

Impacts of grazing and burning on terrestrial invertebrate assemblages in dry eucalypt forests of north-eastern New South Wales: implications for biodiversity conservation

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ABSTRACT

Cattle have been grazed in the forested areas of northern NSW for over 150 years. While this practice is considered to have significant benefits for forest management and the local economy, the combined effects of grazing and fire has raised concerns about the impact of this composite management practice on the flora and fauna. The effects on a biodiverse and functionally important component, the terrestrial invertebrates, are largely unknown. This study looked at ground-active invertebrates and found that grazing impacts operate within a configuration of broader environmental and historical factors. At a landscape scale, abundance and taxon richness were influenced by geology (and related aspects of topography and soil), although response patterns varied between groups. There was a marked spatial patterning in richness, probably as a response to a rainfall-related productivity gradient. Past logging practices have created patches of more open environments within the overall forest matrix and it appears that cattle graze preferentially in these areas. At this smaller scale, abundance and richness were related to aspects of forest structure and soil physical properties. Grazing and associated burning appear to have decreased the amount and spatial variability of understorey vegetation and soil organic matter, with these changes influencing community composition (at the ordinal level). Grazing related impacts on invertebrate assemblages were however subtle, which is expected given the low overall range of grazing intensities studied in this project. The applicability of coarse-level data to describe and interpret patterns and disturbance effects is discussed. Future management needs to consider the role of grazing in the context of changed land tenure in these forests, particularly with regard to altered fire regimes and their effect on biodiversity conservation.

Key words: conservation, fire, grazing, invertebrates

Introduction

The grazing of domestic animals in forests of the north coast of New South Wales has occurred for over 150 years. On State Forests, grazing is currently carried out under two tenures; grazing leases granted under the Crown Lands Act 1989 and Occupation Permits under the Forestry Act 1916. State Forests of NSW considers that forest grazing has significant benefits for forest management through the control of dense grass and associated fire hazard (SFNSW 1995). Grazing of publicly owned forests also has a substantial historical and cultural basis, and by providing a seasonal resource, has become an integral part of livestock production, contributing substantially to economy of the local area (SFNSW 1995).

Because graziers often burn a large proportion of the more flammable forests each spring to improve fodder, grazing impacts appear inseparable from those of the associated fire regime. While grazing is seen as a cost-effective method of fuel reduction, in association with regular low-intensity burning, it has been identified as having a

potentially adverse impact on flora and fauna (Smith *et al.* 1994). Although a number of Australian studies have investigated the influence of livestock grazing on native vegetation (*e.g.* Leigh and Holgate 1979, Petit *et al.* 1995, Fensham and Skull 1999, Henderson and Keith 2002), few have investigated the impact of grazing on components of the native fauna. Within the fauna, studies of the effects of grazing on invertebrates in Australia have previously mainly considered pastoralism in rangelands or savanna landscapes (*eg.* Landsberg *et al.* 1999, Hoffmann 2000, Woinarski *et al.* 2002), or remnant patches of eucalypt forest within a matrix of cleared land (Abensperg-Traun *et al.* 1996, Bromham *et al.* 1999, Harlen 2000). Studies in these heavily grazed grasslands and woodlands have linked changes in the structure and composition of invertebrate communities to reduction in vegetation and litter cover.

The impact of low-intensity grazing on invertebrates in large continuous areas of forest is less well understood, particularly with regard to the combined effects of grazing

and burning. Bickel and Tasker (2004), in an investigation of invertebrates using tree trunks in the tableland forests of NSW, found that trunk invertebrates differed in composition between grazed/burnt and ungrazed sites, but not in abundance or diversity. Lack of detailed knowledge concerning the impact of grazing and burning on terrestrial invertebrates is of concern, given that this group of organisms (including the insects, molluscs, spiders and mites etc) have been shown to play an important role in regulating energy flow and nutrient cycling (Spain and Hutson 1983, Seastedt 1984) and therefore in ecosystem function (see Schultz and Mooney 1993). There is increasing awareness that this biodiversity contributes to the maintenance of primary ecosystem processes by providing an array of pathways for the flux of nutrients, water and energy (Lambeck 1992). In this way invertebrates play an important role in the provision of a number of key ecosystem services that are fundamental to our quality of life and to our economy (see Daily 1997, Milburn-Clark 2001).

The primary aim of this study was therefore to assess the impacts of long-term grazing and associated burning on forest invertebrate assemblages. Since grazing does not occur in isolation from burning in north-eastern NSW, the two factors were considered as a composite management system. The primary outcome is an assessment of this practice as a sustainable long-term management strategy with regard to the conservation of forest biodiversity. The conservation of biodiversity is a fundamental principle underlying Ecologically Sustainable Management and is of considerable strategic importance to forest managers. The secondary aim was to assess of the applicability of data at the taxonomic level of order (or equivalent) to elucidate a coarse-scale interpretation of the response of invertebrates to environmental factors and disturbance by grazing and associated burning. While ordinal-level data may have severe limitations with regard to site-specific biodiversity assessment (Cranston and Trueman 1997), studies of the effects of grazing (Abensperg-Traun *et al.* 1996, Bromham *et al.* 1999) and burning (York 1999a, Andersen and Müller 2000) have shown that data at this scale can adequately detect both environmental and disturbance effects.

Methods

Study design

The study area lies principally (at the time of investigation) within State Forests' Northern Rivers Region and incorporates areas of State Forest, Crown Land and a National Parks and Wildlife (NPWS) Nature Reserve. The forests chosen for this study belong to the Bungawallbin and Richmond Range Group, which lie south of Casino, and are bordered approximately by latitudes 29° 00' to 29° 30' S and longitudes 152° 35' to 153° 20' E. The overall experimental design and sampling strategy was developed so as to best sample representative areas of the forest environment, with geological type and management history as primary stratification variables (York 1997). Geological types had previously been mapped and described in terms of their soils (Veness and Associates 1994, SFNSW 1995). Sites were located on Alluvials (Unconsolidated Materials) occurring predominantly on alluvial flats with

low slopes, the Grafton Formation (Mixed Sediments) on gentle undulating hillslopes, Walloon Coal Measures (Carbonate Sediments) on steep hillslopes, and Kangaroo Creek Sandstone (Sandstones) on moderately steep-sided plateaux. These geological types were the most widespread within the study area and, while broadly banded north-south, were sufficiently widely distributed to permit effective spatial replication. Management history (grazed/ungrazed) was determined utilising SFNSW records of grazing leases and Occupation Permits and, following discussions with staff, verified by field inspections.

Study sites were selected from "grassy open" and "heath forest/woodland" forests, the drier forest types in which grazing predominantly occurs (see Binns 1995). These forests are characterised by an overstorey dominated by Blackbutt *Eucalyptus pilularis*, Spotted Gum *Corymbia maculata*, Red Bloodwood *C. gummifera*, Grey Ironbark *E. siderophloia*, Bastard Tallowwood *E. planchoniana*, and Woods' Apple *Angophora woodsiana*, with an understorey of moderately dense to dense grasses, usually with a sparse to dense (1-2 m) sclerophyllous shrub stratum. Areas logged within the last 10 years were excluded from the design. Forest areas satisfying these criteria were selected with the aid of the State Forests spatial GIS database, with sites located using a randomisation process. To ensure sites were accessible to cattle (*i.e.* grazing effects not confounded by topography) and not subject to extreme grazing pressure as would occur near watering points, sites were constrained to being on a slope less than 10°, within 100 m of a road and more than 50 m from a watercourse.

In January 1997, 20 sites were located within each geological type, 10 grazed and 10 ungrazed, giving a total of 80 sites. Paired grazed and ungrazed sites were matched across comparable soil-types, land-use history and broad forest types. Since the study area extended over approximately 50 × 60 km, and sites were separated by a minimum distance of 500 m, sites were considered independent. The original objective of 80 sites was subsequently modified following heavy rain and flooding in February 1997, which prevented access to a number of areas (primarily sites on Carbonate Sediments). Data from 52 sites across three geological types (16 Mixed Sediment, 18 Sandstone and 18 Unconsolidated Materials sites) are presented here (Fig. 1). Within each geological type, numbers of grazed:ungrazed sites were 7:9, 6:12 and 10:8 respectively. Names of State Forests and Reserves used in this paper relate to land tenure at the time of the study, although changes as part of the Regional Forest Agreement (RFA) process are considered in the Discussion.

Measurement of environmental variables

At each site, a 50 m transect was established using a random compass bearing while ensuring it traversed a representative vegetation community and avoided drainage lines and heavily disturbed areas. A 50 m × 20 m (0.1 ha) quadrat was established around this transect. Environmental variables considered most likely to affect invertebrate assemblages were quantitatively assessed within the quadrat. These included general site characteristics, aspects of habitat structure and variables indicating disturbance history.

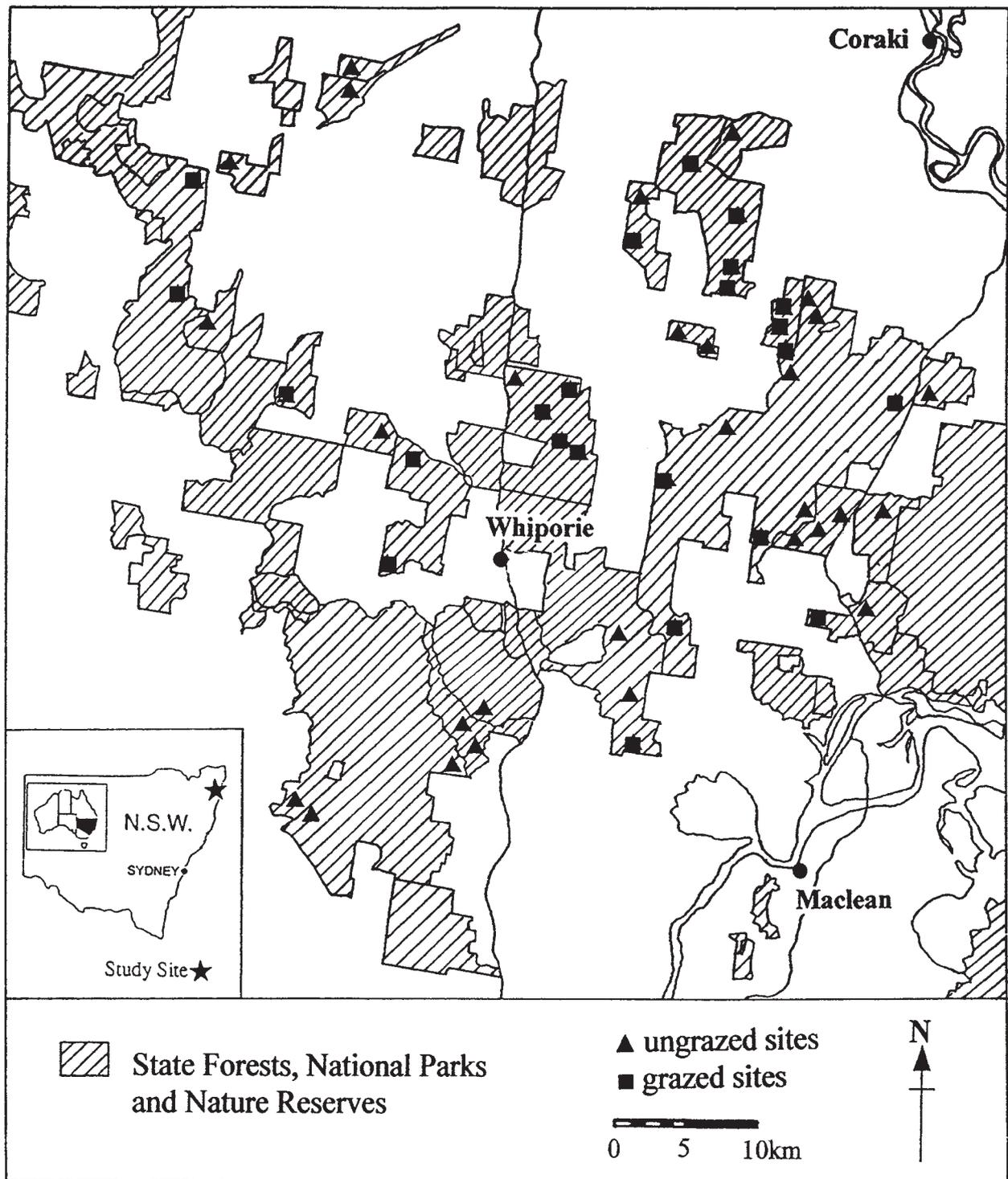


Figure 1. Location of study area.

Site characteristics

Aspect, slope and altitude were recorded for each site by use of a compass, clinometer and by reference to the appropriate 1:25000 topographic sheet. Sites were allocated to one of five Broad Forest Type groups (leagues), based on the Baur forest types (FCNSW 1989), from reference to State Forests forest-type maps and by field inspection. Recorded groups were: Grey Gum-Grey Ironbark (n=3), Spotted Gum (n=20), Blackbutt (n=15), Maritime/Red Gum (n=10), and Grey Box-Iron Bark (n=4).

Habitat structure

The framework within which terrestrial invertebrate communities function involves the vegetation understorey, topsoil and leaf litter. Vegetation density was calculated for five levels of the understorey using the coverboard technique of MacArthur and MacArthur (1961). The levels were: ground herbs (0-20 cm), small shrubs (20-50 cm), medium-sized shrubs (50-100 cm), tall shrubs (100-150 cm) and very tall shrubs (150-200 cm). Twenty measurements were systematically made within each quadrat for each level. An index of the overall vertical complexity (Foliage Height

Diversity) was calculated utilising the Shannon Index, $-\sum_i p_i \log_e p_i$, where p_i is the proportion of the total foliage that lies in each vegetation layer. Ten soil cores (5 cm diameter \times 10 cm deep) were collected and bulk density and organic matter content (expressed as % loss on ignition) were measured using the procedures of Corbett (1969) and Pitty (1978). Leaf litter depth was measured to the nearest 0.5 cm at 20 points within each quadrat using a graduated probe. For each of these variables, the mean value was used to describe the condition at each site, with the standard error (s.e.) used as a measure of spatial variability (patchiness). The diameter at breast height over bark (DBHOB) of all woody vegetation with a diameter greater than 5 cm was measured and converted to basal area, the sum of which was used as an index of the overstorey vegetation structure.

Disturbance history

Logging histories were not available for all sites, so indices of past disturbance were based on the number of stumps and small (<10 cm diameter) and large (\geq 10 cm diameter) logs within each quadrat. Site inspections revealed that there were highly variable levels of grazing activity on grazed sites. An index was developed to describe current grazing intensity based on the number of cowpats within the site, around the perimeter of the site and along a 100 m length of the adjacent road (see York 1998). Based on the index, sites were allocated to one of five grazing categories, ranging from ungrazed sites (1), through to sites with a relatively high grazing intensity (5) (see York 1998). This enabled the initial factorial design to be complemented by the use of a gradient analysis approach (Krebs 1985) to investigate the effect of grazing intensity on measured habitat variables and terrestrial invertebrate communities.

Spatial pattern

Given the extent of the study area (\sim 50 \times 60 km), a certain amount of variation in invertebrate assemblages could be expected purely on the basis of the geographical separation between sites. Invertebrates have been shown to exhibit rapid species turnover, or gamma diversity, between similar habitat types that are geographically separated (Ferrier and Watson 1997, Ferrier *et al.* 1999). To take this into account, a geographic data matrix based on the coordinates (x,y) of each site was made containing the terms for a cubic trend surface regression (Borcard *et al.* 1992, Legendre and Legendre 1998) of the form:

$$z = b_1x + b_2y + b_3x^2 + b_4xy + b_5y^2 + b_6x^3 + b_7x^2y + b_8xy^2 + b_9y^3$$

To investigate a possible east-west productivity (rainfall) gradient (SFNSW 1995), the 'easting' component of each site locality (x) was used to describe the spatial variable *geographic position*, with terms from the above equation used within the ordination analyses (see below).

Terrestrial invertebrate communities

Terrestrial invertebrate assemblages were assessed by composite sampling methods. The principal method involved a summer pitfall-trapping program to capture epigeic (surface-active) invertebrates, supplemented by leaf-litter extraction and vegetation sweeping. Data from the pitfall-trapping component of the study are presented here. Nine points were systematically established along

the 50 m transect at each site and 8 cm \times 12 cm deep plastic pitfall traps established flush with the ground surface. Traps were half filled with a preservative solution (alcohol + ethylene glycol 50:50) and left open for a period of two weeks. All sites were trapped concurrently. Samples were returned to the laboratory and examined using a binocular microscope, with material identified to the taxonomic level of Order (or nearest equivalent).

Data analyses

Four basic approaches were used to elucidate patterns in the invertebrate data. Firstly, data were tabulated by taxa in order to describe and summarise, and to identify rare groups, which, for sampling reasons, might not be amenable to meaningful analysis. Secondly, data were compared across primary stratification criteria (geological type and grazing) using Analysis of Variance (ANOVA) and Multiple Analysis of Variance (MANOVA) testing procedures. Exploratory data analysis was utilised to investigate underlying patterns in the distribution of data and transformations applied as appropriate. Thirdly, relationships between primary data descriptors (abundance and ordinal (taxon) richness) and environmental variables were explored using correlation techniques. Fourthly, invertebrate assemblages were compared between grazed and ungrazed sites, and relationships with environmental variables explored, using ordination procedures.

Abundance and richness

Site values for total abundance and ordinal (taxon) richness were compared between geological types (Mixed Sediments, Sandstones and Unconsolidated Materials) and grazing treatments (grazed/ungrazed), with the effects of these factors tested using two-way ANOVA (Type II). Where there were adequate data to permit reliable statistical analysis (spiders, ticks and mites, pseudoscorpions, woodlice, centipedes, springtails, dipturans, cockroaches, grasshoppers and crickets, bugs, thrips, beetles, flies, (non-ant) hymenoptera, ants and insect larvae), abundance data were analysed using MANOVA, testing for treatment effects at a finer taxonomic scale.

Effect of environmental variables

Overall abundance (grouped) was cross-tabulated against Broad Forest Type with the degree of association tested with the χ^2 statistic. Pearson's Product Moment Correlation Coefficients (parametric) and Spearman's Rank Correlation Coefficients (non-parametric) were calculated to investigate the relationship between grazing (intensity) and the measured habitat variables. Results were generally consistent and, unless otherwise stated, Spearman's (r_s) coefficients are presented here.

Spatial pattern

The effect of geographic position (E-W) on ordinal richness was examined graphically and using non-linear regression techniques. During the Canonical Correspondence Analysis (CCA) terms from the derived geographic data matrix were tested for inclusion, with the best explanatory term used as a covariate in the final partial-CCA (see below).

Invertebrate community composition

Comparison of multivariate patterns in community composition was undertaken by comparing the similarity matrices (grazed vs ungrazed) using the *RELATE* routine within *PRIMER*. *RELATE* measures how close together two sets of multivariate data are by calculating a rank correlation coefficient (Spearman's) between all elements of their respective similarity matrices (Clarke and Gorley 2001). The null hypothesis that there is no relation ($\rho = 0$) between the matrices is tested using a simple permutation test (999 permutations).

Canonical Correspondence Analysis (CCA) (ter Braak 1986) was used to investigate the relationship between the sites based on the composition of their invertebrate assemblages (at the ordinal level), and to determine how the assemblages responded to gradients in environmental and habitat variables. CCA is a multivariate direct gradient analysis, which integrates regression and ordination techniques. This method arranges species along environmental gradients by constructing linear combinations of environmental factors that result in maximal separation of species' distributions in ordination species-space. The analysis was performed using the program *CANOCO* Version 4 (ter Braak and Smilauer 1998) using the forward selection procedure to select those terms that explained a significant amount of variation in the invertebrate data ($\alpha=0.05$). The presence of spatial trends within the environmental data was investigated using terms from the above regression equation. Effects of large-scale factors such as broad forest type and geological type were also tested using the forward selection procedure, and those factors found to have a significant influence controlled for by being included as a covariable in subsequent analyses (partial CCA).

Prior to this analysis, inter-relationships between environmental variables were examined using the linear ordination technique Principal Components Analysis (PCA), which allowed a simplified sub-set of variables to be selected. This technique provides an indication of the amount of variability (in the overall data set) explained by the measured environmental (quadrat-based) variables and highlights any correlations between the variables. This enables much of the overall variability to be (potentially) summarised in a few dimensions (ter Braak and Prentice 1988). In this analysis, separate components are formed by groups of interrelated variables. The grouping is defined by the loading of each variable, which measures the degree to which the variable contributes to each component axis. A subset of environmental variables was used in the CCA for two reasons. Firstly, the power of this analysis is improved if the number of environmental variables is small compared to the number of sites (ter Braak and Prentice 1988). Secondly, interpretation and presentation of the CCA results is simplified with a reduced set of environmental variables. One representative from each of the independent groups identified in the PCA was chosen. A Monte Carlo permutation test (300 permutations) was used to test the statistical significance of the relationship between the invertebrate data and each of the environmental variables. Results of the CCA

are displayed as a bi-plot that shows the configuration of the variables, the scatter of the sites, and the relationship between the two.

This approach allowed us to partition the variation in community composition among spatial, environmental and disturbance components in order to better understand factors influencing patterns across both landscape and habitat scales.

Results

The abundance and ordinal richness of epigeic terrestrial invertebrates in the study area was high, with a total of 208,813 individuals from 38 broad taxonomic groups collected during pitfall trapping (Table 1). Numerically, the most abundant taxa overall were the springtails (42% of individuals), ants (19%), ticks and mites (10%), bugs (8%), flies (7%) and beetles (6%), with these six groups making up (92%) of the total number of organisms caught.

Abundance

The numbers of individuals from many taxa were insufficient to reliably comment on possible effects of fire and grazing. For certain groups (scorpions, harvestmen, amphipods, snails and slugs, earthworms, leeches, silverfish, termites, praying mantids, stick-insects, lacewings, fleas, moths and butterflies) the trapping method may not have been the most appropriate and has potentially contributed to the low or erratic capture rate. Low numbers of schizomids, symphylans, millipedes, pauropods, proturans, archaeognaths, earwigs, embiids and booklice is most likely a reflection of their low abundance in these habitats. Data for these groups are included in analysis of overall abundance and taxon richness. For 16 groups there were sufficient data for further statistical analyses. These were the spiders, ticks and mites, pseudoscorpions, woodlice, centipedes, springtails, diplurans, cockroaches, grasshoppers and crickets, bugs, thrips, beetles, flies, (non-ant) hymenoptera, ants and insect larvae.

Effect of geological type and grazing

A two-way ANOVA (\log_e transformed data) indicated that there was no effect of either geological type ($F_{2,46} = 4.78$ $P = 0.173$) or grazing ($F_{1,46} = 1.66$ $P = 0.327$) on overall invertebrate abundance at sites, although the mean value for Mixed Sediment sites was substantially lower than that for Sandstone and Unconsolidated Sediment sites ($2,812 \pm 433$, $4,451 \pm 412$ and $4,650 \pm 556$ respectively). There were no interaction effects between grazing and geological type.

This response was, however, not consistent across all ordinal groups. An analysis of the 16 taxa with sufficient data (\log_e transformed MANOVA) revealed that the abundance of eight groups (spiders, ticks and mites, springtails, grasshoppers and crickets, bugs, thrips, flies and non-ant hymenoptera) was significantly influenced by geology but not by grazing (Table 2). Although the mean abundance of all groups was generally lower on Mixed Sediment sites, patterns exhibited by these groups were not consistent across geological type (Fig. 2). It may be seen from this figure that the effect of geology on the mean abundance of these taxa is considerably greater than that of grazing history.

Table 1: Terrestrial invertebrates collected from grazed and ungrazed sites using pitfall trapping. Values represent numbers of individuals.

Taxa	Ungrazed		Grazed		Grand total
	$\bar{x} \pm \text{S.E.}$	total	$\bar{x} \pm \text{S.E.}$	total	
Chelicerata					
Araneae (spiders)	83.9 \pm 16.8	2433	64.3 \pm 7.1	1478	3911
Schizomida (schizomids)	-	1	-	1	2
Acarina (ticks & mites)	416.45 \pm 51.2	12077	363.2 \pm 59.5	8354	20431
Scorpionida (scorpions)	-	5	-	2	7
Pseudoscorpionida (pseudoscorpions)	6.4 \pm 1.3	185	4.4 \pm 1.0	102	287
Opiliona (harvestmen)	-	5	-	0	5
Crustacea					
Amphipoda (landhoppers)	-	32	-	2	34
Isopoda (woodlice)	13.9 \pm 2.9	403	12.4 \pm 3.3	285	688
Mollusca					
Gastropoda (snails & slugs)	6.7 \pm 1.7	195	10.8 \pm 3.1	249	444
Annelida					
Oligochaeta (earthworms)	4.0 \pm 1.3	117	28.2 \pm 14.2	648	765
Hirudinidea (leeches)	-	12	-	2	14
Uniramia					
Chilopoda (centipedes)	3.6 \pm 0.5	103	2.7 \pm 0.6	61	164
Symphyla (symphylans)	-	32	-	31	63
Diplopoda (millipedes)	-	44	-	42	86
Paupoda (paupods)	-	14	-	30	44
Hexapoda					
Collembola (springtails)	1780.1 \pm 228.9	51622	1529.3 \pm 309.4	35173	86795
Protura (proturans)	-	2	-	0	2
Diplura (diplurans)	3.9 \pm 1.0	115	3.2 \pm 0.7	73	188
Archaeognatha (archaeognaths)	-	5	-	3	8
Thysanura (silverfish)	-	0	-	1	1
Blattodea (cockroaches)	3.9 \pm 0.6	112	4.4 \pm 0.8	100	212
Isoptera (termites)	-	27	-	36	63
Mantodea (praying mantids)	-	7	-	4	11
Dermaptera (earwigs)	-	26	-	23	49
Orthoptera (grasshoppers & crickets)	42.8 \pm 7.8	1242	36.8 \pm 6.2	847	2089
Phasmatodea (stick-insects)	-	3	-	5	8
Embioptera (embiids)	-	1	-	3	4
Psocoptera (booklice)	-	71	-	56	127
Hemiptera (bugs)	313.2 \pm 44.0	9084	300.1 \pm 43.4	6903	15987
Thysanoptera (thrips)	17.7 \pm 2.6	512	11.1 \pm 1.6	256	768
Neuroptera (lacewings)	-	2	-	0	2
Coleoptera (beetles)	241.8 \pm 28.6	7011	256.5 \pm 24.9	5899	12910
Siphonaptera (fleas)	-	0	-	2	2
Diptera (flies)	290.8 \pm 41.8	8432	250.9 \pm 53.5	5771	14203
Lepidoptera (moths & butterflies)	-	103	-	80	183
Hymenoptera (bees & wasps)	95.8 \pm 12.3	2777	83.5 \pm 11.5	1920	4697
Hymenoptera (ants)	797.0 \pm 69.9	23114	686.4 \pm 68.4	15786	38900
Larvae (insects)	93.9 \pm 23.5	2725	84.1 \pm 11.8	1934	4659
Total		122,651		86,162	208,813
Number of sites		29		23	52

Table 2: Results of a 2-way ANOVA investigating the effects of the two design stratification variables (factors), geological type and grazing, on abundance of the 16 most numerous taxa caught by pitfall trapping. For each factor, the values represent the F statistic and associated probability (P) value. Significant results ($0.05 > P > 0.01$) are indicated by * with very significant results ($P < 0.01$) indicated by **. Interactions between geological type and grazing were non-significant for all groups.

Taxon	Geological Type		Grazing	
	F _{2,46}	P	F _{1,46}	P
spiders	7.20	0.010*	1.41	0.240
ticks & mites	4.37	0.018*	0.19	0.668
pseudoscorpions	1.75	0.185	1.02	0.319
woodlice	1.20	0.312	0.54	0.466
centipedes	1.39	0.259	1.26	0.267
springtails	5.78	0.006**	2.98	0.091
diplurans	1.52	0.229	0.00	0.982
cockroaches	2.48	0.095	0.32	0.577
grasshoppers & crickets	6.74	0.003**	0.09	0.757
bugs	4.02	0.025*	0.10	0.924
thrips	3.59	0.035*	2.98	0.091
beetles	1.07	0.352	0.41	0.525
flies	6.86	0.002**	1.37	0.249
hymenoptera (non-ants)	6.49	0.003**	0.74	0.396
ants	0.63	0.540	1.30	0.260
insect larvae	1.51	0.231	1.55	0.219

Effect of environmental variables

There was no association between overall abundance and broad forest type ($\chi^2 = 13.60$ df = 20 $P = 0.327$) indicating that, at that broad scale of classification, forest tree communities supported similar abundances of epigeic terrestrial invertebrates.

Invertebrate abundance at sites was positively correlated with tree basal area ($r_s = 0.363$ $P = 0.007$), the patchiness of the soil organic matter ($r_s = 0.317$ $P = 0.022$) and geographic position ($r_s = 0.323$ $P = 0.020$). These results show that, irrespective of forest type, abundance increases with tree basal area and topsoil organic matter patchiness and decreases with distance from the coast, although the last relationship is non-linear (see results for ordinal richness below). Invertebrate abundance did not show consistent relationships with any other environmental variables.

Ordinal (taxon) richness

Representatives of 38 broad taxonomic groups were collected during the pitfall trapping program (Table 1). Ordinal richness at sites varied from 12-26, with an overall mean (\pm s.e.) of 19.9 (\pm 0.4).

Effect of geological type and grazing

A two-way ANOVA indicated a significant effect of geological type ($F_{2,46} = 23.81$ $P = 0.040$) but not grazing ($F_{1,46} = 0.12$ $P = 0.757$) on ordinal richness, with no

significant interaction between these two factors. Mean richness was 21.1 (\pm 0.6) on Sandstone sites, 19.4 (\pm 0.9) on Mixed Sediment and 19.4 (\pm 0.5) on Unconsolidated Sediments, however post-hoc testing (SNK) did not discretely differentiate between geological types.

Effect of environmental variables

There was no association between ordinal richness and broad forest type ($\chi^2 = 19.34$ df = 20 $P = 0.50$) indicating that, at that broad scale of classification, forest tree communities supported similar levels of terrestrial invertebrate (taxon) richness.

Taxon richness at sites was negatively correlated with soil bulk density (BD) ($r_s = -0.321$ $n = 52$ $P = 0.020$), and positively correlated with the spatial patchiness of soil BD ($r_s = 0.286$ $n = 52$ $P = 0.040$) and the spatial patchiness of soil organic matter content ($r_s = 0.366$ $n = 52$ $P = 0.008$). Soil BD and organic matter content were significantly negatively correlated ($r_s = -0.711$ $n = 52$ $P < 0.001$). These relationships varied with grazing history. Ordinal richness was strongly correlated with soil bulk density on ungrazed plots ($r_s = -0.502$ $n = 29$ $P = 0.006$) but not grazed plots ($r_s = -0.094$ $n = 23$ $P = 0.671$). Similarly, ordinal richness was strongly correlated with the patchiness of soil organic matter content on ungrazed ($r_s = 0.454$ $n = 29$ $P = 0.013$) but not grazed ($r_s = 0.313$ $n = 23$ $P = 0.146$) plots.

This suggests that ordinal richness increases as soil organic matter content increases (with an associated decrease in BD) and becomes patchier on ungrazed plots, but these relationships are not found on grazed plots. This implies that grazing (and associated burning) influences soil properties in such a way to affect ordinal richness. This conclusion is supported by the fact that on sites where grazing occurred there was a negative relationship between grazing intensity (see below) and soil organic matter content ($r_s = 0.387$ $P = 0.029$).

Spatial pattern

There was a significant relationship between ordinal richness and the geographic position (E-W) of study plots (Fig. 3). This was best described by a cubic regression function of the form: *ordinal richness* = constant + $ax + bx^2 + cx^3$ (where $x =$ easting); $r = 0.635$ $F_{3,48} = 10.82$ $P < 0.001$. Ordinal richness was high in the west of the study area (Mt. Belmore SF), declined slightly to the east (Camira and Banyabba SFs), rose again in Bungawalbin, Gibberagee and Doubleduke SFs before declining towards Monoro SF near the boundary with Bundjalung National Park (which is on the coast).

Invertebrate community composition

Effect of grazing

A comparison of similarity matrices (grazed vs ungrazed), based on relative abundance of taxa at the ordinal level, found that there was a significant relationship between the matrices ($\rho = 0.966$ $P = 0.001$), with community composition (at this level of organisation *i.e.* Order) not being influenced by the occurrence of livestock grazing.

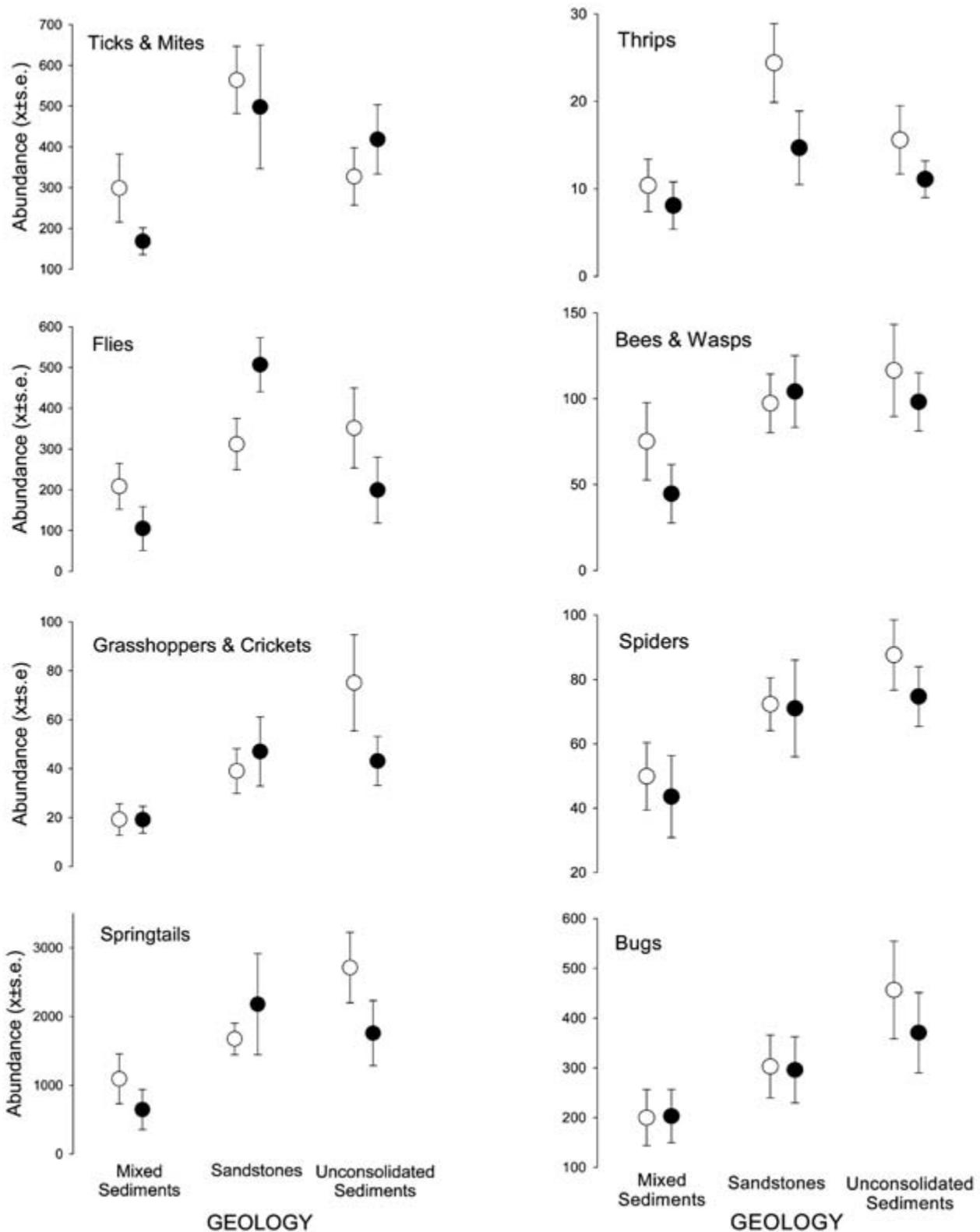


Figure 2. Abundance of eight major taxa of terrestrial invertebrates on grazed (●) and ungrazed (○) sites across three geological types. Taxa were chosen as data were sufficiently robust to justify statistical analysis (see text). Values represent mean and standard error.

Effect of environmental variables

The Principal Components Analysis (PCA) reduced the array of 25 environmental variables to seven independent components, explaining 83% of the variance in the environmental and habitat data (Table

3). The first component (*vegetation understorey structure*) described the amount and patchiness of understorey vegetation and explained 32.4% of the overall variance. The second component (*logging history index*) comprised variables associated with past logging history and explained an additional 14.6%. Subsequent components

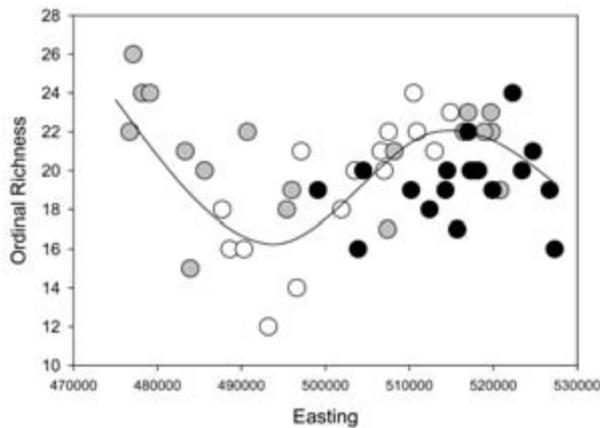


Figure 3. Relationship between invertebrate taxon richness and geographic position (easting). Displayed function is a cubic regression function of the form: $ordinal\ richness = constant + ax + bx^2 + cx^3$ (where $x = easting$); $r = 0.635$ $F_{3,48} = 10.82$ $P < 0.001$. Geologies: ○ Mixed Sediments, ● Sandstones, ● Unconsolidated Sediments.

were associated with *topography* (+11.8%), *soil physical properties* (+8.1%), *leaf litter* (+6.1%), and the variables *patchiness of small shrubs* (+5.0%) and *patchiness of topsoil structure* (+4.8%). See Harris *et al.* (2003) for a more detailed explanation of these components.

The forward selection procedure in CANOCO indicated that the variability in the composition of invertebrate assemblages was significantly influenced by geological type ($F = 4.28$ $P = 0.005$) and geographic position (x^3 : $F = 2.44$ $P = 0.015$). In subsequent analyses these two broad-scale factors were 'controlled for' by including them as covariables in a partial Canonical Correspondence Analysis (pCCA), so as to elucidate the effects of smaller-scale habitat variability. Broad forest type did not explain a significant amount of variance in invertebrate community composition and was excluded from further analyses.

The results of the pCCA show that, having controlled for geological type and geographic position, there is no clear pattern in assemblage composition related to the presence or

Table 3. Principal component matrix for twenty-five environmental and habitat variables. Values represent component loadings, with boxes indicate groupings of variables based on these loadings.

Environmental and habitat variables	Component						
	1	2	3	4	5	6	7
Tall shrubs	.967						
s.e. tall shrubs	.943						
Very tall shrubs	.888						
s.e. very tall shrubs	.870						
Medium shrubs	.922						
s.e. medium shrubs	.723					.401	
Small shrubs	.773	-.388				.354	
Herbs	.666					.492	
s.e. herbs	-.573	.356				-.348	
FHD	.837						
s.e. FHD	-.538	.540					
Small logs		.873					
Large logs		.822					
# stumps		.710					-.361
Basal area		-.306	-.305	.322			
Slope			.909				
Altitude			.879				
Aspect			.730				
Bulk density				-.893			
% organic matter				.825			
Litter depth					.783		
s.e. litter depth					.883		
s.e. small shrubs						.992	
s.e. bulk density							.913
s.e. % organic matter				.463			.702
% variance explained	32.4	14.6	11.8	8.1	6.1	5.0	4.8
% cumulative variance	32.4	47.0	58.8	66.9	73.0	78.0	82.8

absence of grazing on sites. This is presented as a bi-plot that shows the scatter of sites, the configuration of the variables, and the relationship between the two (Fig. 4). The scatter of the sites reflects the similarity (or dissimilarity) of their invertebrate assemblages, with sites that are close together having similar species in similar abundance. These first two canonical axes explained 75.4% of the variance in the species-environment relationship.

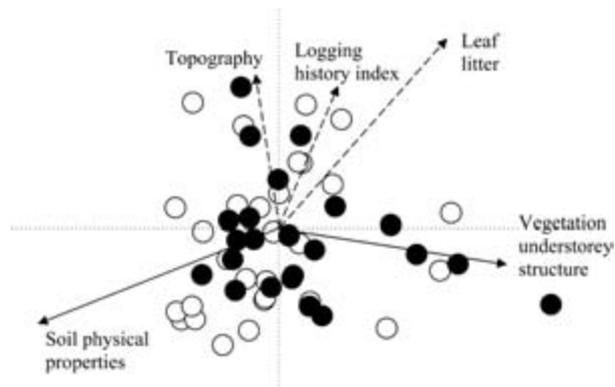


Figure 4. Biplot from the Canonical Correspondence Analysis (CCA) of invertebrate abundance data (ordinal level) from pitfall samples. Points represent sample sites: ungrazed (○) and grazed (●), with vectors (arrows) represent environmental variables. The length of the arrow signifies the relative contribution of that variable to the assemblage composition, while the direction signifies its contribution to the differences between treatments.

With regard to the contribution of environmental variables, the length of the arrow signifies the relative contribution of that variable to species composition, and the direction signifies its contribution to the differences between treatments. The results of the Monte Carlo significance test for the environmental and habitat variables after forward selection are shown in Table 4. Environmental components *vegetation understorey structure* and *soil physical properties* explained a significant amount of variation in invertebrate (taxon) community composition, with a lesser (and non-significant) amount explained by *leaf litter*, *topography* and *logging history index*. Other variables, including grazing intensity, did not make a significant contribution. Community

Table 4: Results of the Monte Carlo significance test for environmental & habitat variables after forward selection in CANOCO (with geology and geographic position included as covariables). Values represent the F statistic and associated probability (P) value. Asterisks indicate variables (and axes) significant at $0.05 > P > 0.01$ (*) and $P < 0.01$ (**).

Variable	F	P
vegetation understorey structure	4.029	0.005**
soil physical properties	2.377	0.025**
topography	1.668	0.155
leaf litter	1.514	0.145
logging history	0.760	0.545
first canonical axis	4.830	0.030*
all canonical axes	2.119	0.010*

composition (at the ordinal level) is therefore primarily influenced by the amount and spatial variability (horizontal and vertical) of understorey vegetation, and the physical properties of the topsoil (specifically relating to the amount of organic matter).

Effect of Grazing Intensity

There was a significant relationship between grazing intensity (grazing index) and slope ($r_s = -0.297$ $P = 0.033$), habitat variables *ground herbs* ($r_s = -0.435$ $P = 0.010$), *small shrubs* ($r_s = -0.420$ $P = 0.002$), *medium-sized shrubs* ($r_s = -0.286$ $P = 0.040$) and the spatial patchiness (s.e.) of *foliage height diversity* ($r_s = 0.486$ $P < 0.001$), and disturbance variables *stumps* ($r_s = 0.510$ $P < 0.001$) and *small logs* ($r_s = 0.401$ $P = 0.003$). This suggests that higher levels of grazing currently occurs on sites with lower slopes and a history of logging, and on these sites grazing and associated burning had reduced the amount of small and medium-sized shrubs and increased the vertical patchiness of the vegetation understorey. There was, however, no correlation between grazing intensity and either invertebrate abundance ($r_s = -0.123$ $P = 0.384$) or ordinal richness ($r_s = -0.075$ $P = 0.597$ $n = 52$). The ordination analysis indicates that grazing intensity, as measured here, was not a major determinant of the composition of terrestrial invertebrate assemblages at this (taxon) coarse scale.

Discussion

North-eastern NSW is an area characterised by exceptional biodiversity, primarily due to its wide range of habitat types and position in the overlap of two major biogeographic sub-regions (RACAC 1996). While recent extensions to the protected areas network have made a substantial contribution to biodiversity conservation (but see Pressey *et al.* 2002), the reserve system will need to be supported by the ecologically sustainable management (ESM) of off-reserve lands in order to minimise adverse effects on regional biodiversity. State Forests, which make up a significant proportion of these (forested) lands will therefore continue to play an important role in regional conservation (Pressey *et al.* 1996, Lindenmayer and Recher 1998).

In order to guide ESM strategies, forest managers will require access to scientific information concerning the impacts of land use practices. While activities such as timber harvesting, silvicultural practices and prescribed burning for fuel management have received considerable attention over recent years; the impact of grazing domestic animals in forests has been largely ignored. Given that 40-45% of the area of State Forests around Casino (~60,000ha), for example (SFNSW 1995), and a considerable proportion of privately owned forests, are regularly grazed, this lack of knowledge is of some concern. In particular, the paucity of information about grazing impacts on invertebrates is a serious omission, given their substantial contribution to overall biodiversity and the critical roles that they play in ecosystem structure and function. This study was undertaken, in part, to address that omission.

Landscape scale considerations

The results of this research suggest that grazing impacts operate within a framework of broader environmental and historical factors. At a landscape scale, it is apparent that geological type (and related aspects of topography and soil) is a major determinant of the structure and composition of biological communities. Geology exerts a strong influence on the stand structure of tree communities, the composition and structure of understorey vegetation and hence terrestrial invertebrate communities.

While geology was the primary determinant of overall community composition, its effects were not consistent across invertebrate taxa. Although ordinal (taxon) richness did not clearly differ between geological types, Sandstone sites recorded highest abundance levels for ticks and mites, flies and thrips, whereas grasshoppers and crickets, springtails, bees and wasps, spiders and bugs were most abundant on Unconsolidated Sediment sites. Mixed Sediment sites had consistently low numbers of all major groups. Although data were only analysed at the relatively coarse level of order, these results highlight the fact that it is important to acknowledge that all invertebrate groups do not respond in a similar way to coarse environmental gradients. Although (apparently) obvious, those advocating simple environmental surrogates for invertebrates (and other groups) in conservation planning often overlook this fact (see Oliver *et al.* 1998, York 1999b).

The mechanisms behind the influence of geology (and soils) in this area are likely to be complex. While ordinal richness was high in forests on Sandstones in both the east and west of the study area, it was relatively low on sandstone geology at other locations. Mixed Sediment sites showed their greatest ordinal richness in the east with values declining steadily westwards (Fig. 3). These patterns may be due, in part, to the clear association between geological type and broad forest type. Sixty-nine percent of sites within the Mixed Sediment geology were classified within the Spotted Gum league. Similarly, sites on the Sandstone geology were predominantly (50%) from the Blackbutt league, with sites on Unconsolidated Material tending to support forests from the Maritime/Red Gum and Grey Gum-Grey Ironbark leagues (14 and 22% respectively). This association between geology and broad forest type is complicated by east-west spatial patterns. Both ordinal richness and community composition were related to distance from the coast, which is most likely to correspond to a trend in rainfall and productivity, with the highest rainfall on the coast and in the mountainous area in the west of the study area (SFNSW 1995).

These results demonstrate that the ability to highlight responses to grazing and associated burning is therefore strongly influenced by the scale of investigation. Sale (1998) emphasised that disturbances have a spatial extent (as well as intensity, duration and frequency) and that ecological systems are hierarchical, with patterns and processes operating at a range of scales. Large-scale investigations of terrestrial communities must therefore consider these landscape scale interactions and spatial patterns which would otherwise obscure more subtle responses to disturbance at the habitat scale.

Responses to grazing and burning

Within this broad framework, invertebrate communities are responding to environmental factors at a smaller scale. Overall abundance at sites was related to one component of overstorey stand structure (total basal area), probably as a consequence of habitat productivity (see above) although this is difficult to separate from past disturbance (logging) history. Irrespective of broad forest type, abundance increased with the spatial patchiness of topsoil organic matter content. Taxon richness was similarly influenced by topsoil physical structure, as was community composition. Richness increased with increases in organic matter content (and associated decreases in bulk density) and spatial patchiness, although this pattern was only clearly evident on ungrazed sites. This implies that grazing and associated burning influence soil properties in such a way as to affect invertebrate taxon richness. York (1999c) found that frequent burning in dry eucalypt forests can significantly reduce topsoil organic matter levels and patchiness. Soil organic matter is a critical component of ecosystem sustainability, important for maintaining storage and cycling of nutrients (Neary *et al.* 1999) and mediating many of the chemical, physical and biological processes that control soil function (Quideau *et al.* 2000). De Bruyn *et al.* (2001) found that the amount of soil organic matter was a primary determinant of the diversity of soil-dwelling saprophagous fly communities in an Australian heathland ecosystem. In native grasslands in Alberta, Clapperton *et al.* (2002) found that there was increased diversity and number of mite (Acari) families associated with higher topsoil organic matter levels on lightly grazed sites. Similarly, in Hungarian grasslands, Dombos (2001) found that heavy grazing reduced soil organic matter levels and that this was associated with a reduction in species richness and altered community composition of the collembolan (springtail) community. These changes were attributed to reductions in soil moisture on grazed sites. Given the essential role played by many invertebrate groups in decomposition, mineralization, carbon flux and biogeochemical cycling (see Seastedt 1984, Schowalter 2000 pp.361-88), loss of soil organic matter and associated nutrient cycling could have serious consequences for long-term sustainability.

Invertebrate communities were also found to be responding to understorey vegetation structure, both the amount of vegetation and its spatial patterning. The dependence of many groups of invertebrates on vegetation composition and structure is well documented (see Matthews 1976, New 1984, Schowalter 2000). Rambo and Faeth (1999) found grazing in Arizona grasslands (independent of fire) had a negative effect on the abundance of insects associated with vegetation. Also in grasslands, Kruess and Tschamtker (2002) found that grazing reduced the richness and structural complexity of the vegetation, with a corresponding decrease in insect diversity. York (1999c, 2000) found that the amount and spatial patchiness of understorey vegetation was an important determinant of the composition of communities for Hemiptera (bugs), flies, spiders, beetles and ants. In this study, grazed sites had lower and more spatially variable levels of vegetation in the ground herb and small shrub layers (York 1998), and lower plant diversity in the shrub layer (York 1999d).

In their study of temperate eucalypt forests in northern NSW, Henderson and Keith (2002) found that grazing and associated burning reduced the richness and density of the woody understorey. In this study, the removal of understorey vegetation through grazing and fire may also be reducing organic matter inputs into the soil layer (see above), affecting soil physical properties.

Effect of grazing intensity

The results indicate that higher levels of grazing occurred on sites on the lower slopes with a history of logging (as indicated by the presence of stumps and logs). It would appear that past logging practices have created patches of more open environments within the overall forest matrix and that cattle graze preferentially in these more open and accessible areas. The grazing and associated burning then causes changes in the structure of the understorey vegetation; principally a substantial reduction in the amount of vegetation in the ground herb and small shrub layers. There are significantly less (36%) shrub species on grazed sites, which also have lower numbers of sub-canopy species, possibly due to preferential grazing of seedlings and juveniles (York 1999d). This effect increases with increasing grazing intensity.

Neither the abundance, richness nor composition of invertebrate assemblages was related to grazing intensity. One possible explanation for this result is that the coarse level of taxonomic resolution obscures the variability in responses between taxa (see Cranston and Trueman 1997). Impacts on sensitive species and groups are swamped by opposite responses of other groups (increasers vs decreaseers) within taxa. Alternatively, given the long history of disturbance in these forests, sensitive species may already have become locally extinct (therefore not detected). In a preliminary analysis of the beetle data at finer taxonomic levels, York (1999d) found that impacts of grazing could only be reliably detected at family or morphospecies level. Further, there was a threshold at which grazing had an impact, with sites experiencing high levels of grazing having different beetle assemblages. However Harris *et al.* (2003) found that for spiders in these habitats there were no clear patterns in abundance, richness or community composition that could, at the morphospecies level, be attributed to grazing history. This suggests that the impacts of grazing in this study may be subtle, which is not unexpected given that grazing intensity in these forests is low (one animal per 7-20 ha depending on conditions) compared with one animal per hectare on adjacent pasture (SFNSW 1995).

Data limitations

Data at a coarse level of resolution (order) were used here to test the applicability of that approach in studies of disturbance and conservation assessment. Numbers of invertebrate orders at sites provided estimates of taxon richness, while the number of individuals within orders was used to represent their relative abundance and community composition. While this approach may have allowed fine-scale differences between sites to be obscured (see above), it was adequate to detect and describe patterns occurring at a landscape scale, and to

identify relationships with environmental and disturbance variables at smaller scales. Given the immense logistical challenge of identifying all taxa to species, this “coarse-filter” approach (Noss 1987) allowed us to deal with a highly diverse fauna across a large spatial scale. With the ecological role and response to disturbance largely unknown for most Australian invertebrates at the species level, this may prove a cost-effective approach for these types of studies. This method has recently proved useful, for example, in elucidating relationships between biodiverse invertebrate assemblages and mapped land systems in northwestern NSW (see Oliver *et al.* 2004).

Conservation issues

As a consequence of the regional forest assessment (RFA) process there have been substantial changes to land tenure in the north east of NSW. Within the area of this study, a number of new National Parks, Crown Reserves and Nature Reserves were created. While reports from this study (York 1997, 1998, 1999d) were submitted to RACAC and a broad-scale assessment of invertebrate communities independently undertaken by the Australian Museum (see Ferrier *et al.* 1999), biotic data supporting the decision-making process incorporated primarily vascular plants and vertebrate animals. Basing important decisions, such as this, on only a fraction of the overall biodiversity has serious ramifications for ecologically sustainable management and regional biodiversity conservation. With invertebrates and non-vascular plants making up nearly 90% of the species in our terrestrial ecosystems (Environment Protection Authority 2000) it is essential that they receive greater consideration in conservation planning and form an integral part of adaptive management strategies for the protection of our biodiversity (York 2003). Similar concerns have been raised in regard to the exclusion of privately-owned lands from the decision-making process (Adam 1992). While one area identified in this study as having high invertebrate taxon richness is now part of the reserve network (Bungawalbin NP), important areas in the west and others in the east remain State Forest.

It is essential therefore that management strategies developed for these forests using principles of ESM give serious consideration to the potential impact of continuing grazing practices. The exclusion of cattle from certain areas would be justified if these forests were deemed to contribute significantly to conservation outcomes. It is also worth considering that systems that have been grazed for a long time develop communities of grazing-tolerant plant species, and may well rely on continued grazing to maintain their composition and structure (Milchunas and Lauenroth 1993). Changing the level of grazing or removing grazers from habitats with a long grazing history may constitute a new form of disturbance with unpredictable consequences. The establishment of long-term monitoring points within a framework of adaptive management would help address these matters. Similarly, issues with regard to the season (currently spring/summer), frequency and extent of burning need to be considered so as to strike a balance between hazard reduction and biodiversity conservation.

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References

- Abensperg-Traun, M., Smith, G. T., Arnold, G. W. and Steven, D. E. 1996. The effects of habitat fragmentation and livestock-grazing on animal communities in remnants of gimlet *Eucalyptus salubris* woodland in the western Australian wheatbelt. I. Arthropods. *Journal of Applied Ecology* 33: 1281-1301.
- Adam, P. 1992. The end of conservation on the cheap. *National Parks Journal* 36: 19-22.
- Andersen, A. N. and Müller, W. J. 2000. Arthropod responses to experimental fire regimes in an Australian tropical savanna: ordinal-level analysis. *Austral Ecology* 25: 199-209.
- Bickel, D. J. and Tasker, E. M. 2004. Tree trunk invertebrates in Australian forests: conserving unknown species and complex processes. Pp. 888-98 in *Conservation of Australia's Forest Fauna* (second edition) edited by D. Lunney, Royal Zoological Society of New South Wales, Mosman, NSW.
- Binns, D. 1995. *Flora Survey Report. Casino Management Area, Northern Region, State Forests of New South Wales*. Supporting Document no. 7. Casino Management Area EIS. (Available from SFNSW Research and Development Division, West Pennant Hills).
- Borcard, D., Legendre, P. and Drapeau, P. 1992. Partialling out the spatial component of ecological variation. *Ecology* 73: 1045-1055.
- Bromham, L., Cardillo, M., Bennett, A. F. and Elgar, M. A. 1999. Effects of stock grazing on the ground invertebrate fauna of woodland remnants. *Australian Journal of Ecology* 24: 199-207.
- Clapperton, M. J., Kanashiro, D. A. and Behan-Pelletier, V. M. 2002. Changes in abundance and diversity of microarthropods associated with Fescue Prairie grazing regimes. *Pedobiologia* 46: 496-511.
- Clarke, K. R. and Gorley, R. N. 2001. *Primer v5: User Manual/Tutorial*. Primer-E: Plymouth. United Kingdom.
- Corbett, J. R. 1969. *The Living Soil*. Martindale Press, Sydney, Australia.
- Cranston, P. S. and Trueman, J. W. H. 1997. “Indicator” taxa in invertebrate biodiversity assessment. *Memoirs of the Museum of Victoria* 56: 267-274.
- Daily, G. C. (ed) 1997. *Nature's Services: Societal Dependence on Natural Ecosystems*. Island Press, Washington, D.C., USA.
- De Bruyn, L., Thys, S., Scheirs, J. and Verhagen, R. 2001. Effects of vegetation and soil on species diversity of soil dwelling Diptera in a heathland ecosystem. *Journal of Insect Conservation* 5: 87-97.
- Dombos, M. 2001. Collembola of loess grassland: effects of grazing and landscape on community composition. *Soil Biology and Biochemistry* 33: 2037-2045.
- Environment Protection Authority. 2000. *State of the Environment 2000* (Report and Backgrounders). Environment Protection Authority, NSW.
- FCNSW (Forestry Commission of NSW) 1989. *Forest Types in New South Wales*. Research Note No. 17. Forestry Commission of New South Wales, Sydney.
- Fensham, R. J. and Skull, S. D. 1999. Before cattle: A comparative floristic study of *Eucalyptus* savanna grazed by macropods and cattle in North Queensland, Australia. *Biotropica* 31: 37-47.
- Ferrier, S. and Watson, G. 1997. *An Evaluation of the Effectiveness of Environmental Surrogates and Modelling Techniques in Predicting the Distribution of Biological Diversity*. Environment Australia, Canberra.
- Ferrier, S., Gray, M. R., Cassis, G. A. and Wilkie, L. 1999. Spatial turnover in species composition of ground-dwelling arthropods, vertebrates and vascular plants in north-east New South Wales: implications for selection of forest reserves. Pp. 68-76 in *The Other 99%: The Conservation and Biodiversity of Invertebrates*, edited by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW.
- Harlen, R. 2000. *Changes in the Epigaic Community Following Livestock Removal From Remnant Woodland*. Unpublished PhD Thesis. School of Rural Science and Natural Resources, University of New England, Armidale NSW, Australia.
- Harris, R., York, A. and Beattie, A. J. 2003. Impacts of grazing and burning on spider assemblages in dry eucalypt forests of northeastern New South Wales, Australia. *Austral Ecology* 28: 526-538.
- Henderson, M. K. and Keith, D. A. 2002. Correlation of burning and grazing indicators with composition of woody understorey flora of dells in a temperate eucalypt forest. *Austral Ecology* 27: 121-131.
- Hoffmann, B. D. 2000. Changes in ant species composition and community organisation along grazing gradients in semi-arid rangelands of the Northern Territory. *Rangelands Journal* 22: 171-189.
- Krebs, C. J. 1985. *Ecology. The Experimental Analysis of Distribution and Abundance*. Third Edition, Harper & Row, New York.
- Kruess, A. and Tscharntke, T. 2002. Contrasting responses of plant and insect diversity to variation in grazing intensity. *Biological Conservation* 106: 293-302.

- Lambeck, R. J. 1992. The role of faunal diversity in ecosystem function. Pp. 129-48 in *Biodiversity of Mediterranean Ecosystems in Australia*, edited by R. J. Hobbs. Surrey Beatty and Sons, Chipping Norton, NSW.
- Landsberg, J., Morton, S. and James, C. 1999. A comparison of the diversity and indicator potential of arthropods, vertebrates and plants in arid rangelands across Australia. Pp. 111-120 in *The Other 99%: The Conservation and Biodiversity of Invertebrates*, edited by W. Ponder and D. Lunney. Royal Zoological Society of New South Wales, Mosman, NSW.
- Legendre, P. and Legendre, L. 1998. *Numerical Ecology*. 2nd English Edition. Developments in Environmental Modelling 20. Elsevier Science B.V., Amsterdam.
- Leigh, J. H. and Holgate, M. D. 1979. The responses of the understorey of forests and woodlands of the Southern Tablelands to grazing and burning. *Australian Journal of Ecology* 4: 25-45.
- Lindenmayer, D. B. and Recher, H. F. 1998. Aspects of ecologically sustainable forestry in temperate eucalypt forests – beyond an expanded reserve system. *Pacific Conservation Biology* 4: 4-10.
- MacArthur, R. H. and MacArthur, J. W. 1961. On bird species diversity. *Ecology* 42: 594-598.
- Matthews, E. G. 1976. *Insect Ecology*. University of Queensland Press. Australia.
- Milburn-Clark, K. 2001. *Business and Biodiversity*. Earthwatch Institute, South Melbourne, Victoria.
- Milchunas, D. G. and Lauenroth, W. K. 1993. Quantative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63: 327-366.
- Neary, D. G., Klopatek, C. C., DeBano, L. F. and Ffolliott, P. F. 1999. Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management* 122: 51-71.
- New, T. R. 1984. *Insect Conservation: an Australian Perspective*. Junk, The Hague.
- Noss, R. F. 1987. From plant communities to landscapes in conservation inventories: a look at the Nature Conservancy (USA). *Biological Conservation* 41: 11-37.
- Oliver, I., Beattie, A. J. and York, A. 1998. Spatial fidelity of plant, vertebrate and invertebrate assemblages in multiple-use forest in eastern Australia. *Conservation Biology* 12: 822-835.
- Oliver, I., Holmes, A., Dangerfield, J. M., Gillings, M., Pik, A. J., Britton, D. R., Holley, M., Montgomery, M. E., Raison, M., Logan, V., Pressey, R. L. and Beattie, A. J. 2004. Land systems as surrogates for biodiversity in conservation planning. *Ecological Applications* 14: 485-503.
- Pettit, N. E., Froend, R. H. and Ladd, P. G. 1995. Grazing in remnant woodland vegetation: changes in species composition and life form groups. *Journal of Vegetation Science* 6: 121-130.
- Pitty, A. F. 1978. *Geography and Soil Properties*. Methuen Pty. Ltd., Cambridge.
- Pressey, R. L., Ferrier, S., Hager, T. C., Woods, C. A., Tully, S. L. and Weinman, K. M. 1996. How well protected are the forests of north-eastern NSW? Analysis of forest environments in relation to formal protection areas, land tenure and vulnerability to clearing. *Forest Ecology and Management* 85: 311-333.
- Pressey, R. L., Whish, G. L., Barrett, T. W. and Watts, M. E. 2002. Effectiveness of protected areas in north-eastern New South Wales: recent trends in six measures. *Biological Conservation* 106: 57-69.
- Quideau, S. A., Anderson, M. A., Graham, R. C., Chadwick, O. A. and Trumbore, S. E. 2000. Soil organic matter processes: characterization by ¹³C NMR and ¹⁴C measurements. *Forest Ecology and Management* 138: 19-27.
- RACAC (Resource and Conservation Assessment Council) 1996. Regional Report of Upper North East New South Wales. Volume 4. *Biodiversity Attributes*. RACAC, Sydney.
- Rambo, J. L. and Faeth, S. H. 1999. Effect of vertebrate grazing on plant and insect community structure. *Conservation Biology* 13: 1047-1054.
- Sale, P. F. 1998. Appropriate spatial scales for studies of reef-fish ecology. *Australian Journal of Ecology* 23: 202-208.
- Schowalter, T. D. 2000. *Insect Ecology. An Ecosystem Approach*. Academic Press, London.
- Schultz, E. and Mooney, H. A. (eds) 1993. *Biodiversity and Ecosystem Function*, Springer-Verlag, New York.
- Seastedt, T. R. 1984. The role of microarthropods in decomposition and mineralization processes. *Annual Review of Entomology* 29: 25-46.
- SFNSW (State Forests of NSW) 1995. *Casino Management Area Environmental Impact Statement*. State Forests of New South Wales, Sydney.
- Smith, A. P., Andrews, S. P. and Moore, D. M. 1994. *Terrestrial fauna of the Grafton and Casino State Forest Management Areas – Description and Assessment of Forestry Impacts*. Report prepared for the Forestry Commission of New South Wales. Austeco Pty. Ltd.
- Spain, A. V. and Hutson, B. R. 1983. Dynamics and fauna of the litter layers, Chapter 38, pp. 611-628. in *Soils: An Australian Viewpoint*, Division of Soils, CSIRO: Melbourne/Academic Press, London.
- ter Braak, C. J. F. 1986. Canonical Correspondence Analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167-1179.
- ter Braak, C. J. F. and Prentice, I. C. 1988. A theory of gradient analysis. *Advances in Ecological Research* 18: 271-315.
- ter Braak C. J. F. and Smilauer, P. 1998. CANOCO Version 4. Canoco Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination. Microcomputer Power, Ithaca, New York, USA.
- Veness and Associates. 1994. *Soil Report: Casino Management Area EIS and Murwillumbah Management Area EIS*. Report prepared for State Forests of NSW, Sydney.
- Woinarski, J. C. Z., Andersen, A. N., Churchill, T. B. and Ash, A. J. 2002. Response of ant and terrestrial spider assemblages to pastoral and military land use, and to landscape position, in a tropical savanna woodland in northern Australia. *Austral Ecology* 27: 324-333.
- York, A. 1997. *Impacts of Grazing and Burning on Forest Biodiversity. Initial Report to the Resource and Conservation Assessment Council*. Commonwealth Key Centre for Biodiversity and Bioresources, Macquarie University, Sydney.
- York, A. 1998. *Impacts of Grazing and Burning on Forest Biodiversity. Second Report to the Resource and Conservation Assessment Council*. Commonwealth Key Centre for Biodiversity and Bioresources, Macquarie University, Sydney.
- York, A. 1999a. Long-term effects of frequent low-intensity burning on the abundance of litter-dwelling invertebrates in coastal blackbutt forests of southeastern Australia. *Journal of Insect Conservation* 3: 191-199.

York, A. 1999b. Ecologically sustainable management: the utility of habitat surrogates for assessing terrestrial invertebrate diversity in temperate forests. Pp. 34-39 in *The Other 99%. The Conservation and Biodiversity of Invertebrates*, edited by W. Ponder and D. Lunney. Transactions of the Royal Zoological Society of New South Wales, Mosman, NSW.

York, A. 1999c. Long-term Effects of Repeated Prescribed Burning on Forest Invertebrates: Management Implications for the Conservation of Biodiversity. Pp. 181-266 in *Australia's Biodiversity – Responses to Fire. Plants, Birds and Invertebrates*. Biodiversity Technical Paper No. 1. Department of the Environment and Heritage. Canberra, Australia.

York, A. 1999d. *Impacts of Grazing and Burning on Forest Biodiversity. Third and Final Report to the Resource and Conservation Assessment Council.* Commonwealth Key Centre for Biodiversity and Bioresources, Macquarie University, Sydney.

York, A. 2000. Long-term effects of frequent low-intensity burning on ant communities in coastal blackbutt forests of southeastern Australia. *Austral Ecology* 25: 83-98.

York, A. 2003. Invertebrates and fire: think small, think big. The need to incorporate a major component of our biodiversity into adaptive management. Pp. 87-92 in *Bushfires: Managing the Risk. Proceedings of a Conference on Ecologically Sustainable Bushfire Management*, edited by Nature Conservation Council of NSW Inc, Sydney.

APPENDIX I



Cattle frequently use forest trails to access preferred grazing sites.

Photo: A. York.



Cattle graze preferentially in more open areas which are often the result of past logging practices.

Photo: A. York.