GRASSLAND MANAGEMENT TO PROMOTE DIVERSITY: CREATION OF A PATCHY SWARD BY MOWING AND FERTILISER REGIMES

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Southampton SO16 7PX

ABSTRACT
The imposition of a range of simple management regimes on a homogeneous area of grassland can quickly create an interesting and varied ecosystem of great value for research and educational purposes. This paper describes the results of an experiment in which thirty-two 0.01 ha plots in a Hampshire meadow have been subjected to various cutting regimes (unknown, June mown, August mown, monthly mown) and a range of fertiliser additions (N, P, K and lime; both singly and in combination) for 11-13 years. The resulting plant and animal communities were analysed for species number, species diversity, community structure and similarity between communities in the different treatments.

For both the plant and invertebrate communities, mowing markedly changed the species composition. It increased plant diversity (mainly by altering the relative contributions of the constituent species to total cover). In contrast, for the invertebrate fauna, mowing notably decreased diversity, largely by reducing the number of taxa present.

Fertiliser applications also resulted in major changes in species composition of both plant and animal communities, especially when applied in combinations rather than singly. Although the identity of the species changed, there were no consistent trends in species number or diversity for either the flora or fauna in response to the added nutrients.

Community structure of both the plants and animals was affected by the treatments. Mowing reduced (and fertilisers increased) the proportion of tall-growing herbs and grasses. This in turn affected the balance of phytophages, predators, scavengers and detritivores amongst the invertebrates. Overall, there was a significant inverse relationship between plant and animal diversity, and a positive relationship between the proportion of tall-growing plant species present and the diversity of the invertebrates.

For conservation purposes, where the aim of management is often to maximise biodiversity, a decision needs to be made as to which component of the community is to be given priority. If both floral and faunal diversity are to be promoted simultaneously, a possible optimum management strategy for a given area of grassland would be the creation of a mosaic of treatments in which diverse, highly localised communities coexist. Even on sites of little conservation interest, the establishment of variously managed plots can provide a useful resource for a wide range of field studies.

INTRODUCTION

The species composition, structure and diversity of a given area of grassland is largely a reflection of the regime under which it is managed. This is amply demonstrated by a number of classic experiments. Jones (1933) found that changes in the timing of sheep-grazing could radically alter the balance between the species in a rye grass/clover pasture. The Rothamsted Park Grass Experiment showed that species composition can be readily manipulated by specific fertiliser treatments (Thurston, 1969). As a rule, a grassland which is allowed to develop a high standing crop declines in plant diversity through the exclusion
of the less competitive species. The biomass above which species density declines has been quantified by Al-Mufti et al. (1977) as being in the range 350-750 g m\(^{-2}\), and by Vermeer & Berendse (1983) as 400-500 g m\(^{-2}\). The high production due to the addition of nitrogen fertilisers generally results in loss of plant species, as was found at Rothamsted and in meadows established on the Somerset peat moors (Mountford, et al. 1993).

Management regimes do not only affect the plants. Morris (1981) demonstrated that the composition of at least certain groups in the insect fauna is altered markedly by differences in timing and frequency of mowing. In general, taller (but less species-diverse) vegetation is associated with increased levels of invertebrate diversity. A fertiliser treatment may cause a change in plant composition, vegetation architecture, productivity and plant quality resulting in greatly increased abundance of plant-feeding insects. Sedlacek et al. (1988) found that fertilising old-field grassland plots resulted in greater numbers and greater species richness of the Auchenorrhyncha (leaf hoppers, Homoptera). Taller vegetation is likely to favour a greater diversity of predators, parasites and scavengers too. Southwood et al. (1979) showed that during the course of succession, plant species richness declined (after a peak at 16 months), but the increased structural complexity of the vegetation ensured a range of habitats for insects which largely compensated for the decline in plant taxonomic diversity.

A common aim of grassland management is enhancement of its ecological interest, which usually implies maintaining or increasing its species diversity. Often however, in enhancing the diversity of the plants, the diversity of the invertebrates may be reduced. Moore (1985) points out the dilemma inherent in many decisions about habitat management for conservation purposes. He gives, as an example, the contrasting merits of a mown, floristically rich grassland, which will attract a range of ground-feeding birds, and an unmown, species-poor sward bearing a great diversity of invertebrates and rodents. In devising treatments to promote diversity, it is clearly necessary to define which organisms are being targeted.

This paper describes an experiment in which an area of neutral grassland in Hampshire was divided into permanent plots which have been subjected to a range of consistent mowing and fertiliser regimes. The plots were set up to provide a long-term research resource for investigating aspects of community ecology. The specific aims of the present study are (1) to examine the effects of the treatments on the taxonomic composition, species diversity and community structure of both the flora and fauna; (2) to determine whether or not there is a general relationship between the diversity of the flora and that of the invertebrate fauna and; (3) to investigate possible causes of any relationships found.

**Methods**

**The site**

The study was carried out in a field of approximately 1 ha (Paddock Field) which is part of the University of Southampton’s Conservation Area at Chilworth, Hampshire (Map ref. O/S Sheet 185, GR 407 184). The site is level, with free-draining sandy soil supporting a neutral grassland community with a wide range of species, but no notable rarities. Prior to its acquisition by the Biology Department in 1980, it had been a strawberry field from 1947 to 1962 and a cattle pasture from 1963 to 1978. Since 1979 it has been cut annually for hay.

In 1981, twelve plots (each 12 m X 9.5 m, or ca 0.01 ha) were established by Dr. S. D. Wratten to determine the effect of different mowing regimes on the species composition and diversity of the flora and fauna. Four treatments were imposed: unmown; mown annually in June; mown annually in August; and monthly mown. There were three replications of each treatment (see Fig. 1). Monthly mown paths (1.5 m wide) are maintained between the plots. These treatments have been maintained for 13 years*.

* At the time of writing (Ed.).
Fig. 1. Community structure of (a) the plants (b) the invertebrates in the mowing and fertiliser treatments.
In 1983, Dr P.J. Edwards and Dr. M. Fenner extended the experiment by adding twenty plots of fertiliser treatments around the original nucleus of the mowing plots. Ten treatments (each with two replications) were allocated randomly within the grid, and have consisted of annual fertiliser applications in spring for 11 years. The treatments are as follows:

- Nitrogen (N) as 5 kg NaNO₃ per plot
- Phosphorus (P) as 1.7 kg NaH₂PO₄·2H₂O per plot
- Potassium (K) as 5 kg K₂SO₄ per plot
- Lime (L) as 25 kg CaCO₃ per plot

plus combinations of these treatments, viz., NPK, NPL, PKL, NKL and NPKL and two control plots (CON). Since 1990, the lime has been applied in alternate years. These levels were based on those used in the Rothamsted Park Grassland experiment.

Sampling and identification

A complete list of the plant species in each plot was drawn up whilst making a systematic search by examining strips of 1m width. In addition, a quantitative survey was carried out by sampling the flora in six randomly placed 50 cm x 50 cm quadrats in each plot. The percentage cover of each of the higher plant species present in each quadrat was estimated, along with the percentage cover of moss, litter and bare ground. The sampling was carried out between 21st June and 8th July 1993, when many of the species were in flower. The vegetation in the monthly mown plots was about 10 cm high; in all other plots it was approximately 0.5-1.0 m in height.

Sampling of the invertebrate community was carried out with the intention of gaining a representative selection of the fauna directly associated with the vegetation. Twenty-five single sweeps were made with a 40cm diameter sweep net while walking for 10m in a straight line down the long axis of each plot. The last metre at each end of the 12m long plots was not sampled so as to avoid edge effects. The sampling was carried out between 11.00 h and 14.00 h on 18th September 1993, a day of broken cloud and sunshine and a temperature of 16-17°C. The contents of the sweep nets were emptied into 32 plastic bags (one for each plot). These were then sealed and subsequently stored in a freezer at -20°C until the identification could be carried out.

Prior to identification the samples were defrosted, and the animals bottled in 70% methylated spirits to preserve them. Identification was carried out to the Family level, except in a minority of cases where identification beyond the Superfamily is particularly difficult (for example, with some of the Hymenoptera). All larvae were identified to the level of the Order, as were woodlice (Isopoda), mites (Acarina) and harvestmen (Opiliones); these latter groups contributed very few individuals to the samples.

Analysis of data

The effects of mowing and fertiliser additions on the flora were determined by calculating:

(i) species richness in terms of the total number of plant species found in each treatment;
(ii) species diversity as the Shannon-Wiener index of dominance concentration,

\[ H = - \sum P \log_2 P \]

(where \( P \) is the proportional contribution of each species using cover data); (iii) the similarity in species composition between the treatments and the controls using the Jaccard coefficient of similarity,

\[ C = j/(a + b - j) \]

(where a and b are the number of species in the treatment and the control respectively, and j is the number of shared (joint) species); and

(iv) community structure as the relative contribution of tall (>50cm) and short plants (≤50cm) in the vegetation. These two categories were defined by data given for height in Rose (1981). See Appendix 1.
Table 1. Effect of (a) mowing regimes and (b) fertiliser regimes on species number, diversity (Shannon-Wiener Index) and similarity to the corresponding control (Jaccard Index) for both flora and fauna.

(a) Mowing regimes

<table>
<thead>
<tr>
<th>PLANTS</th>
<th>INVERTEBRATES</th>
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<tbody>
<tr>
<td></td>
<td>Mean number</td>
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<td></td>
<td>of species per</td>
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<tr>
<td></td>
<td>quadrat</td>
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<tr>
<td></td>
<td>(and s.e.)</td>
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<tr>
<td>Unmown</td>
<td>3.56 (0.51)</td>
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<td></td>
<td>(± 0.214)</td>
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<tr>
<td>June mown</td>
<td>7.94 (0.45)</td>
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<td>(± 0.113)</td>
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<tr>
<td>August mown</td>
<td>9.94 (0.65)</td>
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<td></td>
<td>(± 0.234)</td>
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<tr>
<td>Monthly mown</td>
<td>9.98 (0.57)</td>
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<td></td>
<td>(± 0.004)</td>
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(b) Fertiliser regimes

<table>
<thead>
<tr>
<th>PLANTS</th>
<th>INVERTEBRATES</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean number</td>
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<td></td>
<td>of species per</td>
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<td></td>
<td>quadrat</td>
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<tr>
<td></td>
<td>(and s.e.)</td>
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<tr>
<td>Control (un-fertilised)</td>
<td>7.25 (0.84)</td>
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<tr>
<td></td>
<td>(± 0.265)</td>
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<tr>
<td>N</td>
<td>7.25 (0.63)</td>
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<td></td>
<td>(± 0.222)</td>
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<tr>
<td>P</td>
<td>7.67 (0.47)</td>
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<td></td>
<td>(± 0.021)</td>
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<tr>
<td>K</td>
<td>9.08 (0.68)</td>
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<td>(± 0.001)</td>
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<tr>
<td>L (Lime)</td>
<td>10.75 (0.80)</td>
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<td></td>
<td>(± 0.192)</td>
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<tr>
<td>NPK</td>
<td>5.92 (0.40)</td>
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<td></td>
<td>(± 0.046)</td>
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<tr>
<td>NPL</td>
<td>7.58 (0.66)</td>
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<td></td>
<td>(± 0.186)</td>
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<tr>
<td>PKL</td>
<td>8.00 (0.67)</td>
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<td></td>
<td>(± 0.164)</td>
</tr>
<tr>
<td>NKL</td>
<td>8.25 (0.52)</td>
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<tr>
<td></td>
<td>(± 0.278)</td>
</tr>
<tr>
<td>NPKL</td>
<td>7.58 (0.54)</td>
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<td></td>
<td>(± 0.1729)</td>
</tr>
</tbody>
</table>

Relationships between the species richness, diversity and community structure of the plants and animals were examined to determine if any correlations could be established between features of the two communities. See Appendix 2.
For the fauna, four corresponding calculations were made, viz.,
(i) invertebrate richness as the number of Families or Superfamilies per treatment;
(ii) diversity by the Shannon-Wiener index, using numbers of individuals in each taxon as a proportion of the total;
(iii) similarity between treatments and the controls as the Jaccard coefficient; and
(iv) community structure in terms of the relative contributions of five trophic groups to the community in each treatment, viz., phytophages, predators/parasitoids, scavengers, saprophytes and detritivores.

RESULTS

The effects of the mowing and fertiliser regimes are shown in Table 1. In all the mowing treatments, the mean number of plant species per quadrat was increased over that in the unmown control. The opposite, however, applies to the invertebrates: the mown plots show a marked reduction in the number of taxa (Families and Superfamilies) per sample. The plant and animal diversity indices show similar contrasting trends; the unmown plots have the lowest plant diversity and the highest animal diversity. Mowing also markedly altered the species composition of both components. The similarity indices between each of the treatments and the control are particularly low in the case of the invertebrates, indicating a marked change in taxonomic make-up. Values in the range 0.33 to 0.40 for the Jaccard Index indicate that only a minority of species was common to the mown and unmown plots.

In the fertiliser treatments, the results for plant species richness are less clear-cut. Mean number of species per quadrat was highest in the limed plots and lowest in the NPK plots, but differed little from the controls in the other treatments. For the invertebrates, the general trend was for slightly reduced species richness with fertiliser addition (down from 18.5 taxa per sample in the controls to a mean of 14.7 for all the fertiliser treatments combined). Nitrogen on its own had no effect on the number of taxa, whereas the addition of PKL (i.e., all nutrients except N) resulted in the fewest species per sample. Diversity as such showed no consistent trend for the invertebrates. The main effect of fertiliser addition on the invertebrates is to alter their faunal composition. This is indicated by the low similarity indices between the treatments and the controls. The treated plots had, on average, only 34.6% of invertebrate species in common with the unfertilised controls.

Fig. 1 shows the community structure of both the plants and animals in each of the treatments. Mowing decreased the proportion of tall-growing species of plant and the proportion of predators and parasitoids. The unfertilised plots had more predators and parasitoids than any of the fertiliser treatments.

Fig. 2a shows the significant (P<0.05) negative relationship between floral and faunal richness in the 32 plots. A similar negative correlation (P<0.05) between plant and animal diversity was found by plotting the Shannon-Wiener index of the plants against the same index for the invertebrates (Fig. 2b).

Fig. 3 shows the relationship between vegetation structure and diversity in both the plant and animal communities. There is a positive correlation (P<0.001) between percent of tall plants and invertebrate diversity (Fig. 3a); and a negative correlation (P<0.05) between the percent of tall plant species in each treatment and plant species diversity (Fig. 3b).

DISCUSSION

In all studies involving the listing of invertebrate species in any community, the inventory obtained depends on the timing of sampling and the technique employed (sweep-net, pit-falls traps, D-vac, etc.). The aim here was merely to take a standardised, representative sample of
the fauna associated with the vegetation, especially the plant sucking and chewing insects and their associated predators and parasites. The results, therefore, refer only to this biased sample of the total invertebrate fauna. The timing of the sampling will have had a particularly important bearing on the results. The fertilised plots received their annual cut in August, and by mid-September were about 15-20 cm in height, with few species in flower. Pollinating insects would probably have featured more strongly if the fauna sampling had been carried out at the same time as the floral survey in June. In view of the rather uniform structure of the vegetation in September, it is remarkable that the diversity of the invertebrate fauna shows

Fig. 2. Relationships between (a) floral and faunal richness and (b) floral and faunal diversity. Open circles, fertiliser treatments; closed circles, mowing treatments.
such a marked correlation with the percentage of tall-growing plant species. This suggests that many of the insects associated with the taller plant species had survived the August cut.

Even though invertebrate species diversity as such was not markedly affected by the various regimes, species composition differed greatly between treatments. Little is known about the precise nutrient requirements of individual plant-feeding species of insects, but we
may surmise that different species may be favoured by different combinations of nutrients taken up by the vegetation. Both the herbivores and their predators and parasites may have exacting structural habitat requirements (e.g., vegetation height, density, ratio of broad-leaved to narrow-leaved plants, the vertical distribution of herbage in the canopy, etc.). Experimental research on the preferred habitat structures of common grassland invertebrates might help to explain the coexistence of species with apparently similar food niches.

The results of this study confirm the contention of Moore (1985) that the management of plant and animal communities for conservation purposes often involves choosing between promoting the diversity of different sets of organisms. No single management regime will maximise diversity in all taxa simultaneously, so conservation objectives have to be highly focused. The protection of a rare species may well involve a general reduction in species diversity in the whole community. For example, the conservation of a rare invertebrate might require the maintenance of a vegetation canopy structure which is only obtainable by means of a management regime which reduces floral diversity.

The most effective way to maximise diversity in a homogeneous grassland is probably to form a mosaic of patches receiving different management. For practical purposes these should be reduced to a small number of easily applied treatments. Mowing regimes on their own yield major differences in both the plant and animal communities. The present study involves rather too many fertiliser regimes for most purposes, and ecologists may in any case balk at adding artificial fertilisers to a conservation area. An annual application of an organic fertiliser could be used to provide a high nutrient regime. The effects of the treatments are noticeable within the first year, but become more marked with time. With relatively little input, a highly diverse, ecologically interesting research and educational resource can be created for a wide range of community studies.

ACKNOWLEDGEMENTS

We thank Mr David Baddams for maintaining the plots and Mr Barry Lockyer for organising the annual fertiliser treatments. We are indebted to Dr Ross Coleman for assistance with the identification of the invertebrates and to Mr Raymond Cornick for preparing the figures.

REFERENCES

List of plant species present in the plots, grouped into the size categories used in Fig. 1, based on data given in Rose (1981).

<table>
<thead>
<tr>
<th>TALL SPECIES (&gt;50cm)</th>
<th>SHORT SPECIES (≤50cm)</th>
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<tbody>
<tr>
<td><strong>Monocotyledons</strong></td>
<td><strong>Dicotyledons</strong></td>
</tr>
<tr>
<td><em>Agropyron repens</em></td>
<td><em>Achillea millefolium</em></td>
</tr>
<tr>
<td><em>Alopecurus pratensis</em></td>
<td><em>Bellis perennis</em></td>
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<tr>
<td><em>Arrhenatherum elatius</em></td>
<td><em>Cerastium holosteoides</em></td>
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<tr>
<td><em>Bromus mollis</em></td>
<td><em>Geranium molle</em></td>
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<tr>
<td><em>Cynosurus cristatus</em></td>
<td><em>Hypochoeris radicata</em></td>
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<tr>
<td><em>Dactylis glomerata</em></td>
<td><em>Lotus corniculatus</em></td>
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<td><em>Holcus lanatus</em></td>
<td><em>Plantago lanceolata</em></td>
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<tr>
<td><em>Phleum pratense</em></td>
<td><em>Potentilla reptans</em></td>
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<tr>
<td><em>Trisetum flavescens</em></td>
<td><em>Ranunculus bulbosus</em></td>
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<tr>
<td><strong>Dicotyledons</strong></td>
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<tr>
<td><em>Castanea sativa</em></td>
<td><em>Ranunculus repens</em></td>
</tr>
<tr>
<td><em>Centauraea nigra</em></td>
<td><em>Raphanus raphanistrum</em></td>
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<tr>
<td><em>Cirsium vulgare</em></td>
<td><em>Stellaria graminea</em></td>
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<tr>
<td><em>Crepis capillaris</em></td>
<td><em>Taraxacum officinale</em></td>
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<tr>
<td><em>Epilobium tetragonion</em></td>
<td><em>Trifolium dubium</em></td>
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<tr>
<td><em>Gaultheria aparina</em></td>
<td><em>Trifolium pratense</em></td>
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<tr>
<td><em>Hypericum perforatum</em></td>
<td><em>Trifolium repens</em></td>
</tr>
<tr>
<td><em>Heracleum sphondylium</em></td>
<td><em>Veronica chamaedrys</em></td>
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<tr>
<td><em>Lathyrus pratensis</em></td>
<td><em>Vicia sativa</em></td>
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<tr>
<td><em>Leucanthemum vulgare</em></td>
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<td><em>Malva moschata</em></td>
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<tr>
<td><em>Quercus robur</em></td>
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<tr>
<td><em>Ranunculus acris</em></td>
<td></td>
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<tr>
<td><em>Rudbeckia hirta</em></td>
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<td><em>Rumex acetosa</em></td>
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<tr>
<td><em>Rumex obtusifolius</em></td>
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<tr>
<td><em>Senecio jacobaea</em></td>
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<tr>
<td><em>Silene alba</em></td>
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<tr>
<td><em>Sonchus asper</em></td>
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<tr>
<td><em>Tragopogon pratense</em></td>
<td></td>
</tr>
<tr>
<td><em>Urtica dioica</em></td>
<td></td>
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<tr>
<td><em>Vicia sylvestris</em></td>
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</tbody>
</table>
Division of invertebrates into trophic groups.

**PHYTOPHAGES**

**MOLLUSCA:**
- **GASTROPODA**
  - Helicidae
  - Zonitidae

**ARTHROPODA:**
- **INSECTA**
  - **PLECOPTERA**
    - Capniidae
  - **ORTHOPTERA**
    - Acrididae

**HEMIPTERA;**

**HETEROPTERA**
- Acanthosomatidae
- Coreidae
- Cydnidae
- Lygaeidae
- Miridae
- Pentatomidae
- Tingidae

**DIPTERA**
- Agromyzidae
- Anthomyiidae
- Asteiidae
- Bibionidae
- Cecidomyiidae
- Chloropidae
- Conopidae
- Tipulidae

**LEPIDOPTERA**
- unidentified larvae

**HYMENOPTERA**
- Cynipidae
- Symphyta larvae

**PREDATORS AND PARASITOIDS**

**ARTHROPODA:**
- **CHELICERATA**
  - Araneae
    - Clubionidae
    - Dictynidae
    - Gnaphosidae
    - Lycosidae
    - Salticidae
    - Theridiosomatidae
    - Thomisidae

**ARTHROPODA:**
- **INSECTA**
  - **DERMAPTERA**
    - Forficulidae
  - **HEMIPTERA;**
  - **HETEROPTERA**
    - Anthocoridae
  - **COLEOPTERA**
    - Coccinellidae
    - Staphylinidae
    - unidentified larvae

**DIPTERA**
- Acroceridae
- Dolichopodidae
- Empididae
- Pipunculidae
- Scathophagidae

**HYMENOPTERA**
- Braconidae
- Chalcidoidea
- Ichneumonidae
- Proctotrupoidea
SAPROZOIDS

ARTHROPODA: INSECTA
   DIPTERA
      Anthomyzidae
      Sepsidae
      Sphaeroceridae

SCAVENGERS

ARTHROPODA: COLEOPTERA
   ACARINA
   DIPTERA
   Anthomyzidae
   Otidae

HYMENOPTERA
   Formicidae

FUNGIVORES AND DETRITIVORES

ARTHROPODA: CRUSTACEA
   DIPTERA
   PSEUDOCOPTERA
   Ectopsocidae
   Campodeidae
   Heleomyzidae
   Lonchopteridae
   Mycetophilidae

   ISOPODA
   Camillidae

   ARTHROPODA: INSECTA
   DERMAPTERA
   Forficulidae
   unidentifed larvae

   ARTHROPODA: INSECTA
   DIPLURA
   Camillidae