is currently unknown. This study characterises the ground active invertebrate assemblages associated with six isolated (*Eucalyptus nova-anglica*) trees and compares them with assemblages from the surrounding pasture matrix. The study was conducted at the Newholme field laboratory on the Northern tablelands of New South Wales. Further investigations concentrated on the isolated trees where soil invertebrates, and soil were sampled along 30m transects from the base of the six trees. Analysis of similarities showed that there was a significant difference between the assemblages of major invertebrate groups (namely Orders) found in pitfall traps under isolated trees compared with the open paddock. I used two approaches to analyse the transect data: Moving split window analysis (MSW) to search for boundaries in the biotic and abiotic multivariate data, and canonical correspondence analysis (CCA) to explore gradients in the data. MSW analysis using the soil data showed a consistent boundary at 6m and another at around15m. A similar pattern in the location of the first boundary was observed for invertebrate data from soil cores and pitfall traps and was consistent with the location of the canopy extent. The boundaries in the abiotic data suggest that the influence of the tree extends past the limits of the tree canopy. CCA showed that distance from tree base, and the soil characteristics, such as pH, electrical conductivity, bulk density, Nitrogen and organic matter, explained significant amounts of variation in the invertebrate assemblages. Finally an analysis of native versus introduced Collembola showed that native Collembola were proportionally more abundant under the tree canopy. These results show that although discrete communities were not detected at the canopy, root and pasture zones, there were changes in the assemblages as distance from trees increased, a finding related to a gradual decrease in occurrence of native Collembola with distance. Isolated trees therefore provide important habitat for native invertebrate species and are potentially important to invertebrate biodiversity conservation in grazed agro-ecosystems.

Introduction

Isolated trees and clumps of trees are common features of the rural landscape of NSW. European settlement preceded the removal of native vegetation (Beattie *et al*. 1992), and resulted in the widespread modification of native forest and woodland communities to monocultures of crop plants or “improved” native grazing pasture. Within these agro-ecosystems single trees or isolated clumps of trees which are the remnants of the past vegetation communities still remain.

The Native Vegetation conservation act (NVC Act; NSW government 1998) came into effect in January of 1998 to ensure the sustainable management of native vegetation in NSW. The Act contains few specific provisions for the maintenance of isolated trees on farms. Exemptions to the NVC Act include the cutting of up to seven trees per hectare in a year for on-farm uses, and the clearing of up to two hectares per annum. The clearance of isolated trees could therefore occur under these exemptions without inclusion in a regional vegetation management plan (RVMP), and without assessment and then approval by the Department of Land and Water Conservation.

It is timely to ask, do these isolated trees in agricultural matrices contribute to biodiversity conservation? Biodiversity, in the context of this paper, refers to the variety of invertebrates at both the major group, (namely ordinal) and species level of taxonomic resolution. Genetic and ecological components of biodiversity are not investigated in this paper.

Past research has shown that isolated trees in agricultural landscapes provide habitats for vertebrates including birds, bats and arboreal mammals, as well as shelter for migrating and nomadic species (Redpath 1998). However, the contribution of isolated trees to invertebrate biodiversity conservation is currently unknown.

Isolated trees are also known to affect the abiotic environment including hydrology, erosion and soil nutrients, factors which also influence agricultural productivity (Redpath 1998). However, little information exists on how far these effects extend into the agricultural matrix in Australian agro-ecosystems.

This study integrates a number of biotic and abiotic data to address these knowledge gaps. Primarily this study will investigate, 1. the differences between the invertebrate assemblages found under isolated trees and in the open paddock; and 2. the variation in invertebrate assemblages along sampling transects from the base of isolated trees. Conclusions will then be drawn as to the value of isolated trees in agro-ecosystems for biodiversity conservation.

For many organisms isolated trees are the ultimate habitat fragment in an otherwise modified agriculture matrix. They have been defined as trees around which the other components of the native vegetation community have been removed, often as a result of land clearance for agricultural purposes (DLWC 1998). The use of the term ‘isolated’ to describe these trees does not infer however that they are no longer linked by gene flow to other plants or are not involved in the ecological processes operating in the agricultural matrix (Hill *et al.* 1997). This matrix may range from a highly modified cropping system, through improved pasture, to native pasture in which tree-dominated patches are often described as “islands of high fertility” (Belsky and Canham 1994; Kellerman 1979). The concentration of nutrients in these patches is a result of high levels of organic matter from the decomposition of leaf litter fallen from the tree canopy. Belsky and Canham (1994) found that isolated trees in tropical savannas are associated with increased plant community diversity beneath the tree canopy.

Lamont (1985) defined three zones associated with isolated patches of *Eucalyptus wandoo* trees, within a mosaic of *E. wandoo* woodland and scrubland. A zone which corresponded to the tree canopy, a suppression zone embracing the canopy zone and the surrounding scrub zone which was external to the influence of the tree patch. These zones were recognised on the basis of field and experimentally determined attributes along transects from the centre of the tree patch. The classification of zones will also be considered in this investigation of isolated trees. For the purpose of this study, it is proposed that these zones include the above ground tree canopy zone, the below ground root canopy zone and the agricultural matrix which is external to the influence of the tree.

This study investigates the variation in invertebrate assemblages throughout the zones of influence of the isolated tree, and attempts to identify whether or not invertebrate communities and the soil itself, 1. exhibit boundaries consistent with the location of these zones, 2. Change gradually through these zones, or 3. Show no change.

It is hard to estimate accurately the benefits of isolated trees to land owners in dollars because the merits of isolated trees are hard to quantify in economic terms.
Isolated trees remain on properties because they increase agricultural productivity by providing shade and shelter for stock. Heat stress has been found to reduce calving rates,

increase calf mortality and reduce milk production in lactating cows (Reid and Bird 1990). Isolated trees also influence aspects of the abiotic environment which may have effects on pasture productivity. Redpath (1988) reports that isolated trees reduce wind and water erosion, control water table height (thus reducing the effects of salinity), and provide important associations with ectomycorrhizal fungi which aid in the uptake of nutrients from the generally nutrient-poor Australian soils.

Pasture productivity is directly related to soil quality and climate. Soil quality can be considered as the degree to which soil can promote plant growth, partition water and ameliorate environmental contamination by acting as a buffer (Linden *et al.* 1994). As the activities of soil animals influence many of the processes that underlie the functional properties of the soil, some measure of faunal abundance, diversity, or activity may provide a useful indicator of soil quality and hence pasture productivity. Soil invertebrates play a vital role in ecosystem processes, such as nutrient cycling (King 1991; Hutchinson and King 1980; Beare *et al.* 1992), water transmission and retention, and the maintenance of soil structure through soil turnover, loosening and aggregation (Lal 1991; Lee 1983; Lobry De Bruyn *et al.*1997). All these services provided by invertebrates serve to maintain the health of the soil ecosystem. It is these indirect economic benefits of isolated trees that relate to the long-term stability of the agro-ecosystem, and that are often the hardest to quantify in monetary terms. Invertebrate communities are sensitive to agricultural management practices. Stocking intensity has been found to affect the abundance and biomass of many invertebrates (Hutchinson and King 1980).

Increased sheep numbers on native pasture severely reduced the numbers of Collembola. Changes in mesofaunal (0.2mm - 10mm length, Lal 1991) abundance have been correlated to changes in herbage, litter, roots, soil pore space and the microclimate that were modified directly or indirectly by the activities of the stock (King and Hutchinson 1976; King and Hutchinson 1980; King and Hutchinson 1983). Increased grazing by sheep has also been found to decrease species richness and result in a change in community composition towards introduced Collembola species (King *et al.* 1985; King *et al.* 1976). In light of these findings, I also investigated the degree to which grazing stock utilize the isolated tree habitat, and whether abiotic variables, including distance from tree, could be used to explain the patterns in the invertebrate assemblages observed.

Methods

Study Site

The study was conducted at the Newholme field laboratory situated on the Northern Tablelands of New South Wales, 10km north of Armidale (latitude $30^0$31'S, altitude 1400m a.s.l., Fig.1). Newholme is located amongst grazing country that has been largely cleared of native woody vegetation to promote the establishment of pastures (Brouwer and Crijns 1994; Reid *et al.* 1996). The area has a cool temperate climate with a mean annual rainfall of about 870mm with a summer incidence of about 65% (King and Hutchinson 1980; 1976). Further fragmentation of the woodland occurred when *Eucalyptus* spp. in the area were heavily impacted by 'dieback' in the 1960s and 1970s (MacKay 1978; Reid *et al*. 1997).

The experimental sites were located within a single paddock, "Corn" with Lateritic podzolic soils at the South-Eastern base of Mount Duval (Fig. 2). The paddock was fertilised with aerial applications of superphosphate (125 kg/ha) in 1983, 1985, 1997 and 1998, and a single aerial application of white clover (*Trifolium repens*) in 1983. The pasture supports both sheep and cattle at 6-8 dry sheep equivalents (DSE) per hectare per year (Brouwer and Crijns 1994).

Sampling Design

Open paddock sites

Six sites were marked within the open paddock by generating random bearings and random distances from the isolated trees. The minimum distance from the isolated tree was set at 50m. At each of these sites a star sampling pattern consisting of eight transects with points at 3m, 5m and 10m was marked with flags (Fig. 2, 3).

Isolated trees

Six isolated New England Peppermint *(Eucalyptus nova-anglica*) trees were chosen within the paddock. The trees were isolated from other woody vegetation by a minimum distance of 30 metres (Fig. 2).

The sampling pattern around each tree consisted of star design consisting of eight transects with points at 3m, 5m and 10m, as in the open paddock sites. At all six isolated trees the north transect of the star design was extended to 30m, with sampling points at every metre.

Trees were selected, as much as possible, to have similar characteristics (Table 1). Trees U and I were the smallest, and tree P had the most well developed ground litter layer surrounding the tree. Other features such as stock tracks, large ants nests and depressions were also recorded.

Assessment of Habitat Use by Grazing Stock

Estimates of dung density were used as an index of sheep and cattle camping behaviour at different habitats within the paddock. A star design sampling pattern was again used, with eight transects with points at 1m, 3m and 5m. This sampling design was repeated at 13 open paddock sites, 7 isolated trees, 5 isolated tree patches, at 3 sites within a single sheep camp at the top of the paddock, and at 3 sites within a single artificial wind break (Fig. 4).

Sampling Methods

Ground active invertebrates

Glass pitfall traps (length10cm, diameter, 2.5cm) were 2/3 filled with 100% ethanol and placed in the ground at each of the six open paddock sites. They were placed at the 3m, 5m and 10m points along each of the transects. At the isolated trees, they were placed similarly, and every metre along the north transect. The pitfalls were left out for 6 days and the rainfall and the maximum temperature recorded for each of these days.

All samples were washed through a 0.5mm sieve before sorting to ordinal level using a dissecting microscope. At the open paddock sites the 3m, 5m and 10m samples were pooled within sites to reduce sorting time. At the isolated trees each trap from the north transects was sorted individually but the 3m, 5m, and 10m samples from the remaining transects were pooled prior to sorting.

Soil Invertebrate

Soil Cores (10cm diameter) were taken at every metre along the 30m North transect for each of the six isolated trees. These samples included the litter layer and the soil to a depth of 5cm. Invertebrates were extracted for 6 days from the inverted cores in tullgren funnels heated from above with a 15 watt pilot light.

The animals from each soil core sample were sorted to ordinal level. The Collembola were then sorted to genus, and where possible to species level identification by Dr Penny

Greenslade. Information was also provided which identified which species were introduced, or native to the area.

Soil Characteristics

Samples of soil (~ 0.5kg) from the beginning of mineral soil down to 10cm were taken every second metre along the 30m north transect at each isolated tree. A separate soil core (10cm depth, 4cm diameter) was also taken every second metre after all leaf litter had been cleared for soil bulk density determination. Analysis of these soil samples was conducted by DLWC staff at the Gunnedah Research Centre. Analyses were performed according to the procedures outlined below (Dight *pers. com.* DLWC Gunnedah Research Centre).

Particle size analysis - The soil (50g) was shaken for 16 hours in 200 mls of 12.5% sodium polymetaphosphate/sodium carbonate solution. Periodic hydrometer readings were then taken to determine size fractions in suspension at set times. After approximately 7 hours, 45 minutes the suspension was sieved for the determination of sand fractions (Craze and Hamilton 1993).

Emerson aggregate test - Soil was divided into 8 classes according to the behaviour of the soil aggregate when immersed in water. Class 1 displayed maximum dispersion.

Kjeldahl Nitrogen test - The soil sample was boiled, with an added catalyst, in concentrated H_2SO_4. Sodium hydroxide was added to release NH_3 by steam distillation. The NH_3 was absorbed by dilute boric acid (H_2BO_3) and the total N determined by titration with standard acid (~ 0.05N H_2SO_4) (Bremner 1965).

Organic Carbon - Matter in the soil was oxidised by dichromate. The reaction was assisted by the heat generated when two volumes of H_2SO_4 are mixed with 1 volume of 1N $K_2Cr_2O_7$. External heat was added to bring the soil solution to 135^0C. The suspension was then titrated with iron(II)sulphate to determine the degrees of oxidisation using a potentiometric auto-titrator (Allison 1965).

Phosphorus - Phosphorus was extracted using Bray no. 1 (0.025N HCL, 0.03N NH_4F). The extract containing the soil sample was centrifuged and an aliquot taken for the analysis. A solution containing ammonium molybdate, potassium antimonyl tartrate, concentrated H_2SO_4

and ascorbic acid was added to the aliquot. The resulting colour development was measured using a double beam spectrophotometer (Bray 1945).

Electrical conductivity - A 1:5 soil water solution was made and allowed to settle. Measurement was then made with a conductivity cell with internal temperature compensation (Rayment and Higginson 1992).

PH- pH was determined using a combination electrode and a digital pH meter on a stirred 1:5 soil water suspension. pH was also measured after adding calcium chloride to a 1:5 soil/water suspension to produce a $CaCl_2$ concentration of 0.01M (Rayment and Higginson 1992).

Ground Litter

Every second metre along the 30m north transects the leaf litter in a 25cm x 25cm square quadrat was collected. Reid's (*et al.* 1994) definition of ground litter, which is all leaf, woody material (< 5 cm diameter) and dung lying on the ground surface and unincorporated in the soil, was adhered to during litter collection. These samples were allowed to air dry at room temperature for one week before weighing. The percentage of the litter sample that was derived from the pasture (grasses) and the percentage derived from the tree (leaves and twigs) was estimated for each sample.

Assessment of Habitat Use by Grazing Stock

The sheep dung density was recorded along each transect of the star design, at 1m , 3m and 5m. The number of sheep pellets was counted in quadrats (25cm x 25cm) placed at each of these points. The number of cattle droppings in each 45^0 sector formed by the transects was also recorded.

The tree patches assessed were dominated by New England Peppermint, with a largely contiguous canopy cover. The canopy area of both the isolated trees and tree patches was calculated by measuring the canopy length at each transect, and transferring these to grid paper and summing the cells enclosed by straight lines joining the end points. For the isolated trees, the tree trunk was used as the focus of the star sampling pattern. For the tree patches a dominant centre tree, or the centre of the patch was used as the focus of the sampling circle. In some patches two sampling circles, positioned to cover as much of the canopy area as possible, were employed to fully characterise the tree patch.

Data Analysis

Comparisons of invertebrate assemblages under trees and in open paddock

Rank abundance curves of the major invertebrate groups sampled by the pitfall traps were constructed to compare the invertebrate assemblages found under the isolated trees with those found in the open paddock sites. For this analysis, the data from all 24 traps on the star design at each of the six isolated trees, and at each of the open paddock sites were pooled, and the abundance of each major group totalled. Raw data were double square root transformed prior to plotting. An analysis of similarities test (ANOSIM) used these data to test whether the major group assemblages were significantly different in the two habitats. The statistical package PRIMER was used for the first ANOSIM test, which used a Bray Curtis dissimilarity measure (Carr 1996).

A second ANOSIM test was conducted that concentrated just on the isolated tree data and tested if there were differences among assemblages according to distance from the tree (3m, 5m and 10m). For this test the data from all the 3m traps were pooled for each tree, and the same was done for the 5m and 10m pitfall trap data. Bonferroni correction was used to correct for post-hoc multiple comparisons.

Variation along the north transects

Moving Split Window Analysis: The moving split window analysis was used to detect boundaries in the invertebrate assemblages and soil characteristics that may have corresponded to the limits of the tree canopy zone and root canopy zone (Cornelius and Reynolds 1991; Ludwig and Cornelius 1987; Webster 1973; 1978). The procedure involves bracketing a set of samples along the 30m transect into a window of pre-assigned width (as for calculating moving averages; Legendre and Legendre 1983). This window is then split into two equally sized number of samples, and the data averaged for each variate within each group. The dissimilarity between these two averages is then calculated and plotted on the Y axis at the window mid-point. The window is moved one metre further along the transect and another dissimilarity is computed. This was repeated for the entire length of the transect. The graphs were examined for sharp, high peaks that identified the location of boundaries between adjacent biotic community zones. The dissimilarity measure used here is the “percentage difference” (Legendre and Legendre 1983) also known as Bray Curtis.

MSW analysis used the major group data, the species level Collembola data and the data from soil analysis. Square root or double square root transformations were used, to reduce the abundance of the most common taxon to a value less than ten. The soil characteristics data was first standardised by subtracting from the recorded value the mean and dividing by the standard deviation for each variable. The Collembola and the mites were excluded from the MSW analysis of the pitfall trap data due to the high probability of specimen loss due to trap flooding.

Direct Gradient Analysis

Canonical correspondence analysis: Canonical correspondence analysis (CCA) is a form of direct gradient analysis which is analogous to multiple regression in that it attempts to identify relationships between community composition and one or more environmental variables. CCA constructs axes of variation in overall community composition, and these axes are constrained to be linear combinations of the environmental variables (Ter Braak and Prentice 1988). CCA was used, in this study, to determine if the variation in the invertebrate assemblages could be explained by the environmental data collected (soil characteristics and leaf litter). In particular, if there was a gradient in the variation in invertebrate assemblages with distance from tree.

The program CANOCO for windows (version 4) (Ter Braak and Smilauer 1998) was used to conduct the analysis. CCA was conducted on both the transformed and untransformed soil invertebrate assemblages, Collembola species assemblages and the ground active invertebrate assemblages. The significance of each environmental variable was tested using two procedures. Firstly, each variable was considered individually (analogous to simple regression). This gave the proportion of variation in the invertebrate assemblages explained by each individual variable, (the marginal effect). Monte Carlo permutation tests were used to test the statistical significance of the proportion of variation explained by the variable. Secondly, using the forward selection procedure the variable that explained the greatest proportion of the variation in the invertebrate assemblages was selected. The remaining variables were then evaluated on the basis of the “extra fit” each additional variable gave in conjunction with the variable(s) already selected (analogous to forward selection multiple regression). That is, how much extra variation was explained by the addition of another variable to the model (the conditional effect). (Ter Braak and Verdonschot 1995). Monte Carlo permutation tests were again used to test the statistical significance of each variable included in the model. The results were plotted as biplots using CanoDraw (version 3.0, Smilauer 1992). The vector length and orientation for each environmental variable indicated how well the variable explains the variation in the invertebrate assemblages observed.

Assessment of Habitat Use by Grazing Stock

ANOVA: A one way analysis of variance (ANOVA) was conducted on the sheep and cattle dung data with the levels representing the habitats studied (i.e. isolated trees, tree patches, open paddock, sheep camp, and artificial wind break). This test assessed if there was a significant difference in the amount of sheep or cattle dung between the habitats sampled. The Student Newman-Keuls test was used for post hoc comparisons. Dung density for both sheep and cattle was regressed against canopy area. An ANOVA was then conducted to test the significance of these regression lines.

Results

Comparisons of Invertebrates Under Isolated Trees and in Open Paddock

Rank abundance plots revealed that ants were the most abundant taxon in both habitats (Fig. 5). The other major groups did not show the same abundance patterns in the two habitats. Overall there were fewer major groups in the open paddock pitfalls. Psocoptera, Blattodea, and Isopoda were not recorded at the open paddock sites.

Using data pooled from 24 traps, ANOSIM found significant differences between the major group assemblages in these two habitats ($P = 0.009$, $\alpha = 0.05$). Using data pooled from 8 traps from the 3m, 5m and 10m distances, ANOSIM found no significant differences between the assemblages at any two distances from the tree base (Table 2). This test was repeated using the data from the open paddock pitfalls. After correction for multiple comparisons there was a significant difference between the major group assemblages found in the 3m pitfalls and 5m pitfalls ($P = 0.017$).

Variation Along the North Transect

Identification of Boundaries along transect

The MSW analysis was used to identify boundaries in the biological communities and the soil environment along the north transect. The data collected were explored at a number of window sizes. A window size of ten was selected because variability due to microhabitat differences was smoothed out, and all tree canopies were not less than 5m along the north transect. Window size of ten means that the average of five adjacent sampling points is calculated for each half of the window (Fig. 6).

The MSW analysis of the soil characteristics data averaged over the six trees showed the clearest trend (Fig. 7). The soil characteristics data was investigated at a different window size because samples were collected at every second metre along the north transect. There is a peak in the MSW graph which corresponds to approximately 7m along the north transect, and a second peak at approximately 15m from the tree base.

The soil invertebrate data shows that the major group assemblages under the tree canopy were very similar. As these assemblages were compared to those just outside the drip line of the canopy there was a sharp increase in the differences between assemblages. A smaller peak was also observed at 18.5m. The Collembola data does not show discernible peaks but rather a gradual increase in the similarity of the assemblages as you move away from the tree base. This is represented on the graph as a gradual decrease in the difference between species assemblages from each soil core, with distance from tree.

The ground invertebrates showed a similar MSW trend to the soil characteristics and soil invertebrates. The difference between assemblages decreased from a peak at the limits of the tree canopy and there was a second peak at 18.5m.

Pitfall data were highly variable between trees, and the position of the drip line varied between 5.3m and 8m suggesting a need to explore these data on an individual tree basis. These MSW patterns were also investigated on an individual tree basis for tree I, tree T and tree P, an incomplete MSW analysis has also been conducted for trees U, V and W. Each tree appears to have quite a unique MSW pattern (Appendix 1). The north canopy boundary for tree P corresponds the most accurately with the observed transition in the invertebrate assemblages. The results suggest that there are gradual changes in the invertebrate assemblages as you move away from the tree base that are not clearly identified in the MSW analysis.

Native and Introduced Collembola Distribution

Twenty-two species of Collembola were identified from the soil cores. The known habitat requirements of each species and whether or not they are native or exotic to the Northern Tablelands is shown in Table 3. Five were exotic species, and twelve native, and five undetermined species that were excluded from this analysis.

The MSW pattern observed for Collembola species can be explained by looking at the distribution of native and introduced Collembola species with distance from tree (Fig. 8). The canopy zone of isolated trees appears to harbour more individuals from native species and the introduced species become dominant as distance from the tree increases. This trend is highlighted by the distribution of the introduced *Cryptopygus* sp. along the north transect (Fig. 9). This was the most abundant species at all three trees. There was a very slight trend in decreased number of native Collembola species with distance from tree (Fig. 10). The dominance of the introduced species towards the end of the transect was a result of changes in the abundance of each species, not from a greater number of introduced species.

Direct Gradient Analysis

To investigate if the changes in the invertebrate assemblages observed along transects could be explained by the environmental data collected CCA was conducted, and the results plotted as biplots. For the soil invertebrates and Collembola species distance from tree was found to significantly explain the variation in the assemblages (Table 4, Fig. 11, Fig. 12). For the soil invertebrate biplot, distance from tree appeared to be related to soil bulk density. However, bulk density was not a significant explanatory variable. A significant proportion of the variation in soil invertebrate assemblages was also explained by soil pH, which was not correlated with distance from tree. When each variable was considered individually, electrical conductivity, and the proportion of ground litter derived from the pasture (grasses) were also found to be significant explanatory variables for the soil invertebrate assemblages.

For the Collembola species the distance from tree was correlated with pH and the percentage of silt in the soil, and negatively correlated with Carbon to Nitrogen ratio (Table 4, fig. 12). However, these were not significant explanatory variables. Total ground litter and the percentage of fine sand in the soil also significantly explained extra variation in the species assemblages when added to the model (Table 4, Fig. 12). The proportion of litter derived from the pasture, percentage of clay in the soil, and bulk density are also significant when each variable was considered individually.

For the ordination of the pitfall trap data, which included all six trees, (Fig. 13, Table 4) distance from tree was a significant explanatory variable if considered individually. Nitrogen content of the soil, pH, percentage of clay in the soil, total ground litter, the percentage of litter derived from the pasture grasses, bulk density and organic matter all explain significant proportions of the variation in the assemblages when considered as components of a model. Bulk density and organic matter were negatively correlated on this biplot. The proportion of grass in the ground litter and distance from tree were correlated on the ground active invertebrate biplot. Phosphorus, and the percentage of fine sand in the soil were also significant when each variable was considered individually.

Environmental Characteristics Along Transect

The variation in each soil characteristics measured was investigated along the north transect. Not all soil characteristics change in the same fashion as you move along the transect (Fig. 14). Nitrogen and organic matter showed an exponential decrease beneath the tree canopy that ceased at the limits of the tree canopy. Both factors remained at this base level in the soil throughout the remainder of the transect. The soil pH drops significantly just outside the tree canopy drip line then gradually increases as you move out into the pasture matrix. For some characteristics such as the percentage of fine sand in the soil no discernible trends were present in the data.

The total ground litter decreased with distance from the tree base (Fig. 15). The composition of the ground litter also changed with distance from tree. The proportion of the litter that was contributed from the pasture gradually increased as the proportion of litter contributed from the tree decreased.

Assessment of Habitat use by Grazing Stock

The sheep and cattle dung at a site is used here as an index for the amount of time spent at that site by the stock, and may give an indication of stock behaviour. The density of dung in each habitat assessed was different for both sheep and cattle. There appeared to be a greater concentration of sheep dung under the isolated trees compared with the open paddock sites, however this difference was not significant ($P = 0.28$) (Fig. 16). The sheep deposited more dung at the established sheep camp at the top of the paddock, and used tree patches within the paddock. There was significantly more cattle dung under the isolated trees ($P = 0.044$) and tree patches ($P = 0.003$) than the open paddock sites (Fig. 16). However, the artificial wind break had more cattle dung than these two areas.

There is also a trend observed for both sheep and cattle of increasing dung density from the open paddock sites to the isolated trees to the tree patches. There appears to be a relationship between canopy area and stock dung density (Fig. 17). However, ANOVA showed that the relationship between the canopy area of a site and the use of that site by both sheep (R^2 = 0.009, P = 0.77) and cattle (R^2 = 0.017, P = 0.69) was not significant.

Discussion

This study revealed significant differences between the ground active invertebrate assemblages under isolated trees and in those in the surrounding pasture matrix (Fig. 5). Differences in environmental conditions between these two areas result in habitats that are most suitable for different assemblages of invertebrates. Such factors may include the substantial litter layer beneath the tree, and changes in microclimate. There was some indication from the uncorrected ANOSIM result (P = 0.039, Table 2) that these differences may be evident at only 10m from the tree base. Following statistical correction this difference was lost suggesting insufficient replication. Following statistical correction a significant difference was observed between the invertebrate assemblages at 3m and 5m within the open paddock. This result was unexpected and is most likely the result of spatial autocorrelation between samples (Legendre 1993).

The data collected from the north transects was used to further characterise the spatial variation in the invertebrate assemblages throughout the regions of influence of the isolated tree, i.e. the canopy, root and pasture zones. This was done by looking for boundaries in the invertebrate assemblages and soil characteristics along the transects using Moving split window (MSW) analysis, and Canonical correspondence analysis (CCA).

The MSW analysis results averaged across all six trees showed a peak at 7m and another at 15m (Fig. 7). The precise location and variation within each of these peaks varied across the data sets analysed. The first peak corresponds well with the average north canopy length of 6.5m (s.d. 1m) measured in the field. This initial peak in the MSW analysis may correspond to the position of the tree canopy boundary. This is supported by both the soil invertebrate data and the ground active invertebrate data, which also show a decrease from a peak in difference between assemblages as move across this region. Analysis based on individual trees revealed this transition zone in the invertebrate assemblages corresponds directly with the position of the north canopy boundary (tree P, Appendix 1), or occurs with some variability around this location (trees I and T, Appendix 1).

In a similar study, Belsky (*et al.* 1989) took vegetation samples along a 50m transect from the base of savanna trees out into the grassland matrix. For three trees there was a sharp transition in the species composition of the herbaceous-layer vegetation at the edge of the tree canopy. For a tree with a sparse canopy the transition occurred 2m before the edge of the canopy limits, and for two trees the transition was more gradual. This suggests that the condition of the canopy as well as the variability in the biota being investigated may influence the transition zone, and its location in relation to the measured canopy boundary.

The boundaries in the abiotic data suggest that the influence of an isolated tree extends past the limits of the tree canopy. The patterns observed may be related to processes occurring within the below ground root canopy zone. The MSW analysis suggests the root canopy zone may extend 15-18m from the tree base. Further field work assessing the distribution of the tree roots would be necessary to confirm this result.

The pitfall trap data and the soil core data showed great variability between trees (Fig. 7, Appendix 1). A study of isolated trees in rural landscapes by Hill *et al.* (unpublished) in the Mt Lofty Ranges also found that the diversity of litter invertebrates present varied dramatically over short distances of just a few metres, even under the canopies of individual trees. The invertebrate fauna also varied between trees. This led Hill to conclude that the litter fauna associated with individual trees is diverse and potentially unique to each tree.

For the pitfall traps, this variability, may in part be due to the weather conditions whilst the traps were in the field. Many of the traps were flooded after heavy rains. The Bureau of meterology recorded the total rainfall at Armidale for the month during collection at 100-200mm, which is much higher than the long term average total monthly rainfall of 48.4mm. Flooding of traps required that Collembola and mites be excluded from this analysis because it is hard to determine the effects of flooding on these two major groups. Collembola in particular have a tendency to float as rafts on the surface of the pitfall trap, and will therefore have a greater probability of being washed from the trap during heavy rains. Other invertebrate taxa sink to the bottom of the traps more readily and are less likely to be lost due to flooding (Oliver *pers. com.*) Changes in the abundance of these two major groups, which are considered an important component of the invertebrate fauna, are not shown in this analysis.

The distribution of other major groups may also be heavily influenced by microhabitat features, such as stock tracks and grass tussocks, that are not discernible at the scale of measurement used here. The inherent variability in the spatial distribution of invertebrate assemblages limited the ability of the MSW analysis to detect boundaries. This can be best illustrated by looking at one data set using different window sizes (Fig. 6). Ludwig and Cornelius (1987) investigated vegetation zones along a transect using different window sizes. Common peaks were present along the transect across the different window sizes. There was just a smoothing out of the variability between and within each of these peaks with increased window size, to give a clearer picture of the true vegetation boundaries. The results presented here show different peaks at each window size, as the invertebrate communities respond to environmental factors along the transect at different spatial scales. This analysis may be better suited to less variable data sets. Furthermore, the MSW analysis is designed to identify sharp differences in biological assemblages, gradual changes as you move along the transect will be missed by this analysis.

The variation in the spatial patterns of Collembola species can best be understood by examining the distribution of the native and introduced species along the transect (Fig. 8). The ground beneath the tree canopy appears to harbour a diverse Collembola community that is dominated by native species. As you move out into the pasture matrix the abundance of the 3 to 5 introduced species present becomes greater. The samples become more homogeneous with distance from tree because just a few introduced species dominate the samples at the end of the transect; whereas the samples closer to the tree are dominated by native species.

Chilcott (1996) found higher species numbers of introduced Collembola beneath trees that were re-introduced in the form of shelterbelts, into long-cleared grazed pastures.
It was predicted that, in time, the native Collembola species would return to the artificial wind breaks (Chilcott *et al.* 1997). Other studies from restored mine pits suggest that this may take as long as 10-13 years (Greenslade and Majer 1993).

Whilst artificial wind breaks ameliorate some of the abiotic degradative processes that reduce agricultural productivity, such as wind and water erosion; they do not harbour the same invertebrate communities as isolated trees. Conversely, isolated trees that are remnants of the past vegetation community, support many native invertebrate species. This suggests that isolated trees may be important for the conservation of invertebrate biodiversity within this agricultural landscape.

The distribution of each individual Collembola species will be influenced by a number of biotic and abiotic factors. The ground litter in particular seems to be an important determinate of Collembola species distribution according to the CCA biplot (Fig. 15). King *et al.* (1985) found that on improved grazed pastures there was an association between the relative abundance of introduced Collembola and the phosphorus content of the litter. The introduced collembolan *Cryptopygus* sp. increased in abundance with distance from tree. *Cryptopygus* sp. lives in humus and leaf litter on the soil surface, but can penetrate the soil at times (Greenslade, *pers. com.*). This species may be responding to the concentration of the trampling effects of the stock under the isolated tree, hence is less abundant in this area.

CCA was also used to investigate gradients in the variation in invertebrate assemblages with distance from tree. The CCA biplots showed that variation in invertebrate major group assemblages was correlated with a number of environmental variables as well as distance from tree (Fig. 11, 12, 13). Zinke (1962) noted that the soil under the influence of a forest develops properties that vary spatially with relation to the location of the trees, and the distribution of ground flora frequently reflects this variation.

In this study distance from tree was a significant explanatory variable for the soil invertebrates and Collembola when tested both, separately from the other variables (analogous to simple regression), and when selected by the program as part of a model explaining maximum variation (analogous to forward selection multiple regression).
For the ground active invertebrates distance was not as important as in the other data sets. It was a significant explanatory variable only if considered separately to the other environmental variables measured. The percentage of grass in the leaf litter which was correlated with distance on the biplot, was chosen for inclusion into the model. Due to the mobility and size of ground active invertebrates they may respond on a different spatial scale to the other groups of invertebrates studied. Therefore, the effects of distance from tree will be less pronounced in this ordination. Other factors such as Nitrogen, organic matter and Phosphorus were more important in this ordination. These three characteristics show similar trends, with decreasing levels throughout the tree canopy zone (Fig. 14).

For Nitrogen and organic matter this decline reaches a base level at the canopy boundary and remains at this level for the remainder of the transect. There was a decrease in soil Phosphorous throughout the canopy zone, and then a gradual increase at 13 to 25m from the tree base. A similar trend was found by Mordelet (*et al.* 1993) with increased Phosphorous and Nitrogen under savanna tree clumps. This was attributed to greater organic matter input beneath canopies from the leaf litter. The trees under investigation here also had a greater quantity of total litter beneath the canopies (Fig. 15). The increase in organic matter and Phosphorus as well as other soil fertility indices found by Belsky (*et al.* 1989) under savanna trees led her to conclude that soils under the tree canopy were more fertile than the soils in the surrounding grassland. These factors are soil characteristics that influence pasture and herbaceous plant growth, and are related to the litter layer. It is the decomposition of litter which releases these nutrients into the soil, where they are available for use by other plants. Invertebrates which live within this litter layer are important in the decomposition process (Hendrix *et al.* 1990). Such factors are therefore important in the distribution of ground active invertebrates.

Isolated trees are exposed to greater intensities of climate such as winds, rain and sunlight than trees sheltered against one another in tree patches. Also, influences arising from the pasture around them, such as the grazing stock, place stresses on the isolated tree (Heatwole and Lowman 1986).

The abundance and distribution of trees within a paddock influences how frequently the stock use a single isolated tree as a camp. Camps are places were stock regularly or habitually rest (Taylor 1980). There was evidence from field observations at Newholme that both sheep and cattle used the isolated trees as diurnal shade camps. Stock camps have been found to concentrate trampling effects, grazing and nutrient inputs from faeces and urine (Chilcott *et al*. 1997). Therefore, if an isolated tree is used as a camp this may have significant effects on the soil invertebrates and soil characteristics. Furthermore, as all sites were located within a grazed paddock, the stock themselves are an important part of the habitat. The stock influence habitat micro-structure and resource availability, and stock grazing is a significant part of the disturbance regime of the area. The activities and the influence of the stock on the isolated trees may be important in explaining the patterns in the invertebrate assemblages found. Hence, the assessment of “campiness” at different habitats across the paddock was considered an important component of this project. The amount of sheep and cattle dung at a site was assumed to be proportional to the time the stock spent at that site, and hence an index of “campiness”.

Sheep frequently used the established sheep camp at the top of the paddock and use tree patches within the paddock (Fig. 16). This supports previous studies which suggest that merinos often aggregate at dusk in camps at the highest, reasonably open locations in the paddock (Taylor, 1988). The cattle preferred the artificial wind break at the base of the paddock. One explanation for this may be that this wind break was the only shelter close to the area where the farm manager regularly fed the cattle. “Campiness” was also found to be not significantly related to canopy area (Fig. 17). Other authors have suggested that the level of use of trees by stock as camps is more dependent on canopy density and shape (Taylor, 1980). These criteria may give a better indication of a trees ability to provide shade and shelter to the stock than canopy area. Taylor (1980) found that shade camps often were large trees with a large, dense canopy of either or form. Other factors within the surrounding paddock such as distance to water sources, climate, density of isolated trees within the paddock, and the presence of other shade/shelter areas may also influence the “campiness” of an isolated tree.

It also should be noted that the stocking level of the paddock studied was relatively low for the Northern Tablelands (Hutchinson and King 1980; King and Hutchinson 1976). Higher stocking rates may have a much greater effect on isolated trees used as stock camps, and hence the invertebrate communities that live in the regions of influence of the isolated tree. Belsky (*et al.* 1993) found that the beneficial effects of savanna trees on their understory environments appeared to diminish with increasing livestock utilisation. This study concentrated on plant species composition and biomass and the physical and chemical properties of the soil below tree crowns and open grassland, rather than the invertebrate assemblages.

The first draft Regional Vegetation Management Plan, under the NVC Act, recently released for the Mid-Lachlan region (DLWC 1998) suggests fencing off isolated trees to maintain the health of the trees. The report recommends fencing off an area twice the canopy size of a tree or clump of trees to encourage the growth of native shrubs and groundcover beneath the tree, and reduce soil compaction and nutrient input from stock. Further studies would be required to determine what effect this would have on the invertebrate community. There is some suggestion from studies by King *et al.* (1985), that this may have a beneficial effect on the invertebrate community. It was found that native species of some Collembola were restricted to native vegetation, and more Collembola species were found in heterogeneous habitats with high floristic richness. However, fencing off isolated trees would prevent the use of these trees by the stock. Changes in the invertebrate community composition that may result from this management practice should be evaluated with this fact in mind.

It is clear that isolated trees have different uses within the pasture matrix, that depending on the management decisions, may conflict. A good understanding of an isolated trees potential to support biodiversity is required to evaluate management decisions. Reserve systems alone will be insufficient to conserve much of Australia's biodiversity (Beattie *et al.* 1990). There is a growing consensus that conservation of biological diversity must be combined with the utilisation of land for agricultural purposes. Invertebrates are capable of living, and persisting in very small habitat fragments (Moran *et al.* 1994; Sarre 1997; York Main 1987; Samways 1994).

For conservation purposes, invertebrates have an advantage over other fauna which require an extensive home range. Isolated trees present a unique opportunity for the management of invertebrate biodiversity within primary production systems.

It has often been argued that small remnant patches of native vegetation gradually loose biotic elements and cease to be examples of the habitats they once to represented. Furthermore, even if the habitats and biotic diversity could be retained within the remnant, management costs would be very high, and in the long term not worth pursuing (Main 1987). This is not the case for isolated trees. Isolated trees do retain native invertebrates, and the cost of management is low in comparison to other farm maintenance practices.

My results have shown that isolated trees are capable of supporting a diverse invertebrate community of native species that are less well represented, in the pasture matrix. This study concentrated only on the terrestrial invertebrate fauna, however isolated trees also support aboreal and other invertebrate faunas. Isolated trees may also be important to the conservation of these other invertebrate faunas. These results build on other studies in the Northern tablelands that have concluded that the retention of tree cover in grazed landscapes may help to conserve the diversity of indigenous herbs (Chilcott *et al.* 1997; Reid *et al.* 1997).

In the 1860's approximately 60 percent of the land in the Walcha district of New England was classified as forests and 40 percent as open woodland. In the 1980's less than 1 per cent is forest and 20 per cent woodland, the remaining 79 per cent having been cleared for grazing livestock (Heatwole and Lowman 1986). Isolated trees within this variegated landscape have become increasingly important for the conservation of native species. That is, the "irreplaceability" of the isolated trees has increased, as alternative habitats for these species became less prevalent on the Tablelands. The irreplaceability concept is most often used in relation to reserve design and is operationally defined as the extent to which the options for a representative reserve system are lost if that site is lost (Pressey *et al.* 1994; Pressey *et al.* 1993).

A single isolated tree cannot be expected to retain a representative sample of all the invertebrate species for the area, however it is also likely that there will be a certain amount of complementarily between trees. It is for this reason that isolated trees should be managed as a combination of potential conservation sites within an agricultural matrix. Furthermore, isolated trees are more vulnerable to catastrophes such as dieback than trees in remnant woodland patches (Landsberg and Gillieson 1995, Kile 1980). Various tree species are more susceptible to dieback than others, however the dieback intensity can be linked to land use practices (DLWC, 1998). Dieback will not affect all isolated trees in an area equally; therefore the presence of many isolated trees on the Northern Tablelands spreads the risk of such chance environmental impacts (Samways 1994).

An alternative to the irreplaceability concept is to consider how invertebrates utilise the isolated trees in the context of surrounding matrix. Isolated trees on the Northern tablelands differ from the true definition of vegetation fragments in that they are not usually isolated by areas that function as hostile environments to all the organisms within the remnants (McIntyre and Barrett 1992). Natural pastures dominate the landscape matrix in various states of modification, and eucalyptuses are present in varying densities across the landscape.

McIntyre and Barrett (1992) suggested that for some organisms the agricultural matrix does not provide a barrier to dispersal and movement, whereas others may be truly intolerant of conditions outside the influence of the isolated tree, and the majority of organisms fall between these two extremes. It is those organisms that are intolerant of the matrix conditions which survive in a truly fragmented landscape, and would benefit least from the clearance of isolated trees. However, those organisms with intermediate tolerances may best be conserved by managing the landscape as a matrix within which the isolated trees are integrated.

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References

Allison, L. E., 1965. Organic carbon. Pp. 1372-1378 *in* Methods of Soil Analysis ed by C. A., Black, D.D. Evans, J. L., White, L. E., Enisminger and F. E., Clark. American Society of Agronomy, Wisconsin.

Beattie, A., Auld, B., Greenslade, P., Harrington, G., Majer, J., Morton, S., Recher, H. and Westoby, M., 1992. Changes in Australian terrestrial biodiversity since European settlement and into the future. Pp. 189-202 *in* Australia's Renewable Resources: Sustainability and Global Change ed by R. M. Gifford and M. M. Barson. Bureau of Resources & CSIRO Division of Plant Industry, Canberra..

Belsky, A. J. and Canham, C.D., 1994. Forest gaps and isolated savanna trees. *BioScience* **44(2):** 77-84.

Belsky, A.J., Amundson, R. G., Duxbury, J. M., Riha, S. J., Ali, A. R. and Mwonga, M., 1989. The effects of trees on their physical, chemical, and biological environments in semi-arid savanna in Kenya. *Journal of Applied Ecology* **26:** 1005-1024.

Belsky, A. J., Mwonga, S. M. and Duxbury, J. M., 1993. Effects of widely spaced trees and livestock grazing on understory environments in tropical savannas. *Agroforestry Systems* **24:** 1-20.

Bray, R. H. and Kurtz, L. T., 1945. Determination of total, organic and available forms of phosphorus in soils. *Soil Science* **59:** 39-45.

Breare, M. H., Parmeleem, R. W., Hendrix, P.F., Coleman, D. C. and Crossley, D. A., 1992. Microbial and faunal interactions and effects on litter nitrogen decomposition in agroecosystems. *Ecological Monographs* **62(4):** 569-591.

Bremner, J. M., 1965. Total Nitrogen. Pp. 1149-1176 *in* Methods of Soil Analysis ed by C. A., Black, D.D. Evans, J. L., White, L. E., Enisminger and F. E., Clark. American Society of Agronomy, Wisconsin.

Brouwer, A.C. and Crijns, D.M.H., 1994. Property Management Plan for Newholme Field Laboratory. Wageningen Agricultural University.

Carr, M. R., 1996. PRIMER Plymouth Routines in Multivariate Analysis User Manual. Plymouth Marine Laboratory, Plymouth.

Chilcott, C., 1996. Ecosystem function of trees in managed temperate pastures. Pp. 113-145 *in* Third milestone report for LWRRDC UNE 12 ed by N. Reid, C. Chilcott, and R. Nett. Department of Ecosystem Management, University of New England.

Chilcott, C., Reid, N. and King, K., 1997. Impact of trees on the diversity of pasture species and soil biota in grazed landscapes on the Northern Tablelands, NSW. Pp. 378-386 *in* Conservation Outside Nature Reserves ed by P. Hale and D. Lamb. Centre for Conservation Biology, The University of Queensland, Brisbane.

Cornelius, J. M. and Reynolds, J. F., 1991. On determining the statistical significance of discontinuities within ordered ecological data. *Ecology* **72(6):** 2057-2070.

Craze, B. and Hamilton, G. J., 1993. Soil Physical properties. Pp. 147-164 *in* Soils, their properties and Management ed by P.E.V., Charman and B. W., Murphy. Sydney University Press, Sydney.

Department of Land and Water Conservation, 1998. Mid-Lachlan regional vegetation management plan draft. Mid-Lachlan regional vegetation committee, Commonwealth of Australia.

Greenslade, P. and Majer, J. D., 1993. Recolonization by collembola of rehabilitated bauxite mines in Western Australia. *Australian Journal of Ecology* **18:** 385-394.

Heatwole, H. and Lowman, M., 1986. Dieback: Death of an Australian Landscape. Reed Books, Frenchs Forest.

Hendrix, P. F., Crossley, D. A., Blair, J. M. and Coleman, D. C., 1990. Soil biota as componenetsof sustainable agroecosystems. Pp. 637-654 *in* Sustainable Agricultural Systems ed by C.A. Edwards, R. Lal, P. Madden, R. H. Miller and G. House. Soil and Water Conservation Society, Anheny.

Hill, B.M., Laan, T. and Paton, D.C., Unpublished. Use of Isolated tree by Native Fauna in the Mt Lofty Ranges. University of Adelaide. Unpublished paper.

Hutchinson, K. J. and King, K. L., 1980. The effects of sheep stocking level on invertebrate abundance, biomass and energy utilization in a temperate, sown grassland. *Journal of Applied Ecology* **17:** 369-387.

Kellman, M., 1979. Soil enrichment by neotropical savanna trees. *Journal of Ecology* **67:** 565-577.

Kile, G. A., 1980. An overview of Eucalypt dieback in rural Australia. Pp.13-26 *in* Eucalypt Dieback in Forests and Woodlands ed by K.M. Old, G. A. Kile and C. P. Ohmart. CSIRO, Melbourne.

King, K. L., 1989. The role of microarthropods in decomposition and nutrient cycling in temperate patures. Thesis abstracts in *Australian Journal of Ecology*. **16:** 131-134.

King, K.L. and Hutchinson, K.J., 1976. The effects of sheep stocking intensity on the abundance and distribution of mesofauna in pastures. *Journal of Applied Ecology*. **13:** 41-55.

King, K.L. and Hutchinson, K.J., 1980. Effects of superphosphate and stocking intensity on grassland microarthropods. *Journal of Applied Ecology*. **17:** 581-591.

King, K. L. and Hutchinson, K. J., 1983. The effects of sheep grazing on invertebrate numbers and biomass in unfertilized natural pastures of the New England Tablelands (NSW). *Australian Journal of Ecology* **8:** 245-255.

King, K. L., Hutchinson, K. J. and Greenslade, P., 1976. The effects of sheep numbers on associations of collembola in sown pastures. *Journal of Applied Ecology* **13:** 731-739.

King, K. L., Greenslade, P. and Hutchinson, K. J., 1985. Collembolan associations in natural versus improved pastures of the New England Tablelands, NSW: distribution of native and introduced species. *Australian Journal of Ecology* **10:** 421-427.

Lal, R., 1991. Soil conservation and biodiversity. Pp. 89-104 *in* The Biodiversity of Microorganisms and Invertebrates: Its role in Sustainable Agriculture ed by D. L. Hawksworth. CAB International, Wallingford.

Lamont, B., 1985. Gradient and zonal analysis of understory suppression by *Eucalyptus wandoo. Vegetatio* **63:** 49-66.

Landsberg, J. and 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. *Australian Journal of Ecology* **20:** 299-315.

Lee, K. E., 1983. Soil animals and pedological processes. Pp. 629-644 *in* Soils: an Australian Viewpoint. CSIRO/Academic Press, Melbourne.

Legendre, P., 1993. Spatial autocorrelation: Trouble or new paradigm? *Ecology* **74:** 1659-1673.

Legendre, L. and Legendre, P., 1983. Numerical Ecology. Elsevier scientific, Amsterdam.

Linden, D. R., Hendrix, P. F., Coleman, D. C. and Van Vilet, P. C. J., 1994. Faunal indicators of soil quality. Pp. 91-106 *in* Defining Soil Quality for a Sustainable Environment. SSSA and American Society of Agronomy, Madison.

Lobry De Bruyn, L. A., Jenkins, B. A. and Sutrisno, 1997. Soil invertebrate biodiversity in stringybark forest in the New England tablelands before clearing. *Memoirs of the Museum of Victoria* **56(2):** 295-303.

Ludwig, J. A. and Cornelius, J. M., 1987. Locating discontinuities along ecological gradients. *Ecology* **68(2):** 448-450.

MacKay, S., 1978. Dying Eucalypts of the New England Tablelands. *Forest and Timber* **14:** 18-20.

Main, A. R., 1987. Management of remnants of native vegetation - A review of the problems and the development of an approach with reference to the wheatbelt of Western Australia. Pp. 1-13 *in* Nature Conservation: The Role of Remnants of Native Vegetation ed by D. A.

Saunders, G. W. Arnold, A. A. Burbidge and A. J. Hopkins. Surrey Beatty and Sons, Chipping Norton.

McIntyre, S. and Barrett, G. W., 1992. Habitat variegation, An alternative to fragmentation. *Conservation Biology* **6(1):** 146-147.

Moran, V. C., Hoffman, J. H., Impson, F. A. C. and Jenkins, J. F. G., 1994. Herbivorous insect species in the tree canopy of a relict South African forest. *Ecological Entomolgy* **19:** 147-154.

Mordelet, P., Abbadie, L. and Menaut, J. C., 1993. Effects of tree clumps on soil characteristics in a humid savanna of West Africa (Lamto, Cote d'Ivoire). *Plant and Soil* **153:** 103-111.

New South Whales Government, 1998. Native Vegetation Conservation Act.

Pressey, R. L., Humphries, C. J., Margules, C. R., Vane-Wright, R. I. and Williams, P. H., 1993. Beyond opportunism: Key principles for systematic reserve selection. *Trends in Ecology and Evolution* **8(4):** 124-128.

Pressey, R. L., Johnson, I. R. and Wilson, P.D., 1994. Shades of irreplaceability: towards a measure of the contribution of sites to a reservation goal. *Biodiversity and Conservation* **3:** 242-262.

Raymont, G. E., and Higginson, F.R., 1992. Australian Laboratory Handbook of Soil and Chemical Methods. Inkata Press, Melbourne.

Redpath, P., 1998. Benefits of Retained Isolated Trees and Clumps of Trees. Working Paper, Department of Land and Water Conservation, NSW.

Reid, R. and Bird, P.R., 1990. Shade and shelter. Pp. 319-335 *in* Trees for Rural Australia ed by K.W. Cremer. Inkata Press, Melbourne.

Reid, N., Chilcott, C. and Nett, R., 1996. Third milestone research report for LWRRDC UNE 12. Department of Ecosystem Management, University of New England, Armidale.

Reid, N., Boulton, A., Nott, R. and Chilcott, C., 1997. Ecological sustainability of grazed landscapes on the Northern tablelands of New South Wales (Australia). Pp.117-130 *in* Frontiers in Ecology: building the links ed by N. Klomp and I. Lunt. Elsevier Science, Oxford.

Samways, M. J., 1994. Insect Conservation Biology. Chapman and Hall, London.

Smilauer, P., 1992. *CanoDraw User's Guide*. Microcomputer power, New York.

Taylor, J. A., 1980. Merino Sheep and the Intrapaddock Patterning of Herbaceous Species on the Northern Tablelands of New South Wales, Australia. PhD thesis, University of New England.

Ter Braak, C. J. and Prentice, I. C., 1988. A theory of gradient analysis. *Advances in Ecological Research* **18:** 271-317.

Ter Braak, C. J. and Verdonschot, P. F., 1995. Cononical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Sciences* **57(3):** 255-273.

Ter Braak, C.J. and Smilauer, P.,1998. CANOCO Reference Manual and User's Guide to Canoco for Windows. Centre for Biometry, Wageningen.

Webster, R., 1973. Automatic soil-boundary location from transect data. *Mathematical Geology* **5(1):** 27-37.

Webster, R., 1978. Optimally partitioning soil transects. *Journal of Soil Science* **29:** 388-402.

York Main, B., 1987. Persistence of Invertebrates in small areas: Case studies of Trapdoor spiders in Western Australia. Pp. 29-39 *in* Nature Conservation: The Role of Remnants of Native Vegetation ed by D. A. Saunders, G. W. Arnold, A. A. Burbidge and A. J.M. Hopkins. Surrey Betty and Sons, Chipping Norton.

Zinke, P. J., 1962. The pattern of influence of individual forest trees on soil properties. *Ecology* **43(1):** 130-133.

Table 1. Structural characteristics of the six isolated *Eucalyptus nova-anglica* trees Canopy shape was classified according to the system proposed by Taylor 1980.

	P	T	I	U	V	W
tree height (m)	17.0	16.0	17.2	13.0	15.0	18.0
DBH# (m) stem 1.	0.85	0.45	0.60	0.38	0.70	1.00
stem 2.	0.57	0.40		0.51		
stem 3.	0.25					
canopy drip line (m, bearing 0^0)*	7.2	5.3	5.9	7.1	5.3	8.0
canopy area (m^2)+	112.0	65.0	50.0	98.0	80.0	138.0
canopy shape**						

* Length of the north canopy, measured along transect at 0^0 bearing.

**Canopy shape was classified according to the system proposed by Taylor 1980.

\# Diameter at Breast Height calculated by measuring trunk circumfrence at 1.5m and using formula: radius = circumfrence/2π

\+ Canopy area calculated by mapping measured canopy lengths for each compass bearing onto graph paper.

Fig. 1. Location of Newholme field laboratory (sorry, not available).

Fig. 2. Location of field sites (sorry, not available)

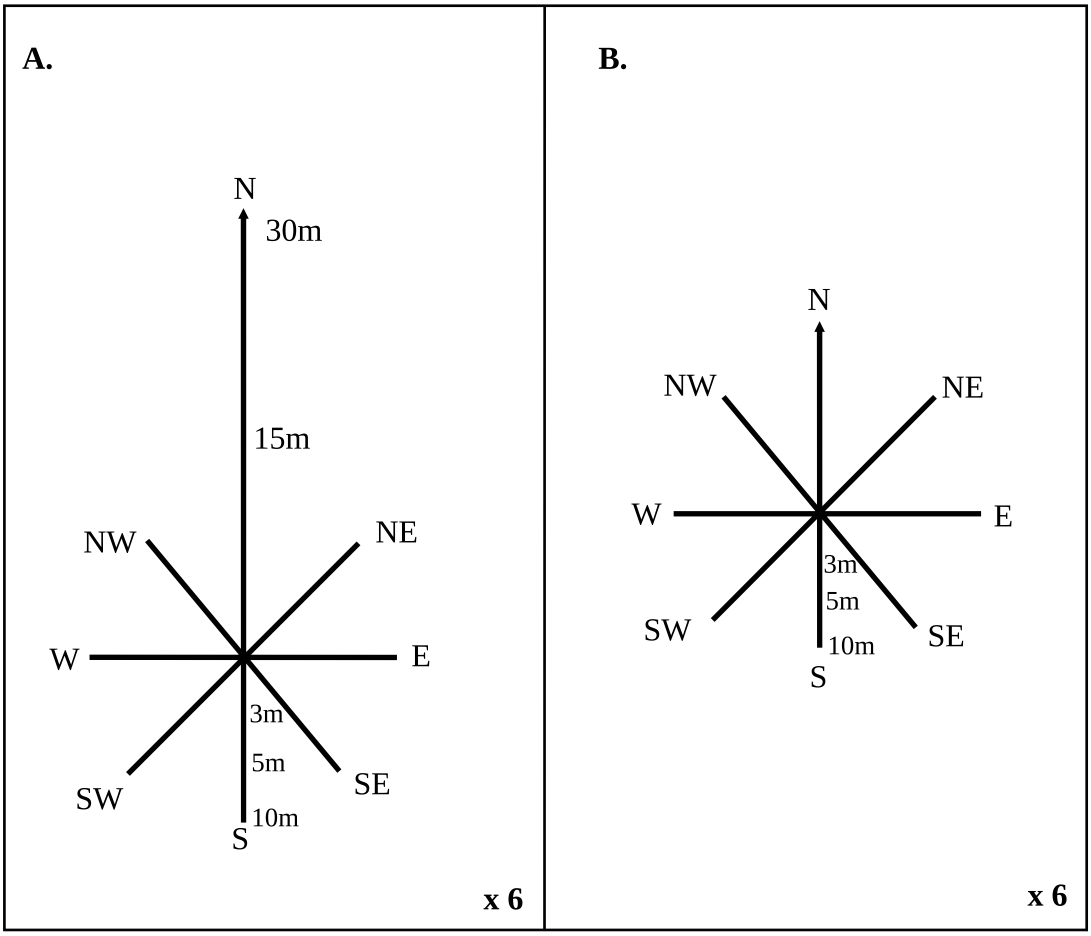


Fig. 3. Sampling pattern at each isolated tree (A) and open paddock (B) sampling site**.**

Fig. 4. Sorry, not available**.**

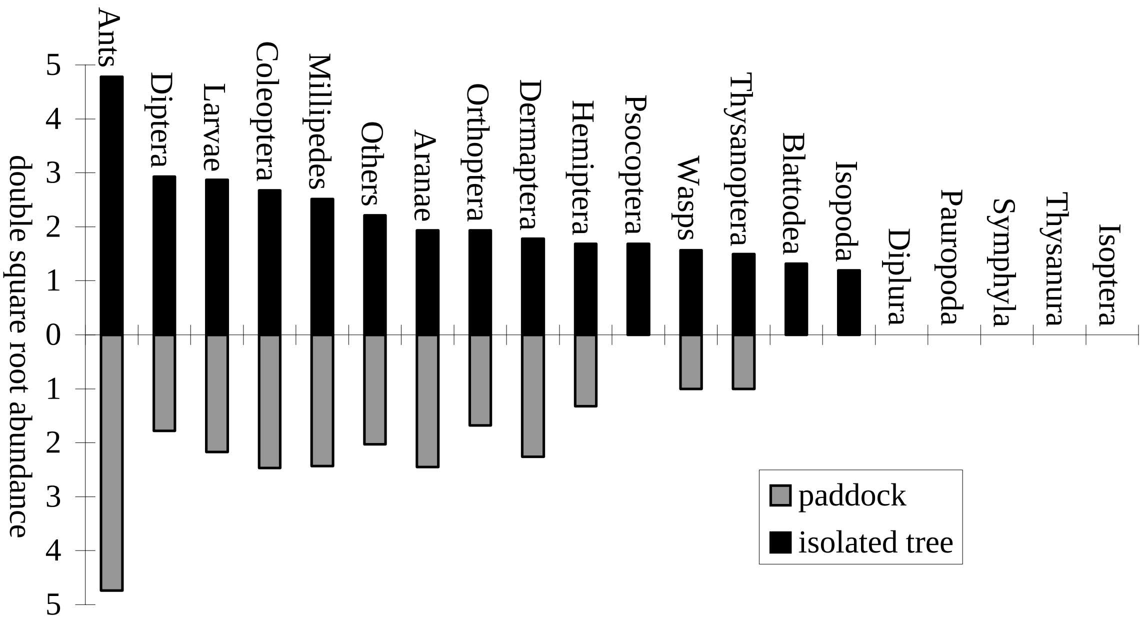
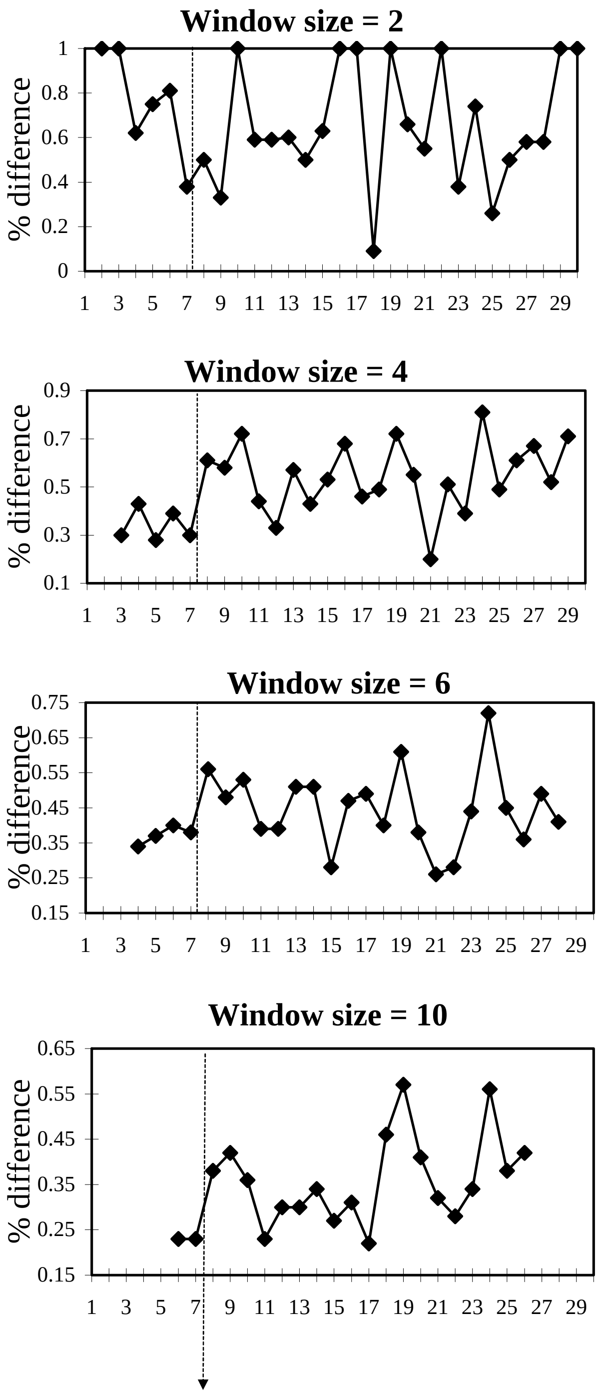


Fig. 5. Rank abundance of ground active invertebrates sampled by pitfall trapping along a 30m north transect from the base of an isolated tree. The data from the 24 traps at each open paddock and isolated tree site were pooled.

Table 2. ANOSIM test results comparing major group assemblages of ground active invertebrates in pitfall traps situated at three distances (3m, 5m 10m) from an isolated tree base to those in pitfall traps situated in a similar sampling pattern in open paddock sites.

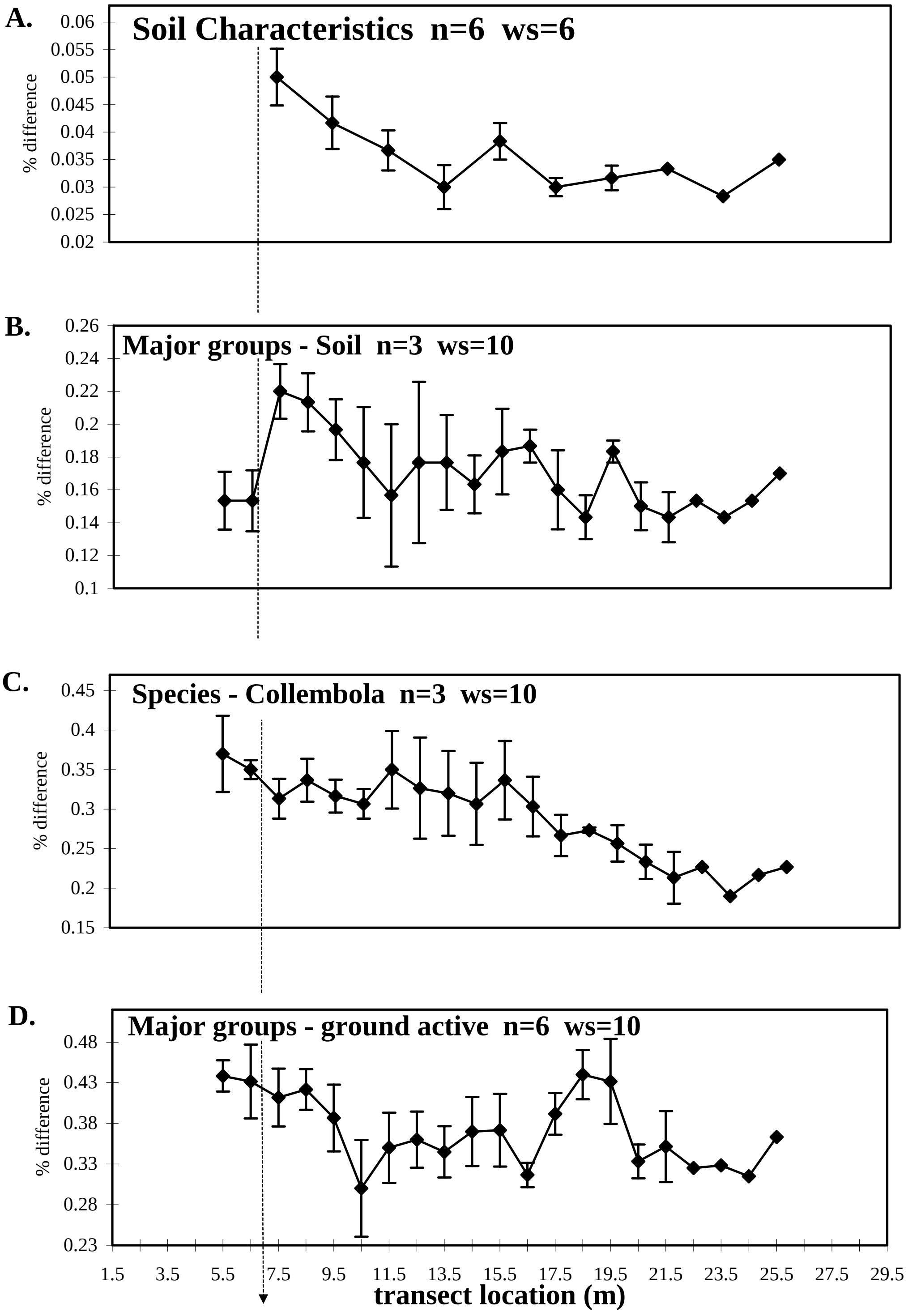
	Isolated Tree		**Open Paddock**	
Distance from tree	**P-value**	**sig. after correction***	**P-value**	**sig. after correction***
3m vs 5 m	0.184	No	0.017	Yes
5m vs 10m	0.100	No	0.271	No
3m vs 10m	0.039	No	0.156	No

***** To correct for multiple comparisons a new significance level of 1.7% was calculated using the bonferroni correction (0.05/3 = 0.017). P-values re-assessed using new significance level.



North canopy = 7.2m

Fig. 6. Moving split window analysis of the ground active invertebrate major group assemblages for a single isolated tree using different window sizes.



Average north canopy = 6.5m

Fig. 7. Moving split window analysis of the soil characteristics (A), soil invertebrate major groups (B), collembola species ©, and the ground active invertebrate major groups (D). WS - indicates window size, n - indicates the number of trees averaged to produce graph.

Table 3. Collembola recovered from soil cores (Greenslade, *pers. com*.).

Family	**Genus**	**Species**	**habitat**	**Native or Intro.**
Hypogasturidae	*Ceratophysella*		dung/decaying organic matter	I
Hypogasturidae	*Xenylla*	*australis*	litter	N
Brachystomellidae	*Brachystomella*		under/among native grasses	N
Onychiuridae	*Onychiurinae*		soil	I
Onychiuridae	*Mesaphorura*		soil	I
Isotomidae	*Folsomides*	*exiguus*	soil	N
Isotomidae	*Isotomodes*		soil	I
Isotomidae	*Cryptopygus*		humus	I
Isotomidae	*Folsomina*	*onychiurina*	soil	N
Entomobryidae	*Lepidoseira*	*nigrocephala*	dry grass, wheat	N
Entomobryidae	*Lepidocyrtoides*	sp. cf *cucularis*	litter	N
Entomobryidae	*Entomobrya*	pale yellow	exotic grasses	?
Entomobryidae	*Entomobrya*	varia	grasses	N
Entomobryidae	*Sinella*		soil	N
Entomobryidae	*Drepanura*	quinquilineata	grasses	N
Entomobryidae	*Lepidocyrtus*		humus	?
Sminthuridae	*Sphaeridia*		litter	?
Sminthuridae	*Sminthurides*		moist native grasses	?
Sminthuridae	*Katianna*	*schoetti*	pastures	N
Sminthuridae	*Sminthurinus*	black	humus	?
Sminthuridae	*Katianninae*	n. gen. N. sp.	litter, native grasses	N
Sminthuridae	*Polykatianna*	sp.	heathy vegetation	N

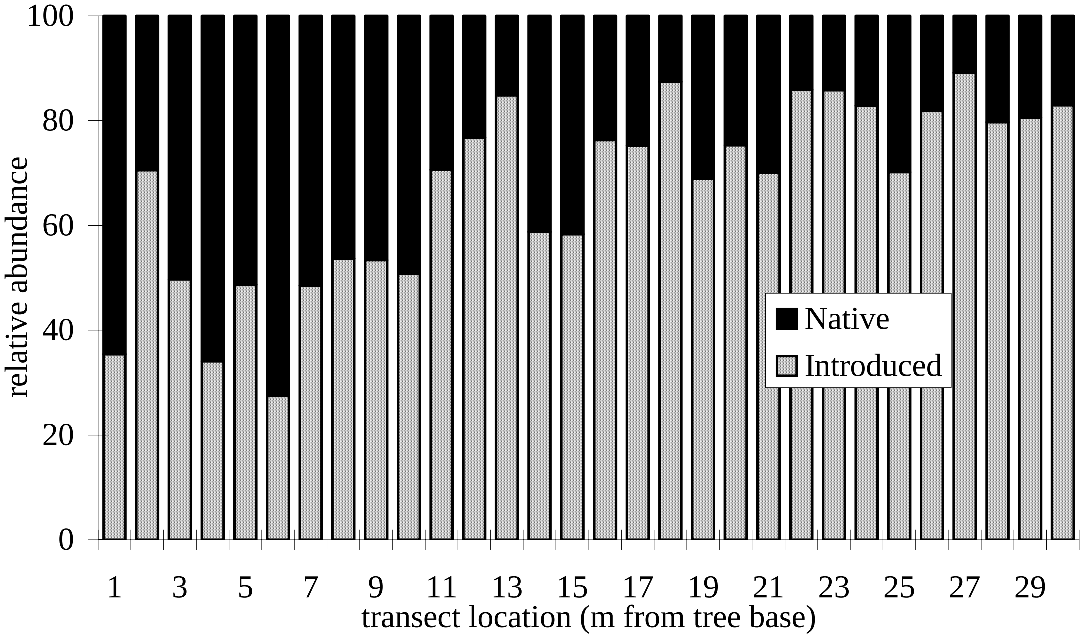


Fig. 8. Average relative abundance of native and introduced collembola species along a 30m north transect from the base of an isolated tree. The relative abundance for both the native and introduced collembola species at each point along the transect has been averaged across three trees.

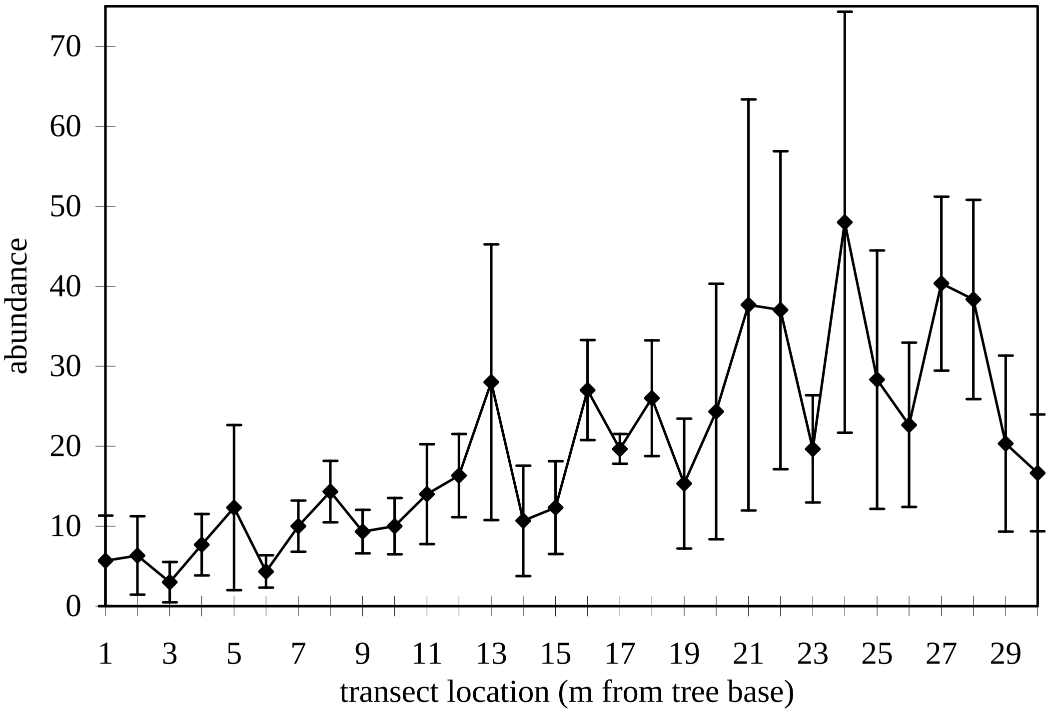


Fig. 9. The abundance of the collembola *Cryptopygus* sp. (Isotomidae) at each point along a 30m north transect. The abundance of this introduced species was averaged across soil cores taken from transects at three trees.

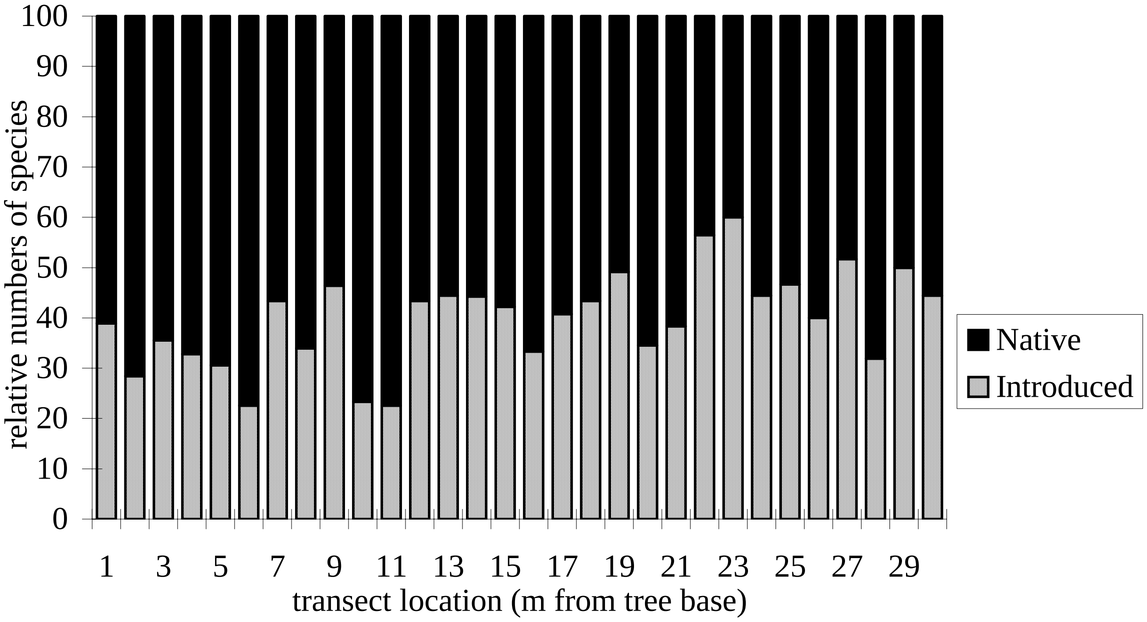


Fig. 10. Average relative number of native and introduced collembola species at each metre along a 30m north transect extending out from an isolated tree base. The collembola were collected by taking soil cores at every metre along the transect, and the numbers of species averaged across soil cores taken from three trees.

Table 4. Summary of CCA analysis results.

	Soil inverts. major groups	**collembola species**	**ground active major groups***
distance from tree	+ +	+ +	+
pH	+ +	-	+
EC	+	-	+ +
ground litter	-	+ +	-
%grass	+	+	+ +
%tree	-	-	-
bulk density	-	+	+ +
Organic matter	-	-	+ +
C:N	-	-	-
nitrogen	-	-	+
phosphorus	-	-	+
% finesand	-	+ +	-
% clay	-	+	-
% silt	-	-	-
% gravel	-	-	-

++ The conditional effects of the environmental variable are significant

\+ The marginal effects of the environmental variable are significant.

***** Samples from six trees were used in this analysis.

Fig. 11. (Sorry, not available)

CCA biplot for Soil invertebrate major group assemblages with respect to a number of environmental variables measured along a 30m north transect from the base of an isolated tree. Data from three trees was used in this analysis. * Indicates the environmental variable explains a significant amount of the variation in the major group assemblages observed (each variable was considered independently of the other variables).

Fig. 12. (Sorry, not available)

CCA biplot for collembola species assemblages with respect to a number of environmental variables measured along a 30m north transect from the base of an isolated tree. Data from three trees was used in this analysis. * Indicates the environmental variable significantly explains the variation in the species assemblages observed (each variable was considered independently of the of the variables).

Fig. 13. (Sorry, not available)

CCA biplot for ground active invertebrate major group assemblages with respect to a number of environmental variables measured along a 30m north transect from the base of an isolated tree. Data from six trees was used in this analysis. * Indicates the environmental variable significantly explains the variation in the major group assemblages observed.