Australian Journal of Ecology (1999) **24**, 199–207

Effects of stock grazing on the ground invertebrate fauna of woodland remnants

LINDELL BROMHAM,[1,*] MARCEL CARDILLO,[2,†] ANDREW F. BENNETT[3,‡] AND MARK A. ELGAR[1]
[1]*Department of Zoology, University of Melbourne, Parkville, Vic. 3052, Australia,* [2]*Department of Ecology, Massey University, Palmerston North, New Zealand,* [3]*Arthur Rylah Institute, Department of Conservation and Natural Resources, PO Box 137, Heidelberg, Vic. 3084, Australia*

Abstract Habitat fragmentation can leave formerly widespread habitat types represented by only small habitat 'islands', and the conservation of these remnants is frequently compromised by ongoing disturbance. In northern Victoria, grazing of woodland remnants by sheep and cattle has profound effects on the vegetation structure of the woodland by removing understorey and ground vegetation. To investigate the effects of grazing pressure on remnant grey box *Eucalyptus microcarpa* woodland in northern Victoria, we surveyed the ground invertebrate fauna in ungrazed woodland remnants, grazed woodland remnants, and grazed pasture. The number of invertebrates caught increased from ungrazed woodland to grazed woodland to pasture, but this increase was due primarily to the most abundant orders (Hymenoptera, Coleoptera and Aranaea), and two abundant taxa characteristic of pasture (Orthoptera and Dermaptera). In contrast, most of the less abundant orders followed the opposite pattern, and were caught in higher numbers (and as a higher proportion of the total catch) in ungrazed woodland. Ungrazed woodland had a more diverse ground invertebrate fauna, most likely due to the greater diversity of food and habitat resources provided by the less disturbed vegetation. The differences in invertebrate communities corresponded to differences in vegetation and litter layers. The reduction in biodiversity of remnants due to grazing has implications for conservation management of remnant woodland in agricultural landscapes.

Key words: ants, diversity, grazing, habitat fragmentation, invertebrates, pitfall trapping, remnant woodland.

INTRODUCTION

Habitat fragmentation occurs when continuous habitats are partly cleared, leaving habitat remnants within an altered landscape. In many temperate regions of the world, and increasingly in tropical regions, such remnants are often the only remaining representatives of once widespread habitat types, and are therefore of high conservation significance. However, conservation of remnants and their flora and fauna is made difficult by the reduced area of available habitat, spatial isolation of remnants, and changed physical conditions within remnants, all of which can influence the capacity of the habitat to support viable flora and fauna populations (Shreeve & Mason 1980; Bennett 1987; Hobbs 1987; Loyn 1987; Klein 1989; Saunders *et al.* 1991; Robinson & Traill 1996).

Conservation of remnant habitats is further complicated by ongoing disturbances, such as grazing by domestic stock, timber harvesting, altered fire regimes, influx of pesticides and organic pollutants, and invasion by alien plant and animal species (Landsberg & Wylie 1983; Hobbs 1987; Loyn 1987; Wylie & Landsberg 1987; Abensperg-Traun 1992). One of the most widespread of these disturbances is grazing by domestic stock, which can have severe effects on native vegetation. Whole vegetation strata can be removed, leaving habitats with little or no understorey or ground cover. Grazing can prevent regeneration of woody tree species and other native vegetation (Hobbs 1987; Bennett *et al.* 1994) and may increase the vulnerability of the area to weed invasion (Hobbs 1987; Saunders *et al.* 1991). Grazing can also affect the soil and litter layers (e.g. King & Hutchinson 1983; Abbott 1989; Scougall *et al.* 1993), causing deterioration of soil structure, decreasing the infiltration capacity of the soil (Abbott 1989), increasing runoff (Laycock 1989) and promoting soil erosion (an effect compounded by vegetation removal). In addition, grazing modifies the ground microclimate, changing soil moisture content and levels of insolation, humidity and exposure (King & Hutchinson 1983; Neave & Tanton 1989).

Habitat disturbances such as these may be reflected in changes in the structure and composition of invertebrate communities (Majer 1983). In many habitats, ground invertebrates form an abundant and diverse

Present addresses: *Department of Zoology, University of Queensland, Brisbane, Qld 4072; †School of Australian Environmental Studies, Griffith University, Nathan, Qld 4111; ‡School of Ecology & Environment, Deakin University, 662 Blackburn Rd., Clayton, Vic. 3168, Australia.
Accepted for publication September 1998.

component of the fauna, and fill a variety of ecological roles (Abbott *et al.* 1979; Abbott 1989; Majer 1989). Both habitat fragmentation and grazing can have dramatic effects on ground invertebrate communities. Grazing can cause a significant decline in the abundance of litter and topsoil invertebrates (Abbott *et al.* 1979; Abbott 1989; Majer 1989), an effect that appears to increase with increasing grazing pressure (King & Hutchinson 1983). Fragmentation may be especially deleterious to invertebrates with limited dispersal powers, because even small distances between remnants can be a barrier to migration (Shreeve & Mason 1980; Klein 1989; Kindvall & Ahlen 1992). On the other hand, invertebrates may be able to persist in small remnants because they require relatively little area to support viable populations (Main 1987; Keals & Majer 1991).

Invertebrates make an ideal focus for a study of the effects of disturbance on fragmented habitats. They are an important component of native ecosystems, they are sensitive to changes in the habitat, and they are easily sampled in large numbers. An important advantage of ground invertebrates in the study of the ecology of remnants is the scale at which they interact with their habitat. In contrast to larger or more mobile animals, many ground invertebrates are less likely to move between remnants, so their presence can be a better indication that the remnant is able to support a viable population (particularly where the time since fragmentation is greater than the expected lifespan of the animals under consideration). Ground invertebrates may therefore be useful indicators of within-remnant processes.

We focused on the impact of grazing by sheep and cattle on the ground invertebrate fauna of remnant grey box *Eucalyptus microcarpa* woodland in the Northern Plains region of Victoria, Australia. This region was once covered by woodlands and native grasslands, but almost all the native vegetation cover has been cleared, leaving only isolated patches of woodland within a matrix of pastoral land. Many woodland remnants are on private pastoral properties and are open to grazing. We investigated the impact of grazing on remnant grey box woodland, by comparing grazed woodland patches to ungrazed woodland and to grazed pasture. We focused on the structure of the vegetation of the remnants and on the abundance, diversity and composition of ground invertebrate assemblages between these three types of sites.

METHODS

Study area

The study was conducted in woodland remnants around Benalla, 200 km northeast of Melbourne, Victoria (~ 36°S, 146°E), a region of temperate climate with hot summers and cool winters (Lee 1986). The native vegetation comprises woodlands dominated by grey box *Eucalyptus microcarpa*, often accompanied by red box *E. polyanthemos*, red stringybark *E. macrorhynca* or white box *E. albens* with river red gum *E. camaldulensis* along streams or on swampy ground. The natural understorey in the grey box woodlands comprises *Acacia* shrubs (e.g. *A. pycnantha, A. genistifolia*) with low sclerophyllous shrubs and native grasses (e.g. *Danthonia* spp.) forming the ground layer. Since European settlement of the region in the mid-19th century, more than 90% of the woodlands has been cleared, primarily for agriculture. Few substantial tracts of woodland are left and the most extensive are along major river frontages (Bennett & Ford 1997). Much of the remaining woodland exists as small remnants scattered throughout pastoral land, or as narrow strips of roadside vegetation. Most of these remaining patches are subject to ongoing disturbance associated with pastoral activity or other uses.

Field surveys of habitats with different grazing regimes

Ground invertebrates were collected during four surveys conducted over a 10-month period in 1993, in summer (February), autumn (April), winter (August) and spring (November). The surveys were conducted at 15 sites, five in each of three grazing 'treatments': (i) Ungrazed woodland—relatively undisturbed patches of grey box woodland protected from domestic stock grazing; (ii) Grazed woodland—patches of grey box woodland open to grazing by sheep and/or cattle; and (iii) Pasture—grazed pasture on pastoral properties, cleared of trees and shrubs and sown with exotic pasture grasses.

The survey sites were located in separate remnants or paddocks, each greater than one hectare in area [most were between 2 and 22 ha, with two substantially larger blocks (one ungrazed and one grazed)], chosen to minimize variation in overstorey vegetation type, geographical area and topography. At each site, a 50×50 m plot was selected, such that the plot edges were at least 15 m from the edge of the remnant or pasture. Ten pitfall traps were placed randomly within this plot (by using a random number generator to select trap co-ordinates), each at least 3 m from neighbouring traps. The number of traps per site was reduced to eight after the initial survey to reduce sorting time. Each pitfall trap consisted of two 225 mL plastic cups (diameter 78 mm, depth 95 mm) placed one inside the other and dug into the ground with the lip level with the soil surface. The inner cup could be lifted out and emptied, minimising disturbance to the soil and litter around the trap. Traps were left for one week before opening to minimize 'digging-in effects' (Greenslade

1973). For each sampling period, 50–100 mL of preservative (50% ethanol, 50% glycerin) was placed in each of the traps, which were then left open for five days. The high percentage of glycerin was necessary to slow evaporation of the preservative in summer. All trapped invertebrates over 4 mm in length were sorted to order level and counted. For the Coleoptera and Lepidoptera, adults and larvae were recorded separately because of their differing functional roles. For the autumn survey only, an exploration of lower taxonomic levels was conducted for the three most abundant orders: the Coleoptera adults and Aranaea were sorted to family level, and the Hymenoptera (which were almost exclusively Formicidae) were sorted to the level of genus. It is important to note that pitfall trap data do not necessarily reflect abundance of animals accurately, and are most useful as a relative measure of ground invertebrate activity for making comparisons between sites.

To describe the vegetation structure of the sites, the following variables were recorded in a 2 × 2 m quadrat around each trap: number of trees, number of shrubs, percentage ground cover (proportion of the plot covered by any living vegetation), percentage cover of native grass and introduced pasture grass, and the percentage cover of bare ground (no vegetation or litter). Percentage cover was estimated by eye to 10% intervals. Samples of leaf litter were taken at every survey. There were 10 random samples per site for the initial survey and five per site thereafter (to reduce sorting time). The samples were obtained by collecting all of the leaf litter and loose organic matter from the ground in a 25 × 25 cm quadrat. To characterize the quantity and structure of the litter, fresh weight and volume were measured for each sample, which was then oven-dried for 7 days at 50°C to obtain a dry weight measurement. The sample was then sifted to measure the amount of particulate matter that fell through a 6 × 6 mm sieve, from which the percentage particulate matter was calculated.

Data analysis

Differences in vegetation, litter and invertebrate variables among the three grazing treatments were tested using General Linear Models with pairwise multiple comparisons between treatments (using the GLM procedure in the SAS statistical package). The models were structured as two-way ANOVAs with treatment and site (nested within treatment) as factors. Invertebrate samples were characterized by catch (number of invertebrates caught for each taxon); relative abundance (taxon as a proportion of the total catch); diversity (Simpson's Index); and richness (number of taxa). Diversity indices were calculated for each site, rather than at the trap level, and were analyzed as one-way ANOVAs with treatment as the only factor.

Analyses were performed separately on data for each of the four surveys, and also on the mean values for all surveys. The patterns for the mean values were consistent with those of the separate surveys. As temporal effects were not a primary focus of this study, only the analysis of mean values are presented here. Log transformation of the data did not alter the results, so the analyses presented here are on untransformed data.

RESULTS

Vegetation and litter

Vegetation structure and complexity varied significantly among the three grazing treatments, and also showed variation among sites within treatments for most variables (Table 1). Undisturbed woodland had trees (overstorey), shrubs (understorey) and ground vegetation; grazed woodland had overstorey trees but no understorey layer and virtually no ground vegetation; and pasture had only ground vegetation with no trees or shrubs. The ground vegetation varied between treatments, in both quantity and composition. The percentage of ground covered by vegetation was very low in grazed woodland, high in ungrazed woodland and high in pasture. Ground vegetation was diverse in ungrazed woodland, with grasses (mostly native species with some introduced pasture grass), small shrubs, herbs and mosses. Introduced pasture grasses were generally the sole component of the ground vegetation of grazed woodland and pasture. Pasture sites had significantly more bare ground (without ground vegetation or litter) than woodland sites.

Litter quantity and quality also varied between treatments. Fresh weight was highest in ungrazed woodland, but dry weight did not differ significantly between ungrazed and grazed woodland (Table 1). This implies that the absolute amount of moisture in the litter is higher in ungrazed woodland (although moisture as a percentage of the weight was not significantly different). The volume of litter was highest in ungrazed woodland, so the litter was less dense. There was virtually no litter in pasture sites (Table 1).

Invertebrate catch and relative abundance

Over 10 000 macroinvertebrates from 26 orders were trapped and counted during the four surveys (Table 2). Total invertebrate catch was highest in pasture, intermediate in grazed woodland, and lowest in ungrazed woodland (Fig. 1a). This pattern was largely attributable to the most common orders, particularly ants (Hymenoptera), which comprised more than half of the total catch in all three treatments. Spiders (Aranaea) and adult beetles (Coleoptera) also showed this pattern

Table 1. Mean values and standard errors for parameters of the vegetation and litter which differed significantly between grazing treatments, analyzed by two-way ANOVA with treatment and site (nested within treatment) as factors

Variable	Ungrazed (U) Mean ± SE	Grazed (G) Mean ± SE	Pasture (P) Mean ± SE	*F*-ratio Treatment	*F*-ratio Site	Pairwise comparisons
Vegetation						
Number of trees	0.72 ± 0.14	0.98 ± 0.24	0 ± 0	9.61***	NS	U=G>P
Number of shrubs	2.95 ± 0.51	0.09 ± 0.04	0 ± 0	31.02***	NS	U>G=P
Ground vegetation (% cover)	59.53 ± 3.34	5.32 ± 1.28	73.67 ± 2.56	213.28***	5.19**	P>U>G
Native grass (% cover)	40.93 ± 4.17	0.64 ± 0.46	6.33 ± 2.76	53.94***	2.76*	U>G=P
Pasture grass (% cover)	12.21 ± 2.88	4.68 ± 1.09	67.96 ± 3.57	165.07***	4.57**	P>U=G
Bare ground (% cover)	6.28 ± 1.48	12.55 ± 2.88	20.41 ± 2.47	9.28***	6.93***	P>U=G
Litter						
Fresh weight (g)	210.23 ± 17.91	176.46 ± 9.67	8.87 ± 1.41	99.37***	3.57**	U>G>P
Dry weight (g)	173.94 ± 13.03	162.97 ± 9.16	8.21 ± 1.37	119.23***	3.47**	U=G>P
Volume (L)	1.67 ± 0.09	1.13 ± 0.08	0.15 ± 0.02	184.11***	6.33***	U>G>P
Density (g/L)	104.8 ± 5.53	194.15 ± 24.36	66.9 ± 9.5	18.36***	5.29**	G>U=P
Particulate matter (% weight)	57.09 ± 1.42	61.27 ± 2.35	85.06 ± 7.68	9.07***	NS	P>U=G

Significance of the *F*-ratios are indicated as follows: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$; NS, not significant. d.f. are 2 and 12 for treatment and site within treatment, respectively.

Vegetation and ground habitat variables were measured in the autumn survey only, while litter variables are the average value of four surveys.

Table 2. Mean number of invertebrates caught per trap (data presented as for Table 1)

Taxon	Ungrazed (U) Mean ± SE	Grazed (G) Mean ± SE	Pasture (P) Mean ± SE	*F*-ratio Treatment	*F*-ratio Site	Pairwise comparisons
Abundance						
Total	10.67 ± 0.87	20.04 ± 2.71	35.46 ± 2.91	37.78***	5.42***	P>G>U
Aranaea	1.67 ± 0.15	1.55 ± 0.13	2.17 ± 0.2	5.43**	3.78***	P>G=U
Blattodea	0.25 ± 0.04	0.16 ± 0.04	0.02 ± 0.01	13.42***	0.93	U>G>P
Coleoptera (adults)	0.7 ± 0.09	1.02 ± 0.1	3.34 ± 0.49	43.26***	10.28***	P>G=U
Coleoptera (larvae)	0.18 ± 0.06	0.17 ± 0.05	0.02 ± 0.01	4.89**	2.77**	U=G>P
Collembola	0.26 ± 0.08	0.14 ± 0.03	0.01 ± 0.01	7.38***	3.07***	U=G>P
Dermaptera	0.02 ± 0.01	0.03 ± 0.02	1.78 ± 0.22	90.1***	7.59***	P>G=U
Diptera	0.56 ± 0.08	0.74 ± 0.11	0.4 ± 0.07	4.05*	2.08*	U=G>P, U=P
Hymenoptera	5.81 ± 0.78	15.46 ± 2.69	25.67 ± 3.18	25.39***	7.43***	P>G>U
Julida	0.04 ± 0.02	0.01 ± 0.01	0 ± 0	3.25*	0.65	U=G=P, U>P
Lepidoptera (adults)	0.05 ± 0.02	0.2 ± 0.05	0.02 ± 0.01	9.34***	2.1*	G>P=U
Lithobiida	0.12 ± 0.04	0.03 ± 0.01	0.02 ± 0.01	6.24**	0.99	U>G=P
Orthoptera	0.15 ± 0.04	0.09 ± 0.03	1.78 ± 0.24	95.93***	13.97***	P>G=U
Polydesmida	0.37 ± 0.09	0.08 ± 0.03	0.03 ± 0.02	12.35***	2.54**	U>G=P
Scorpionida	0.06 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	5.86**	0.38	U>G=P
Aranaea						
Amauribiidae	0.03 ± 0.02	0.24 ± 0.08	0 ± 0	6.25**	1.11	G>U=P
Lycosidae	0.21 ± 0.06	0.03 ± 0.02	0.80 ± 0.17	16.78***	5.37***	P>U=G
Zodariidae	0.28 ± 0.08	0.76 ± 0.14	0.51 ± 0.16	3.23*	3.5***	G>U=P, G=P
Coleoptera						
Curculionidae	0.03 ± 0.02	0 ± 0	0.44 ± 0.14	8.23***	2.97**	P>U=G
Hymenoptera						
Camponotus	0.36 ± 0.11	1.13 ± 0.24	0.15 ± 0.05	9.16***	1.34	G>U=P
Iridomyrmex	0.13 ± 0.06	1.79 ± 0.58	0.26 ± 0.12	6.19**	2.14*	G>U=P
Rhytidoponera	3.89 ± 1.26	2.46 ± 0.41	16.26 ± 3.10	16.39***	4.98***	P>U=G

Orders trapped but not shown here because they did not vary significantly between treatments (all caught in low numbers) were Amphipoda, Embioptera, Hemiptera, Lepidopteran larvae, Mantodea, Neuroptera, Haplotaxida, Isopoda, Opilonida, Pseudoscorpionida and Thysaneura. Lists of the spider and beetle families and ant genera recorded are available from the authors.

(Fig. 1b). The high catch in the pasture treatment was further inflated by two abundant orders found primarily in pasture, grasshoppers (Orthoptera) and earwigs (Dermaptera) (Fig. 1c). Many of the less abundant orders, notably Scorpionida, Lithobiida, Polydesmida and Blattodea, showed the opposite pattern (highest in ungrazed woodland, lower in grazed woodland, lowest in pasture), although many such orders were caught in too small numbers for the pattern to be significant. Coleoptera larvae, Collembola and Julida did not differ significantly in catch between the two woodland treatments, but fewer were caught in pasture (Fig. 1d).

The patterns of relative abundance (catch per order expressed as a proportion of the total catch) show that while the absolute catch of spiders, beetles and ants increased from ungrazed woodland to grazed woodland to pasture, they formed approximately the same proportion of the total catch in each treatment (Table 3). Grasshoppers and earwigs, however, formed a significantly higher proportion of the catch in pasture (Table 3). The orders found in higher numbers in ungrazed woodland, such as Blattodea, Lithobiida, Polydesmida and Scorpionda, also formed a higher proportion of the catch in ungrazed woodland than in grazed woodland or pasture (Table 3). No order was found to be highest in either catch or relative abundance in the grazed woodland treatment.

To investigate patterns at a finer taxonomic level, spiders and beetles caught in the autumn survey were sorted to family level, and ants to genera. Among the spider families, the Amauribiidae and Zodaridae were caught in significantly higher numbers in grazed woodland than ungrazed woodland, and more Lycosidae were caught in pasture than in woodland (Table 2). Among beetle families, only the Curculionidae varied significantly between grazing treatments, for which catch was higher in pasture than woodland (Table 2). Spider and beetle families were not caught in sufficient numbers to allow reliable calculation of relative abundances. Three ant genera varied significantly between treatments in numbers caught. *Camponotus* and *Iridomyrmex* were highest in catch in grazed woodland, while *Rhytidoponera* were caught in highest numbers in pasture (Table 2). The composition of the ant catch also varied among treatments. *Iridomyrmex* and *Camponotus* formed a higher proportion in grazed woodland, and *Rhytidoponera* formed a higher proportion of the ant catch in pasture than in woodland (Table 3).

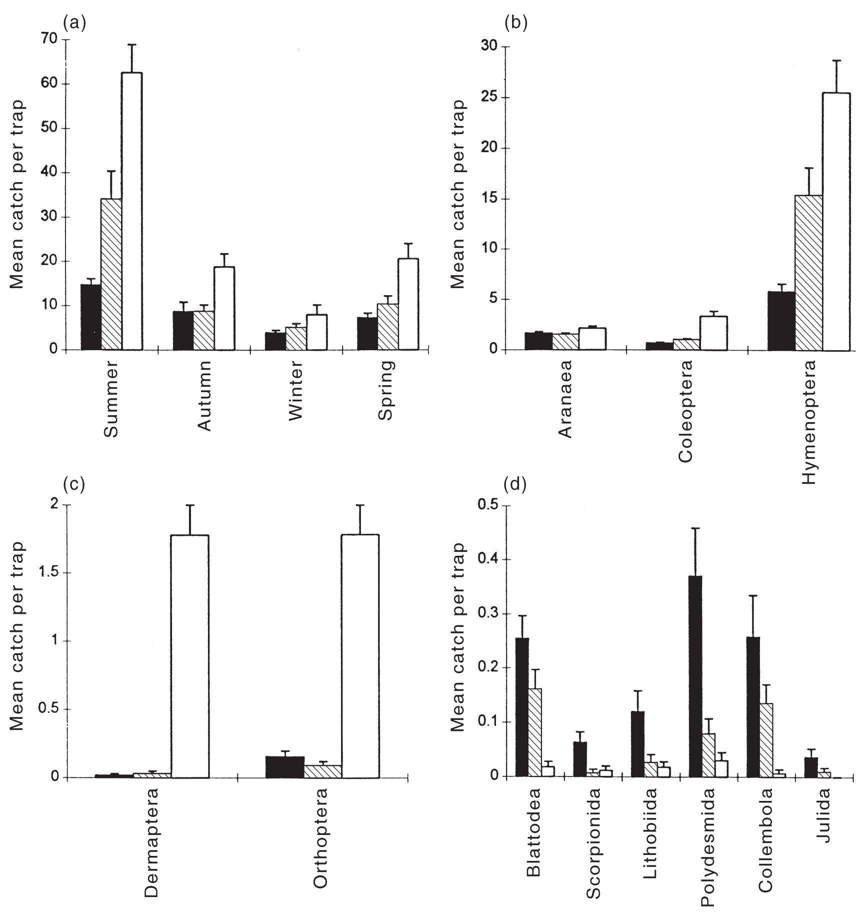

Fig. 1. Mean number of ground macroinvertebrates caught per trap in each of three grazing treatments: ungrazed woodland (■), grazed woodland (▧), and grazed pasture (□): (a) for all orders for each of the four surveys: (b) the three most abundant orders: Hymenoptera (ants), Coleoptera (beetles) and Aranaea (spiders) (mean of the four surveys): (c) two orders characteristic of pasture sites: Orthoptera (grasshoppers) and Dermaptera (earwigs): (d) less abundant orders that were caught in higher numbers, and in higher proportions of the catch, in ungrazed woodland: Blattodea (cockroaches), Lithobiida (centipedes), Scorpionda (scorpions), Collembola (springtails), Polydesmida and Julida (millipedes). Details of the statistical tests are given in Table 3.

Table 3. Mean values and standard errors of relative abundance for invertebrate orders and hymenopteran genera (per trap), and of Simpson's diversity index and taxon richness (per site)

Taxon relative abundance	Ungrazed (U) Mean ± SE	Grazed (G) Mean ± SE	Pasture (P) Mean ± SE	*F*-ratio Treatment	Site	Pairwise comparisons
Blattodea	0.03 ± 0.01	0.01 ± 0.002	0.001 ± 0.001	17.45***	NS	U>G=P
Coleoptera (larvae)	0.03 ± 0.01	0.02 ± 0.01	0.001 ± 0.001	7.06**	4.72***	U=G>P
Collembola	0.03 ± 0.01	0.02 ± 0.003	0 ± 0	9.77***	4.68***	U>G=P
Dermaptera	0.003 ± 0.003	0.001 ± 0.001	0.08 ± 0.04	61.18***	10.45***	P>U=G
Lepidoptera (adults)	0.004 ± 0.002	0.02 ± 0.01	0.002 ± 0.001	6.7**	NS	G>U=P
Lithobiida	0.02 ± 0.01	0.003 ± 0.002	0.001 ± 0.001	6.09**	NS	U>G=P
Orthoptera	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	41.57***	11.11***	P>U=G
Polydesmida	0.04 ± 0.01	0.01 ± 0.01	0.001 ± 0.001	12.10***	NS	U>G=P
Scorpionida	0.01 ± 0.001	0.001 ± 0.001	0.0002 ± 0.0001	7.43***	NS	U>G=P
Hymenoptera						
Camponotus	0.15 ± 0.1	0.19 ± 0.06	0.01 ± 0.01	9.16**	NS	G>U=P
Iridomyrmex	0.06 ± 0.06	0.23 ± 0.1	0.1 ± 0.1	6.19**	2.14*	G>U=P
Rhytidoponera	0.6 ± 0.19	0.46 ± 0.13	0.78 ± 0.15	16.39***	4.58***	P>U=G
Richness						
Orders	17.8 ± 0.2	15.4 ± 1.21	11.4 ± 1.33	9.12**	–	U>G>P
Diversity						
Orders	3.55 ± 0.12	2.85 ± 0.11	2.45 ± 0.49	6.08*	–	U>G=P
Aranaean families	2.28 ± 0.34	2.19 ± 0.24	1.29 ± 0.09	4.93*	–	U=G>P

Significance of the *F*-ratios are indicated as follows: *$P<0.05$; **$P<0.01$; ***$P<0.001$; NS not significant. d.f. are 2 and 12 for treatment and site within treatment, respectively.

Results of pairwise comparisons between treatments are represented as follows: (=) indicates no significant difference, (>) or (<) indicate the value for one treatment was significantly higher or lower than the other. Treatments are represented by U (ungrazed woodland), G (grazed woodland) and P (pasture).

Invertebrate diversity

While the number of invertebrate orders trapped was only slightly higher in ungrazed woodland than grazed woodland, in ungrazed woodland there was a more even distribution of abundances among taxonomic groups, giving it a significantly higher value for Simpson's Diversity Index (Table 3). The number of orders recorded in pasture was significantly lower than in either of the woodland treatments. Both the diversity and richness of ant genera were significantly higher in grazed woodland than in ungrazed woodland. Richness of spider and beetle families was not significantly different among treatments, but spider diversity was significantly higher in ungrazed woodland than in pasture.

DISCUSSION

This study revealed differences in vegetation, litter and ground invertebrate assemblages between ungrazed woodland, grazed woodland and pasture. While the ground invertebrate samples from ungrazed woodland consisted of many orders but relatively few individuals, those from pasture contained few, very abundant orders. Grazed woodland was in many ways intermediate, with increased catch of the most common invertebrate orders but decreased representation of most other orders. The increase in total catch from ungrazed woodland to grazed woodland to pasture was the result of an increase in only the most abundant taxa. The majority of orders followed the opposite pattern, decreasing in abundance from ungrazed woodland to grazed woodland to pasture.

Pitfall trapping is an efficient way of collecting large numbers of animals for a comparison of invertebrate activity between sites, but should not be relied upon to provide a complete inventory of the fauna of a site. Care must be taken in interpreting pitfall trap data as an accurate representation of the community, as the composition of the catch may be influenced by 'trappability'. The likelihood of an animal falling into a trap depends on its mobility, activity levels, size and foraging behaviour, as well as the physical surroundings of the trap (Greenslade 1964, 1973). Pitfall trapping is therefore not a reliable measure of absolute abundance, but is best used as an indicator of spatial or temporal changes in the composition of invertebrate assemblages. For example, spiders, beetles and ants were caught in greater numbers in the grazed sites than in ungrazed woodland, but their relative abundances did not differ between treatments, nor did the diversity of suborder taxa increase with catch (in fact, spider diversity was highest in undisturbed woodland). These observations suggest that the most likely explanation for the pattern in catch for spiders, beetles and ants is either increased activity or trappability in grazed woodland and pasture – for example, decreased litter volume at grazed sites could increase trappability by decreasing the available foraging surface around the trap. However, variation in trappability alone cannot account for the patterns in composition of the ground invertebrate fauna, because it would require taxa to differ in patterns of trappability in different grazing treatments. This seems unlikely, and therefore the general pattern of decreasing diversity from ungrazed woodland to grazed woodland to pasture most likely reflects a true difference between the invertebrate communities of the three treatments.

The differences in composition of the ant fauna across grazing treatments confirms the findings of other studies. The ant fauna of grazed woodland had a high proportion of *Iridomyrmex*, a genus that often dominates ant communities in disturbed areas (Andersen 1990; see also Scougall *et al.* 1993). The ant fauna of pasture sites consisted primarily of *Rhytidoponera*, a diurnal generalist able to forage in hot, dry conditions with high levels of insolation (Andersen 1986b). *Rhytidoponera* is frequently dominant where vegetation structure is simple, and species of this genus are successful colonizers of disturbed areas (Andersen 1986b). Scougall *et al.* (1993) also found marked differences in the composition of ant communities in woodlands subject to different grazing regimes, including increased dominance of *Iridomyrmex* in grazed woodland remnants in the Western Australian wheatbelt.

Many of the less abundant orders showed highest representation in undisturbed woodland, such as cockroaches (Blattodea), millipedes (Polydesmida, Julida), centipedes (Lithobiida), springtails (Collembola), beetle larvae (Coleoptera) and scorpions (Scorpionida) (Table 3). The lower numbers of scorpions in disturbed woodland mirrors results of study of invertebrates in fragmented gimlet (*Eucalyptus salubris*) woodland by Abensperg-Traun *et al.* (1996), although the same study found cockroach abundance highest in moderately disturbed woodland. Abensperg-Traun *et al.* (in press) note that the effect of grazing on the invertebrate communities varies between woodland types, so studies in different habitat types may be expected to show differences in their results. A lower level of taxonomic identification may be needed to determine if the differences in response to disturbance are due to the presence of different species, an effect masked by broad ordinal classification.

Changes to specific aspects of the ground habitat of grazed woodland may explain the reduced representation of particular orders – for example, drier, more compact leaf litter may be less suitable for detritivorous millipedes or cockroaches – but a more general explanation may arise from a consideration of habitat structure and complexity. There are several ways in which the observed differences in the ground habitat between grazing treatments may be responsible for differences in the ground macroinvertebrate community. Firstly, removal of the ground vegetation and litter represents a reduction in the quantity of resources (food and habitat) which may directly affect abundance of the taxa that rely on those resources, such as millipedes which eat living and dead plant material (Harvey & Yen 1989; Hopkin & Reed 1992). Secondly, environmental changes resulting from grazing may alter the ground-level microclimate. Removal of ground and understorey vegetation leaves the ground habitat less sheltered, increasing insolation to the soil surface. This is consistent with the lower litter moisture level in grazed woodland, and may be an important determinant of invertebrate distribution. For example, this may account for the low catch of animals that require moist conditions and loose soil for burrowing, such as centipedes (Lithobiida) (Abbott *et al.* 1979; Abbott 1989). Finally, loss of vegetation and the reduction and compaction of the litter layer simplifies the structure and reduces the diversity of microhabitats in grazed sites. Structural diversity of the understorey, ground vegetation and leaf litter layer can influence the diversity of invertebrate communities (Majer 1983; Andersen 1986a,b; Erhlich & Murphy 1987). Grazed woodland may have a less diverse ground invertebrate fauna because it does not provide the same breadth of resources or as many possible niches as undisturbed woodland.

The ecological consequences of alterations to woodland systems resulting from grazing are largely unknown, but a major concern is the cycling of organic matter. In forest systems, a large proportion of the productivity is processed by detritivores (Begon *et al.* 1996). Many of the orders found in reduced numbers in grazed woodland are primarily detritivorous, contributing to nutrient turnover by breaking down organic matter in the litter layer (e.g. Blattodea), and promoting movement of organic matter into the soil horison (e.g. Polydesmida). Nutrient cycling in grazed woodland may also be affected by the reduction in moisture level in the litter layer, and compaction of the soil by hoofed animals. While invertebrate communities may form an important part of the energy and nutrient cycles in woodlands, the effects of changes in invertebrate community abundance and/or composition on these ecological processes are poorly understood. Aside from the possible alteration of ecological processes, biodiversity loss is itself a major conservation concern. Furthermore, the reduced diversity of ground invertebrates in grazed woodland may be indicative of a reduction in biodiversity of other groups due to grazing (e.g. Robinson & Traill 1996).

Assessment of the conservation status of a region based primarily on the area of native habitat remaining may give an over optimistic view of the current conservation value of the land. Habitat remnants scattered throughout agricultural regions are commonly subject to ongoing disturbance which compromises the habitat quality of the remnants. We have described a case study where grazing by sheep and cattle appears to reduce the diversity of native fauna in remnant *Eucalyptus* woodland. Habitat conservation in fragmented landscapes needs to be based not only on landscape-scale issues such as remnant size and connectivity, but also requires management of land uses and disturbance factors that affect within-remnant processes (Saunders *et al.* 1991; Scougall *et al.* 1993; Bennett *et al.* 1994). Programs that focus on limiting disturbance, such as assisting graziers to fence woodland remnants, could bring great benefits to conservation in fragmented landscapes.

ACKNOWLEDGEMENTS

The surveys and experiments in Reef Hills Park were conducted under Research Permit 934/003 (National Parks Act). Financial support for the project was provided by a Museum of Victoria Student Research Grant, the W. V. Scott Fund and the Flora and Fauna Branch of the Department of Conservation and Natural Resources (DCNR). We thank Alan Yen, Peter Lilywhite and Graham Milledge (Invertebrate Survey, Museum of Victoria), and Ian Davidson and Doug Robinson (Benalla DCNR) for their help and advice. Many thanks to Elizabeth Long, Peter Holmes and Fred and George Jones for permitting the surveys to be conducted on their properties.

REFERENCES

Abbott I. (1989) The influence of fauna on soil structure. In: *Animals in Primary Succession; the Role of Fauna in Reclaimed Land*. (ed. J. D. Majer), Cambridge University Press, Cambridge.

Abbott I., Parker C. A. & Sills I. D. (1979) Changes in the abundance of large soil animals and physical properties of soils following cultivation. *Aust. J. Soil Res.* **17,** 343–53.

Abensperg-Traun M. (1992) The effects of sheep grazing of the subterranean termite fauna (Isoptera) in the Western Australian wheatbelt. *Aust. J. Ecol.* **17,** 425–32.

Abensperg-Traun M., Smith G. T., Arnold G. W. & Steven D. E. (1996) The effects of habitat fragmentation and livestock grazing on animal communities in remants of gimlet *Eucalyptus salubris* woodland in the Western Australian wheatbelt. I. Arthopods. *J. Appl. Ecol.* **33,** 1281–301.

Abensperg-Traun M., Smith G. T., Steven D. E. & Atkins L. (in press) Different woodland types, different grazing effects? Plants and soil and litter arthropods in remnant woodlans in the Western Australian wheatbelt. In: *Temperate Eucalypt Woodlands in Australia: Biology, Conservation, Management and Restoration* (eds R. J. Hobbs and C. Y. Yates). Surrey Beatty & Sons, Chipping Norton, NSW.

Andersen A. N. (1986a) Diversity, seasonality and community organization of ants at adjacent heath and woodland sites in southeastern Australia. *Aust. J. Zool.* **34,** 53–64.

Andersen A. N. (1986b) Patterns of ant community organization in mesic Southeastern Australia. *Aust. J. Ecol.* **11,** 87–97.

Andersen A. N. (1990) The use of ant communities to evaluate change in Australian terrestrial ecosystems: a review and a recipe. *Proc. Ecol. Soc. Aust.* **16,** 347–57.

Begon M., Harper J. L. & Townsend C. R. (1996) *Ecology* 3rd ed. Blackwell Science, Oxford.

Bennett A. F. (1987) Conservation of mammals within a fragmented forest environment; the contributions of insular biogeography and autecology. In: *Nature Conservation: the Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins), pp. 41–52. Surrey Beatty & Sons, Chipping Norton, NSW.

Bennett A. F. & Ford L. A. (1997) Land use, habitat change and the conservation of birds in fragmented rural environments: a landscape perspective from the Northern Plains, Victoria, Australia. *Pacific Conserv. Biol.* **3,** 244–61.

Bennett A. F., Lumsden L. F. & Nicholls A. O. (1994) Tree hollows as a resource for wildlife in remnant woodlands; spatial and temporal patterns across the Northern Plains of Victoria, Australia. *Pacific Conserv. Biol.* **1,** 222–35.

Erhlich P. R. & Murphy D. D. (1987) Monitoring populations on remnants of native vegetation. In: *Nature Conservation: the Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins), pp. 201–10. Surrey Beatty & Sons, Chipping Norton, NSW.

Greenslade P. J. M. (1964) Pitfall trapping as a method for studying populations of Carabidae (Coleoptera) *J. Anim. Ecol.* **33,** 301–10.

Greenslade P. J. M. (1973) Sampling ants with pitfall traps: digging-in effects. *Insectes Sociaux* **20,** 343–53.

Harvey M. S. & Yen A. L. (1989) *Worms to Wasps: an Illustrated Guide to Australia's Terrestrial Invertebrates.* Oxford University Press, Australia.

Hobbs R. J. (1987) Disturbance regimes in remnants of natural vegetation. In: *Nature Conservation: the Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbridge & A. J. M. Hopkins), pp. 233–40. Surrey Beatty & Sons, Chipping Norton, NSW.

Hopkin S. P. & Reed H. J. (1992) *The Biology of Millipedes*. Oxford University Press, Oxford.

Keals N. & Majer J. D. (1991) The conservation status of ant communities along the Wubin-Perenjori corridor. In: *Nature Conservation 2: the Role of Corridors.* (eds D. A. Saunders & R. J. Hobbs) Surrey Beatty & Sons, Chipping Norton, NSW.

Kindvall O. & Ahlen I. (1992) Geometrical factors and metapopulation dynamics of the Bush Cricket, *Metrioptera bicolor* Philippi (Orthoptera: Tettigoniidae). *Conserv. Biol.* **6,** 520–9.

King K. L. & Hutchinson K. (1983) The effect of sheep grazing on invertebrate numbers and biomass in unfertilized natural pasture of the New England Tablelands (NSW) *Aust. J. Ecol.* **8,** 245–55.

Klein B. C. (1989) Effects of forest fragmentation on dung and carrion beetle communities in central Amazonia. *Ecology* **70,** 1715–25.

Landsberg J. & Wylie F. R. (1983) Water stress, leaf nutrients and defoliation; a model of dieback of rural eucalypts. *Aust. J. Ecol.* **8,** 27–41.

Laycock W. A. (1989) Reclamation of land for agricultural grazing. In: *Animals in Primary Succession; the Role of Fauna in Reclaimed Land*. (ed. J. D. Majer), pp. 245–68. Cambridge University Press.

Lee D. M. (1986) Climate. In: *Atlas of Victoria* (ed. J. S. Duncan), pp. 26–31. Government of Victoria, Melbourne.

Loyn R. H. (1987) Effects of patch area and habitat on bird abundances. In: *Nature Conservation: the Role of Remnants of Native Vegetation*. (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins), pp. 64–7. Surrey Beatty & Sons, Chipping Norton, NSW.

Main B. Y. (1987) Persistence of invertebrates in small areas: case studies of trapdoor spiders in Western Australia. In: *Nature Conservation: the Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins), pp. 29–40. Surrey Beatty & Sons, Chipping Norton, NSW.

Majer J. D. (1983). Ants: bio-indicators of minesite rehabilitation, land-use and land conservation. *Environ. Manag.* **7,** 375–83.

Majer J. D. (ed.) (1989) *Animals in Primary Succession: the Role of Fauna in Reclaimed Land*, Cambridge University Press, Cambridge.

Neave H. M. & Tanton M. T. (1989) The effects of grazing by kangaroos and rabbits on the vegetation and the habitat of other fauna in the Tidbinbilla nature reserve, Australian Capital Territory. *Aust. Wildl. Res.* **16,** 351–77.

Robinson D. & Traill B. J. (1996) Conserving woodland birds in the wheat and sheep belts of Southern Australia. *Wingspan* **S6,** 1–15.

Saunders D. A., Hobbs R. J. & Margules C. R. (1991) Biological consequences of ecosystem fragmentation: a review *Conserv. Biol.* **5,** 18–32.

Scougall S. A., Majer J. D. & Hobbs R. J. (1993) Edge effects in grazed an ungrazed Western australian wheatbelt remnanats in relation to ecosystem reconstruction. *Nature Conservation 3: Reconstruction of Fragmented Ecosystems* (eds D. A. Saunders, R. J. Hobbs & P. R. Erlich), pp. 163–78. Surrey Beatty & Sons, Chipping Norton, NSW.

Shreeve T. G. & Mason C. F. (1980) The number of butterfly species in woodlands. *Oecologia (Berl.)* **45,** 414–8.

Wylie F. R. & Landsberg J. (1987) The impact of tree decline on remnant woodlots on farms. In: *Nature Conservation: the Role of Remnants of Native Vegetation* (eds D. A. Saunders, G. W. Arnold, A. A. Burbidge & A. J. M. Hopkins), pp. 331–32. Surrey Beatty & Sons, Chipping Norton, NSW.