APPENDIX 4A.3

SYSTEM STUDIES: INVERTEBRATES

R A Sanderson

Institute for Research on Environment & Sustainability, Devonshire Building,
Newcastle University, Newcastle upon Tyne NE1 7RU.

1. PWLLPEIRAN

BACKGROUND

A standard protocol was used to sample invertebrates from the factorial (randomised block design) experiment at Pwllpeiran; samples were collected between May and September at six-week intervals in 2006. Five traps were sunk into the soil beside each permanent quadrat, with 1 m between traps. Ethylene glycol was used as a preservative in the base of each trap, and as this sometimes causes interference from livestock, each trap was secured with coarse wire mesh. Pitfall traps are an 'activity-density' measure, and do not provide an absolute estimate of the population size, being affected by both the density of the ground layer, and the behaviour of the invertebrate. Nevertheless, they have been successfully used in this type of survey in the past (Sanderson *et al*., 1995). The major groups analysed at Pwllpeiran were Hemiptera (Auchenorrhyncha and Heteroptera), Araneae (spiders), Diptera (Tipulidae), Coleoptera (Carabidae and Staphylinidae), with total abundance counts within each group. Unlike the studies at Redesdale (see below), not all groups were identified down to the species level. As the species turnover was relatively low (length of gradient on first ordination axis less than 3.0 on a unimodal detrended correspondence analysis), linear methods of multivariate analysis (PCA – principal components analysis and RDA – redundancy analysis) were used. Sheep, cattle and sheep x cattle interaction, vegetation DCA1 and DCA2 and vegetation height were used as predictor variables, with block treated as a covariable to partial out its effects.

RESULTS

Species PCA plot of the invertebrate groups is shown in Figs. 1 and 2; the main pattern is from the Diptera as a whole, including the subset of the Tipulidae, with high axis 1 scores, through to Hemiptera, Collembola and Mollusca with low scores. (Eigenvalues axis 1: 0.627; axis 2: 0.166).

Redundancy analysis of the same dataset (Fig. 3), with block as covariable, indicated that cattle had the largest overall impact, followed by vegetation height:

Predictor	**Permutation R-squared**	**P-value (999 permutations)**
Cattle	0.209	0.005
Sheep	0.039	0.419
Cattle x Sheep	0.074	0.230
Veg. DCA 1	0.050	0.366
Veg. DCA 2	0.062	0.241
Veg. Hght.	0.164	0.020

The response of individual taxa to the different treatments was investigated through standard univariate analysis of variance. Tipulidae were related to vegetation composition (F=7.12, P=0.011), declined in number with cattle (F=6.28, P=0.017), and were borderline significant on the sheep x cattle interaction (F=3.72, P=0.060). A similar pattern was obtained for the Hemiptera, with greater abundance in the absence of cattle (F=14.11, P<0.001), and again a sheep x cattle interaction (F=10.72, P=0.002). Coleoptera only showed a significant effect of cattle grazing (F=7.92, P=0.008), but Araneae abundance was significantly affected by cattle grazing (F=4.28, P=0.045), vegetation DCA2 (F=5.71, P=0.022) and the sheep x cattle interaction (F=15.646, P<0.001). In all cases where the interaction term was significant, it indicated that the decline in invertebrate numbers with cattle was not as severe if sheep were also grazing. No treatment effects were detected for Hymenoptera.

DISCUSSION

This experiment has highlighted the importance of the type of grazing livestock used, in terms of their impact on the invertebrates, as well as, to a lesser extent, the effects of vegetation height and composition in some of the analyses. The decline in abundance of several invertebrate groups with cattle-only grazing may be important, particularly in the context of the role of some invertebrates, especially Tipulidae (Buchanan *et al*., 2006), in bird diets. The exact mechanisms causing this change is unclear, and it is obvious that the process may be complex, as there was not a simple relationship between overall stocking rate and invertebrate abundance, in that the sheep and cattle interaction was sometimes significant. One possibility is that large herbivores such as cattle, which tend to be relatively indiscriminate feeders compared to sheep, cause substantial changes to the vegetation structure over a relatively short period, leading to a loss of suitable habitat for many invertebrates. That the Araneae (spider) abundance was affected by cattle grazing, which will directly alter the availability of habitat in terms of vegetation structure, is therefore not unexpected. There is anecdotal evidence that patterns of cattle grazing change when in combination with sheep; for example, it is possible that cattle graze less in areas already grazed by sheep. The latter are relatively selective feeders, and in combination with cattle it is possible that there will be greater overall habitat heterogeneity. Several studies have suggested that maintenance of a mosaic of habitats is important to maximise invertebrate diversity. Whilst maximum invertebrate abundance was obtained in the sheep-only treatments, it is possible that if cattle are only used in combination with sheep, then any negative effects on the invertebrate fauna will be minimised.

2. REDESDALE

BACKGROUND

The same sampling protocol in terms of placement and servicing of pitfall traps was used at Redesdale as described above. Samples were collected between May and September at intervals of approximately 6 weeks in both 2003 and 2005 at Redesdale. Five traps were sunk into the soil, with the aid of an auger, in a line beside each permanent vegetation quadrat, with 1 m between each trap. As at Pwllpeiran, ethylene glycol was used as a preservative in the base of each trap, and as this sometimes causes interference from livestock, each trap was secured with coarse wire mesh. Invertebrate samples were sorted to a higher level of taxonomic detail at Redesdale, with several major groups taken to the species level. Where possible biomass was also recorded, although this can be unreliable with samples collected in pitfall traps due to fluid intake into the arthropod body. The major groups identified, with their characteristics, were as follows:

Araneae (spiders) – all were identified down to species. This group of invertebrates is thought to be particularly sensitive to structural change in the vegetation, but being predatory, only indirectly affected by changes in species composition.

Coleoptera (beetles) – all were identified to family, and all Carabidae identified to species. In addition the biomass of Carabidae and Staphylinidae was determined (both groups are predatory)

Hemiptera-Auchenorrhyncha (plant hoppers, frog hoppers, leaf hoppers) – all identified to species. The sub-order is entirely herbivorous, but includes specialist and generalist feeders.

Hemiptera-Heteroptera (ground bugs, damsel bugs, capsid bugs etc.) – all identified to species. This sub-order contains a mixture of predatory, herbivorous and omnivorous species, as well as some whose life-history is poorly understood.

Diptera (true flies) – all identified to family. All craneflies (Tipulidae) were identified to species and their biomass determined, as their larvae do considerable damage to plant roots, and the newly emerged adults are important for many moorland birds during the breeding period.

Only the Araneae were sorted for 2003, whereas the other taxa were sorted for 2005. The low sheep, and low sheep plus cattle treatments were sampled. Additional samples were also collected in the restoration plots, which are currently being written up for a PhD thesis and are not reported here. Standard multivariate analyses of detrended correspondence analysis (DCA – Hill & Gauch, 1980) and canonical correspondence analysis (CCA - Ter Braak, 1986) were used to summarise community variation. Procrustes rotation (Gower, 1971) was used to compare ordinations.

RESULTS

In the vegetation DCA ordination (Fig. 4), axis 1 described a trend from heather-dominated communities, through to *Molinia*, and finally grass/rush communities (*Holcus, Agrostis, Juncus*-dominated). Vegetation DCA 1 was positively correlated with Diptera species richness (P=0.008), and weakly correlated with Tipulidae and Heteroptera species richness (P=0.05). There were few significant relationships between vegetation community composition or structure and invertebrate Shannon diversity. Grazing treatment regime was not significantly related to the species richness or diversity of any of the invertebrate taxa.

When individual DCA ordinations of each invertebrate taxon (not shown) were compared to that for the vegetation composition using Procrustes permutation tests (Oksanen, 2006), all were significant (Table 1). Note that unimodal methods (DCA and CCA) were used at Redesdale reflecting the high species turnover (Leps & Smilauer, 2005).

Table 1 Correlations between sample scores for vegetation composition DCA and invertebrate DCA ordinations (significance values based on 1000 permutations) at Redesdale

Taxon	Correlation	P-value
Araneae	0.890	<0.001
Auchenorrhyncha	0.445	<0.001
Heteroptera	0.534	0.003
Carabidae	0.450	0.002
Coleoptera	0.387	0.007
Diptera	0.422	<0.001
Tipulidae	0.388	0.021

The impacts of individual components of the vegetation community on the invertebrates, as well as the grazing treatment as a categorical factor, were investigated using CCA (summarised in Table 2).

Table 2 Results of permutation tests for individual explanatory variables used in CCA analyses. P-values based on 1000 permutations

Taxon	Veg. DCA 1	Veg. DCA 2	Sward height	Heather height	*Molinia* height	Grazing treatment
Araneae	<0.001	0.597 ns	0.794 ns	<0.001	<0.001	<0.001
Auchenorrhyncha	<0.001	<0.001	0.596 ns	<0.001	0.028	0.943 ns
Heteroptera	<0.001	<0.001	0.653 ns	<0.001	<0.001	0.006
Carabidae	<0.001	<0.001	0.009	<0.001	<0.001	<0.001
Coleoptera	<0.001	<0.001	<0.001	0.157 ns	0.209 ns	0.151 ns
Diptera	<0.001	<0.001	<0.001	<0.001	0.174 ns	0.225 ns
Tipulidae	<0.001	0.214 ns	<0.001	0.215 ns	<0.001	0.154 ns

The overall biomass of Carabidae, Staphylinidae and Tipulidae was strongly affected by vegetation composition, as measured by the vegetation DCA axis scores. Carabidae biomass was negatively correlated with DCA 1 ($P=0.03$) and DCA 2 ($P<0.001$); Staphylinidae biomass was positively correlated with DCA 1 ($P=0.01$) and Tipulidae biomass was positively correlated with DCA 1 ($P<0.001$). No direct effect of grazing treatment regime on biomass was detected.

DISCUSSION

It is immediately apparent from the results that the vegetation is having a major impact on the invertebrates, both in terms of invertebrate community composition, and (for some taxa) their biomass and diversity. Vegetation species composition, as measured by the first two ordination axis scores, was a major determinant, but most taxa were also strongly affected by some component of the vegetation structure. Whilst the results were more variable for the grazing management regime, this might be because of a lack of time for the grazing management to have had sufficient influence on the vegetation (especially its composition). One might expect that taxa that are particularly sensitive to changes in vegetation structure would also respond most to changes in grazing regime. Whilst this was certainly true of some groups, especially spiders, there was no evidence of a grazing regime effect on the Auchenorrhyncha. Again, this may simply reflect the importance of host-specificity in this plant-feeding group, and therefore an Auchenorrhyncha response to grazing management might not appear until sufficient time has elapsed for major changes in vegetation species composition. Many of the results accord with those of previous findings. For example, the species composition and biomass of the Tipulidae responded most to changes in vegetation DCA axis 1. Tipulidae larvae are particularly abundant in grasslands, and this axis reflected a transition from heather moorland to grassland areas with patches of *Juncus* in wetter areas.

Overall, the results perhaps emphasise the importance of implementing moorland management regimes to maintain a mosaic of habitats in upland ecosystems, both to retain the diversity of the invertebrate fauna, and to provide resource for the birds and mammals that depend on them. These conclusions would also appear to be supported by the results of the modelling exercise, to link the invertebrate communities to the vegetation model (see Appendix 3c for full details of the invertebrate model).

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Fig. 1 Species PCA of the major invertebrate groups at Pwllpeiran

Eigenvalues axis 1: 0.440, axis 2: 0.142.

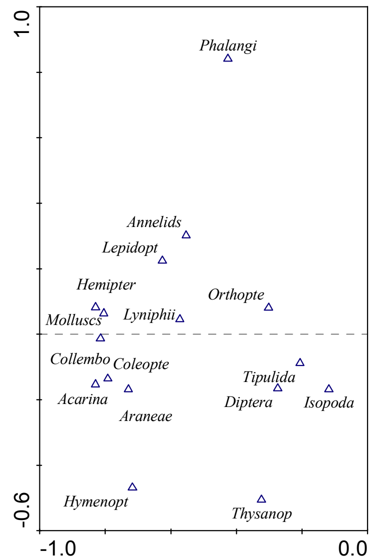

Fig. 2 Samples PCA of major invertebrate groups at Pwllpeiran

Samples classified separately for sheep and cattle grazing (animals per ha).

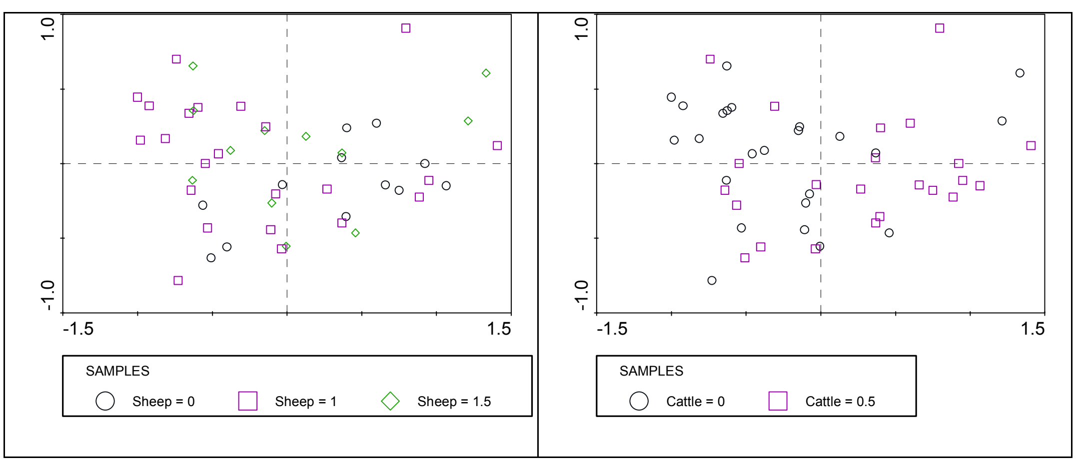

Fig. 3 RDA biplot for Pwllpeiran invertebrates, with sheep, cattle and vegetation predictors

Blocks treated as covariables and are not shown. Cattle grazing and vegetation height are significant environmental variables.

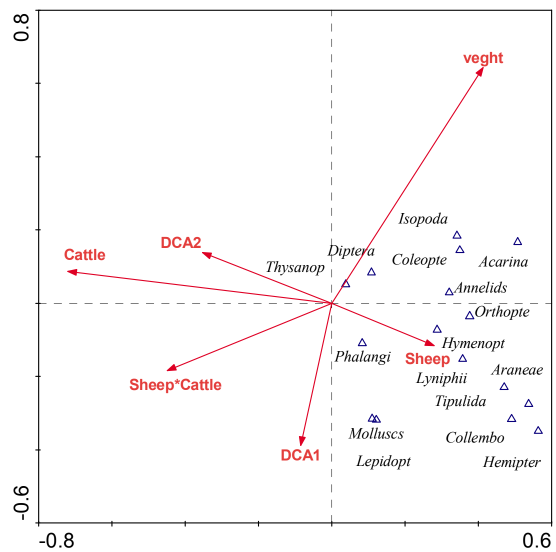

Fig. 4 DCA of vegetation from quadrats sampled for invertebrates at Redesdale (2005 data)

For clarity, only the top 20 out of 54 most highly weighted species in the ordination are shown. Eigenvalues Axis 1: 0.875, Axis 2: 0.350.