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

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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 (unmown, 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 *de*creased 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.).

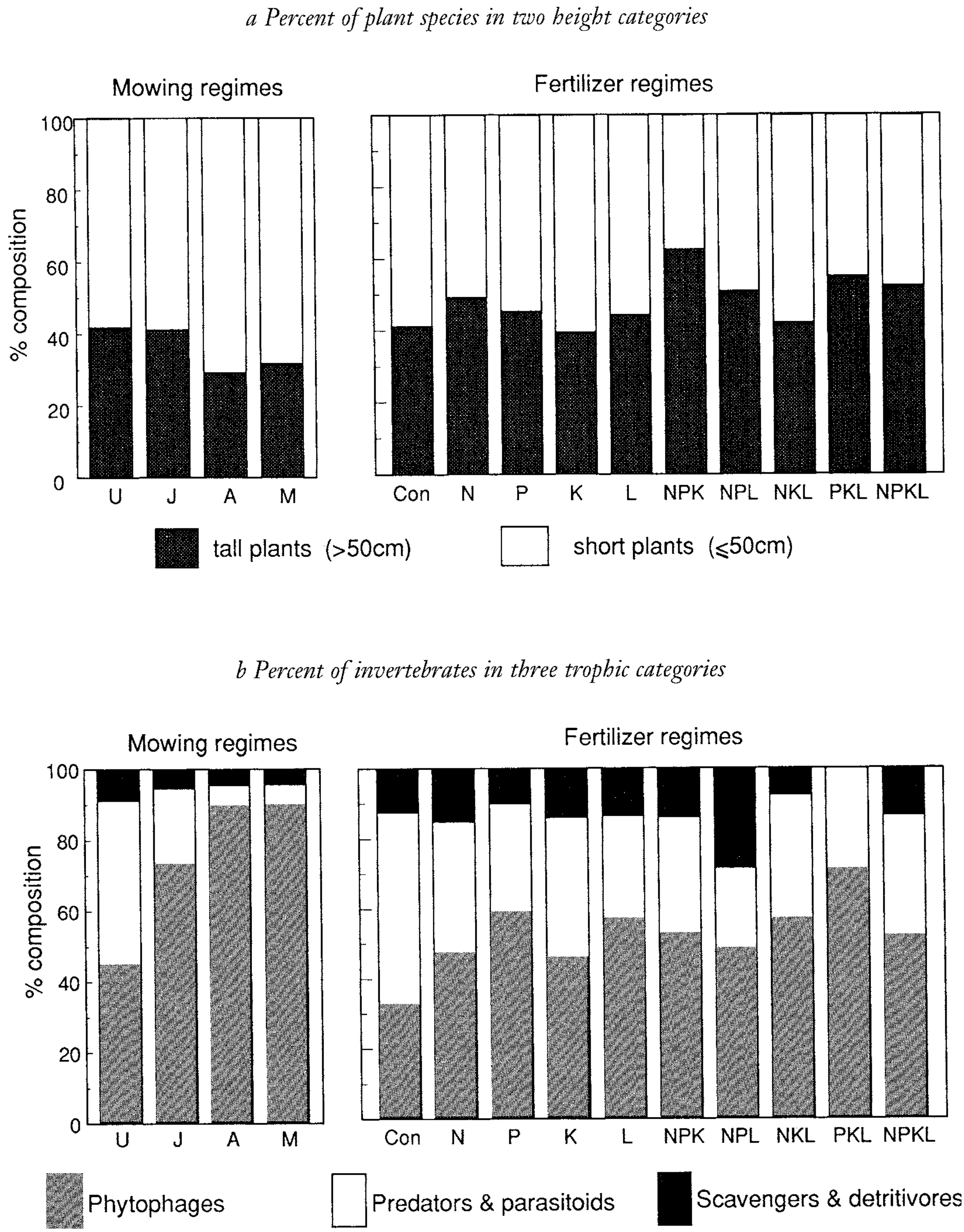

FIG. 1. Community structure of (a) the plants (b) the invertebrates in the mowing and fertiliser treatments.

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 $NaNO_3$ per plot
Phosphorus (P) as 1.7 kg $NaH_2PO_4.2H_2O$ per plot
Potassium (K) as 5 kg K_2SO_4 per plot
Lime (L) as 25 kg $CaCO_3$ 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,

$$H = - S p \log_e p$$

(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

	PLANTS			INVERTEBRATES		
	Mean number of species per quadrat (and s.e.)	Diversity (mean and range)	Similarity to control	Mean number of taxa per sample (and range)	Diversity (mean and range)	Similarity to control
Unmown	3.56 (0.51)	0.815 (± 0.214)	(1.00)	18.3 (± 3.5)	2.680 (± 0.197)	(1.00)
June mown	7.94 (0.45)	1.677 (± 0.113)	0.705	10.0 (± 2.5)	1.578 (± 0.206)	0.333
August mown	9.94 (0.65)	1.858 (± 0.234)	0.581	12.0 (± 1.5)	1.248 (± 0.452)	0.341
Monthly mown	9.98 (0.57)	1.883 (± 0.004)	0.587	11.3 (± 2.5)	1.325 (± 0.779)	0.400

(b) *Fertiliser regimes*

	PLANTS			INVERTEBRATES		
	Mean number of species per quadrat (and s.e.)	Diversity (mean and range)	Similarity to control	Mean number of taxa per sample (and range)	Diversity (mean and range)	Similarity to control
Control (un-fertilised)	7.25 (0.84)	1.607 (± 0.265)	(1.00)	18.5 (± 0.5)	2.437 (± 0.149)	(1.00)
N	7.25 (0.63)	1.580 (± 0.222)	0.634	18.5 (± 1.0)	2.588 (± 0.114)	0.390
P	7.67 (0.47)	1.665 (± 0.021)	0.700	13.5 (± 2.5)	2.351 (± 0.204)	0.412
K	9.08 (0.68)	1.815 (± 0.001)	0.690	13.0 (± 1.0)	2.342 (± 0.170)	0.394
L (Lime)	10.75 (0.80)	1.890 (± 0.192)	0.683	17.0 (± 2.0)	2.798 (± 0.006)	0.447
NPK	5.92 (0.40)	1.355 (± 0.046)	0.535	15.5 (± 2.5)	2.427 ± 0.186)	0.412
NPL	7.58 (0.66)	1.607 (± 0.186)	0.512	15.5 (± 1.5)	2.554 (0.029)	0.289
PKL	8.00 (0.67)	1.491 (± 0.164)	0.600	8.5 (± 1.5)	1.989 (± 0.219)	0.212
NKL	8.25 (0.52)	1.562 (± 0.278)	0.512	16.5 (± 1.5)	2.494 (± 0.115)	0.244
NPKL	7.58 (0.54)	1.701 (± 0.1729)	0.614	14.5 (± 2.5)	2.371 (± 0.231)	0.316

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 mean 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

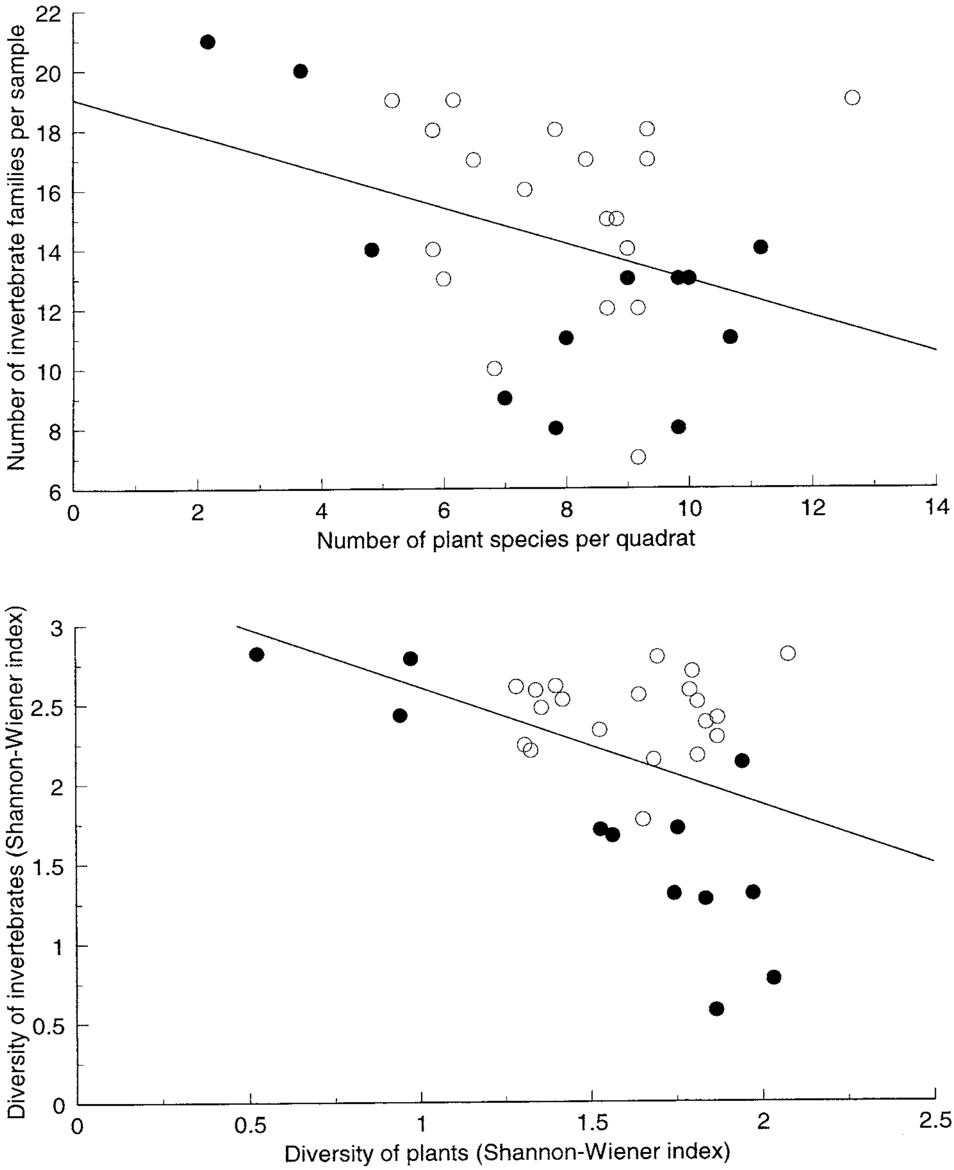

FIG. 2. Relationships between (a) floral and faunal richness and (b) floral and faunal diversity. Open circles, fertiliser treatments: closed circles, mowing treatments.

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

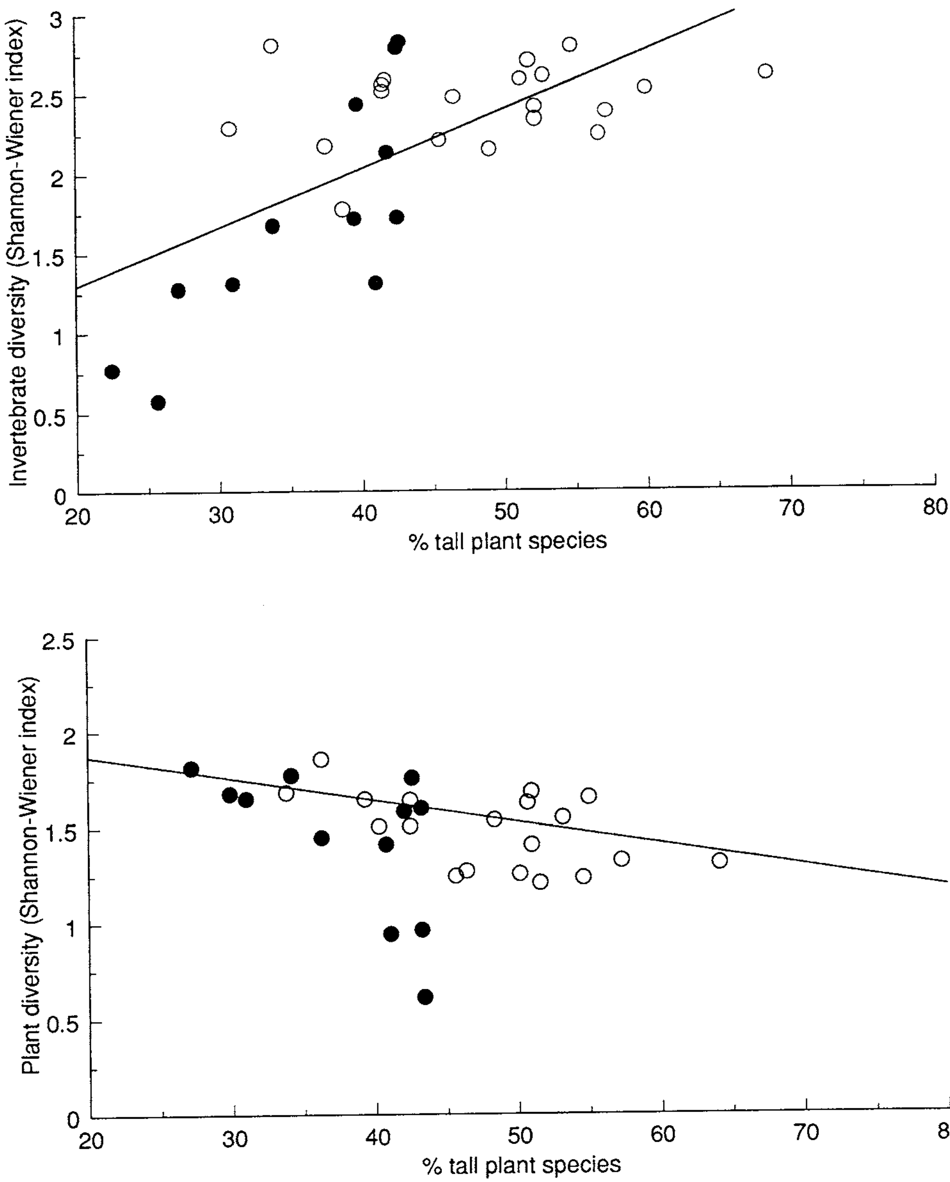

FIG. 3. Relationships between vegetation structure (measured as percent of tall plant species present) and (a) plant diversity and (b) invertebrate diversity. Open circles, fertiliser treatments: closed circles, mowing treatments.

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.

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APPENDIX 1

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

Monocotyledons

TALL SPECIES (>50cm)	SHORT SPECIES (≤50cm)
Agropyron repens	*Agrostis capillaris*
Alopecurus pratensis	*Anthoxanthum odoratum*
Arrhenatherum elatius	*Festuca rubra*
Bromus mollis	*Lolium perenne*
Cynosurus cristatus	*Luzula campestris*
Dactylis glomerata	
Holcus lanatus	
Phleum pratense	
Trisetum flavescens	

Dicotyledons

TALL SPECIES (>50cm)	SHORT SPECIES (≤50cm)
Castanea sativa	*Achillea millefolium*
Centaurea nigra	*Bellis perennis*
Cirsium vulgare	*Cerastium holosteoides*
Crepis capillaris	*Geranium molle*
Epilobium tetragonium	*Hypochoeris radicata*
Galium aparine	*Lotus corniculatus*
Hypericum perforatum	*Plantago lanceolata*
Heracleum sphondylium	*Potentilla reptans*
Lathyrus pratensis	*Ranunculus bulbosus*
Leucanthemum vulgare	*Ranunculus repens*
Malva moschata	*Raphanus raphanistrum*
Quercus robur	*Stellaria graminea*
Ranunculus acris	*Taraxacum officinale*
Rubus fruticosus	*Trifolium dubium*
Rumex acetosa	*Trifolium pratense*
Rumex obtusifolius	*Trifolium repens*
Senecio jacobaea	*Veronica chamaedrys*
Silene alba	*Vicia sativa*
Sonchus asper	
Tragopogon pratense	
Urtica dioica	
Vicia sylvatica	

APPENDIX 2

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

HEMIPTERA;
HOMOPTERA
Aleyrodidae
Aphididae
Cicadellidae
Coccoidea
Delphacidae
Pemphigidae
Phylloxeridae
Psyllidae

THYSANOPTERA
Thripidae

COLEOPTERA
Apionidae
Bruchidae
Chrysomelidae
Curculionidae

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: CHELICERATA
OPILIONES

ARTHROPODA : INSECTA
DIPTERA
Anthomyzidae
Muscidae
Sepsidae
Sphaeroceridae

SCAVENGERS

ARTHROPODA: CHELICERATA
ACARINA

ARTHROPODA : INSECTA
DERMAPTERA
Forficulidae

COLEOPTERA
Dermestidae
Staphylinidae

MECOPTERA
unidentified larvae

DIPTERA
Anthomyzidae
Otitidae

HYMENOPTERA
Formicidae

FUNGIVORES AND DETRITIVORES

ARTHROPODA: CRUSTACEA
ISOPODA

ARTHROPODA : INSECTA
DIPLURA
Camillidae

PSOCOPTERA
Ectopsocidae

DIPTERA
Campodeidae
Heleomyzidae
Lonchopteridae
Mycetophilidae