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The effects of horse grazing on species-rich grasslands

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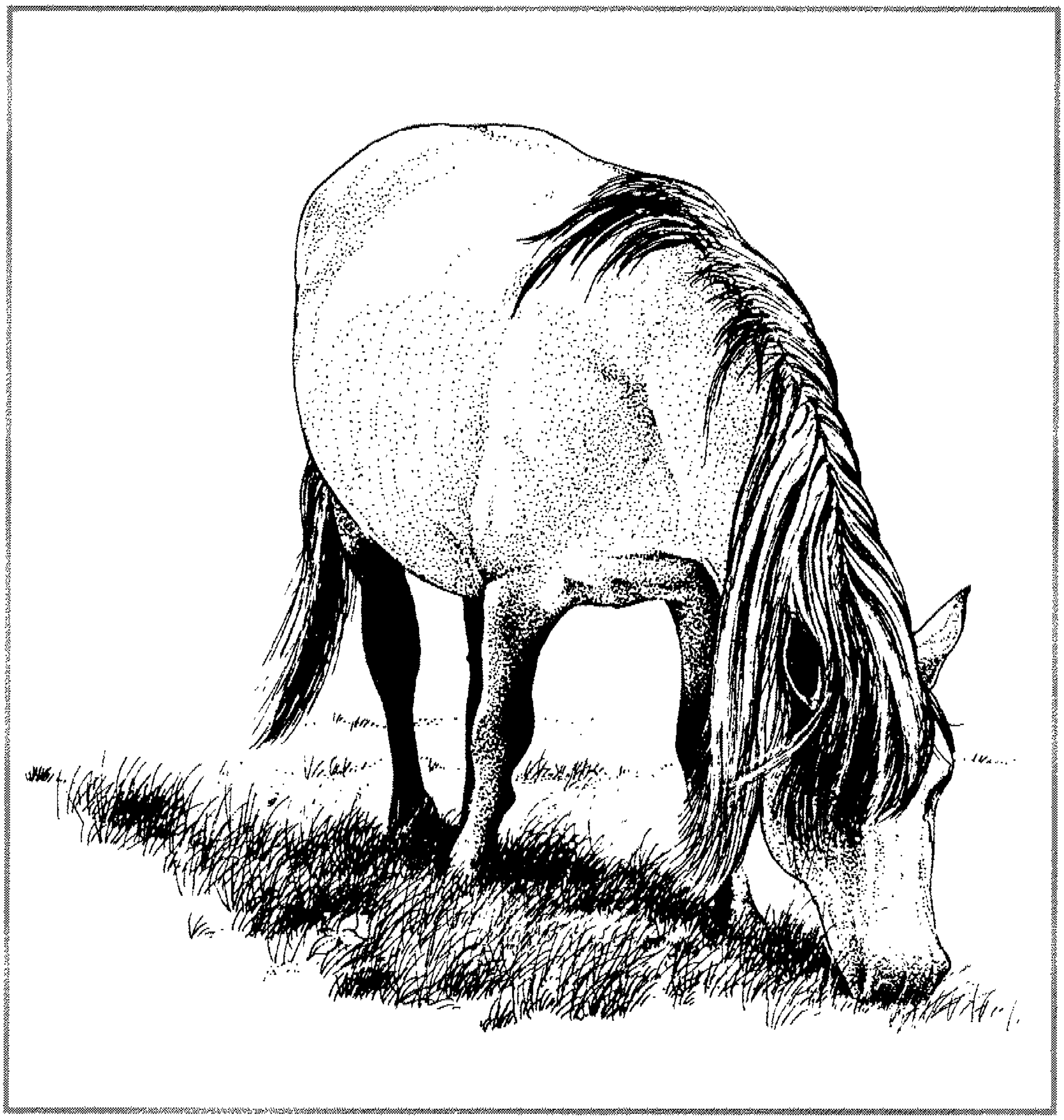

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THE EFFECTS OF HORSE GRAZING

ON

SPECIES-RICH GRASSLANDS

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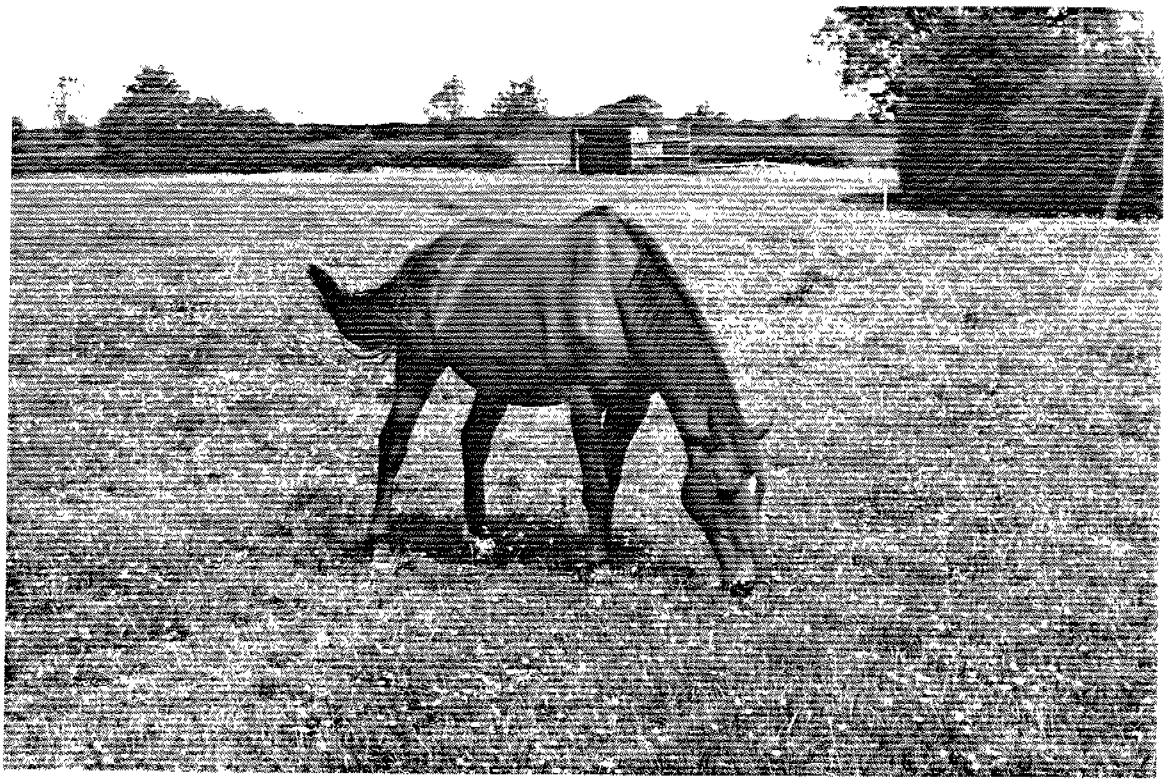
Horse at Portway Farm



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1 Summary

1.1 This document reports on a structured survey during 1995 of twenty *Centaurea nigra* - *Cynosurus cristatus* grassland (MG5 in the National Vegetation Classification) sites in Worcestershire. The aims are to determine if horse, as opposed to cattle, grazing (with or without traditional hay management) damages the nature conservation interest of these grasslands. If so, is there any way in which horses can still be used for grazing but controlled so that they do not damage the interest?

1.2 Twenty sites were chosen in discussion with English Nature to cover the full range of natural variation within MG5 in Worcestershire and the key variables of grazing species, grazing intensity and whether or not a hay cut was taken. Some sites had more than one of these treatments and/or MG5 subcommunity, giving 38 fields in all.

1.3 Recording was done by placing a minimum of five randomly positioned 1m square quadrats in each field and making a species list of vascular plants present in each of 25 20 cm square cells within the quadrat. Vegetation height was estimated and other environmental and geographical information attached to each site and quadrat.

1.4 Analysis used the multivariate package CANOCO in a sequence of analyses designed to provide a robust test of the effects of management while discarding as much of the inevitable bias due to grassland locations as possible. This was followed by an examination of species categorised according to life history and other features.

1.5 The results show that the species of grazing animal has a minor effect compared to grazing intensity. The damage commonly associated with horse grazing is confirmed but revealed as restricted to heavily grazed sites. Heavy grazing by cattle may cause an equal amount of damage. The best sites as measured by species diversity and the abundance of indicator species and others of nature conservation interest are marginally those which are lightly or moderately grazed by horses and also put up for hay. However, the small but distinct differences between hay meadows and pastures and between cattle and horse grazed fields are valuable in their own right.

1.6 Damage is manifested by a reduction in overall diversity, in indicator species and in species in decline in Britain. These features are closely related to seedbank characters and to established plant strategies. In the extreme, heavy horse grazing results in a mosaic of latrine and short patches, each with a distinct low-diversity sward containing few species of interest. Heavy grazing may also in the long term turn MG5 grasslands into MG6 and other species-poor *Lolium* pastures. These conclusions derive both from the present data set and the way in which some grasslands have changed since previously recorded.

1.7 The results are examined critically in relation to the intrinsic pressures resulting from the way in which horses, as opposed to cattle, tend to be managed. In conclusion, horse grazing is a legitimate and valuable way of managing MG5 grasslands, but only if the intensity and pattern of grazing is carefully controlled.

2 Introduction

2.1 Management of species-rich grasslands

British species-rich grasslands need active management to maintain their nature conservation value. Depending on the type of grassland, this is usually by cutting, grazing, or some sort of combination of these treatments.

The best sites have often had centuries or even longer of active management. Ideally, the nature conservation manager aims to replicate "traditional" management: the type of management which caused a site to gain its interest in the first place and to keep it through the centuries. On many sites however, the traditional management is not known in detail. Even when it is, it may not be practical to replicate it under modern conditions.

In such circumstances, the manager tries to set up the best available option based on the vegetation type(s) (eg NVC classification - Rodwell 1992 ed.) of interest, where appropriate taking into account other factors such as key invertebrate species.

Such management is achieved against a tide of difficulties caused by the changed circumstances of the British countryside and modern farming practices. Occasionally, a site is fortunate enough to be in special circumstances: either part of a network of nature reserves where traditional farming is carried on by the nature conservation body, or near to a farm which is run on traditional lines. The key problems faced in normal circumstances are as follows.

1. Hay is rarely taken except where horses are kept: grass is usually conserved as silage which is only economic on improved grasslands and in any case means too-frequent cuts at the wrong time of year for nature conservation management.

2. Modern farm stock belong to tightly run and intensive farm economies. There are few circumstances when a farmer is willing or can afford to pasture animals on unimproved grasslands or feed them hay from such places. Occasionally, there are circumstances which can be used to advantage, as when ewes are being dried off after weaning lambs.

Horses are frequently a major exception to these rules. Horses and ponies are not required to produce meat or milk to a tight economic schedule. Even when fed artificially they need pasture space for exercise and hay is usually a fundamental part of most horses' diet. Unimproved pastures and meadows can still be highly useful to most horse and pony keepers, indeed improved swards can be over-lush and risk laminitis (Oates 1994). Moreover, horse and pony keeping is a growing use of the countryside, especially but not exclusively near the urban fringe.

The converse is more controversial: grassland of nature conservation value is useful to horse and pony keepers, but are horses and ponies good or bad for grassland management?

Until recently, there has been a widely held view, even a consensus, that horse and pony grazing is bad for grassland management. It was acknowledged that some heath and mire vegetation and particular areas such as the New Forest lawns have been traditionally grazed by ponies and that their interest is in part maintained by this (e.g. Putman 1986). Nevertheless, there are a number of features of horse grazing which were considered to be bad for most species rich grasslands.

2.2 Key features of horse grazing

The reasons why horse and pony grazing has been thought detrimental are broadly as follows.

1. Horses select species differently from sheep and cattle. Therefore their grazing may cause changes in the balance of species in the sward.

2. Horses graze in a different spatial pattern to other stock. When a pasture is intensively used, it can become a patchwork of very short turf and coarse areas ("latrines") which horses refuse to graze because they have dunged there (Odberg and Francis-Smith 1976).

3. Horses are not always put in a field just to feed; exercise may be at least as important. It may be worth the owner's while putting animals in a field for exercise even when it is so poached and overgrazed that there is nothing left to eat. Feed is then provided on the field, which causes even more damage. Also, horses tend to be in the field all the year round, so the grassland is never rested. Not all horse and pony owners have the training and skills in pasture management which are common among farmers.

4. Horses and ponies are often kept on very small landholdings. Exercise as in (3) above may be so important that hay can be brought in from elsewhere. If the only available paddock were a traditional hay meadow, there would be pressure for this management to cease and to be replaced by continuous grazing.

In contrast, there are possible advantages of horse grazing in practice. These have been ably reviewed by Oates (1994) but in species-rich grasslands the following are among the most important.

1. Horses and ponies may be available when other stock are impossible to get. Light grazing by horses may be better than no grazing at all.

2. Patchy structure (grazing mosaics) produced by horses may be valuable in its own right, for instance by favouring key invertebrates.

3. Horses may have been the traditional grazers in more areas than suspected (eg. meadows associated with inns, such as Duke of York meadow). Prior to the internal combustion engine horses were a main source of transport and labour - even more so prior to the advent of the railways.

4. Perceived problems with horse grazing may be not because of the animals themselves, but because they are run in different ways from sheep and cattle.

If the last is true, then a great many species-rich grasslands could be managed more easily and effectively by placing appropriate controls on the way horses and ponies are used. Here, we report on a study which attempts to answer the key questions of potential damage and its avoidance for one particular type of species-rich lowland grassland.

2.3 Scope of this report

The study reported on here was commissioned by the Lowlands Team of the Nature Conservancy Council for England (English Nature) in April 1995. The major aims of this study are to examine the effects of horse grazing on the most widespread type of neutral (mesotrophic) grassland community in England. The need for such a study has been outlined above, but it was made more urgent by the widespread and conflicting opinions on the effects of horse grazing, coupled with a lack of quantitative data on its effects on more than a very narrow range of grassland types. Aside from studies coordinated by Putman (eg Pratt *et al* 1985, Putman *et al* 1987, 1991) in the New Forest and elsewhere, there have been very few quantitative studies contrasting the effects of horses with other stock on species-rich grasslands in Europe (but see Bioscan 1995).

The most relevant studies to the effects horse grazing on species rich grasslands have covered selection behaviour in controlled conditions (eg Marinier and Alexander 1991), studies of horses grazing alone in simpler (species-poor) or artificially created grasslands in north-west Europe (eg Archer 1973, Odberg and Francis-Smith 1976, 1977) and studies of horses and/or ponies grazing with cattle on a variety of grassland types including acid grass and heathland mosaics (eg Pratt *et al* 1985, Putman *et al* 1987) and mesotrophic grasslands (Putman *et al* 1991).

The main finding of these studies has been that horses grazing alone or where overall grazing pressure is heavy tend to generate a mosaic of closely-cropped areas and taller "latrine" areas where the animals dung and urinate. The main mechanism for this is that horses tend to avoid grazing where they have dunged: the latrine areas in consequence of low grazing pressure and/or fertilisation become tall, rank and often poor in species. Even when mixed grazing can partially mitigate this, the latrine areas tend to reappear year after year (Putman *et al* 1987).

This would suggest that horse grazing is likely to damage species-rich grasslands. However, observations on chalk grasslands of varying history in Berkshire grazed by equids (horses, donkeys and mules) over six years from 1989 to 1995 showed that overall diversity and ancient grassland indicator species were maintained or increased under equid grazing (Bioscan 1995).

In conclusion, the behavioural reasons for damage by horse grazing are known, and in at least one grassland type it is possible to use equid grazing without causing this damage. However, the means of avoiding damage and the knowledge of whether or not it can be avoided in the neutral grasslands which include some of the scarcest grasslands of value in Britain, are unknown except in anecdotal terms.

The study is based on observations of vegetation corresponding to MG5 grassland (*Centaurea nigra-Cynosurus cristatus* grassland - Rodwell 1992) within Worcestershire in England. The vegetation types studied and geographical range were restricted to provide a manageable data set which at the same time is likely to be as representative as possible of species-rich lowland neutral grasslands. Amongst the scarce resource of species-rich neutral grasslands, MG5 is one of the most widespread in England, and Worcestershire contains the best surviving range and concentration of sites of any county.

The report describes the methods used for site selection, data gathering and analysis. Results are then presented and discussed in relation to the following key questions.

1 Do observations made in 1995 show any difference between sites with a history of horse grazing and those grazed by cattle?

2 Are observed differences better explained by other management details such as grazing intensity, grazing season and hay cutting?

3 Do any previous observations on the same sites concur with the patterns shown by the 1995 observations?

4 As a result, what practical guidance can be given as to whether horses should be used or not? If horses are used, how should their grazing regime be managed?

3 Methods

3.1 Site selection

An initial selection of sites was made in discussion with English Nature staff, which was further refined as the study progressed. Some sites chosen at the start were not used because they had changed due to factors other than grazing species, or because the vegetation was not within the range of MG5 grassland. Other sites were brought in to replace them from a reserve list. The sites studied finally comprised twenty, fulfilling the following requirements.

1 They contained typical representatives of MG5 vegetation, of one or more of the three subcommunities.

2 Recognisable homogeneous blocks of vegetation could be found within which to place samples.

3 Past management was known, and known to be consistent. Where it was possible to discover such details, confounding factors such as regular dung removal or spreading were avoided.

4 Sites containing several fields with differing management and/or subcommunities were favoured.

5 As far as possible, only long-established grassland sites were chosen. For instance, fields with evidence of steam-ploughing were avoided because they may still be in a process of natural successional change.

6 Sites with previous vegetation data were favoured.

In addition, sites were chosen to provide replicates of horse grazing as compared with cattle grazing, covering three grazing intensities (light, medium and heavy) and whether or not a hay cut was taken. Full definitions of these factors are given in Appendix 1. As shown in Table 1, a complete balance was not feasible, mainly because not all types of management are carried out in practice.

These can be summarised as follows: although all are simple consequences of stock management, they introduce an inevitable bias and are therefore emphasised here. The importance or otherwise of such bias is examined in the analysis.

1 If an unimproved field is grazed heavily, it is unlikely to produce enough grass for a hay cut to be worthwhile as well.

2 Horses are often allowed to graze heavily, cattle hardly ever are.

3 More fields are grazed moderately, whatever the other circumstances, because this is the "sensible" stock management aside from what is required for a nature reserve.

Table 1: Summary of key treatments sampled

Horse/Cattle	Intensity	Hay cut	Number of fields
Horse (22 fields)	Light (3)	Hay	2
		No hay	1
	Medium (11)	Hay	3
		No hay	8
	Heavy (8)	Hay	0
		No hay	8
Cattle (16 fields)	Light (3)	Hay	2
		No hay	1
	Medium (12)	Hay	5
		No hay	7
	Heavy (1)	Hay	0
		No hay	1

In consequence, the effects of heavy cattle grazing, and the effects of light grazing whether or not hay is cut, will inevitably be judged from the condition of very few fields. In deciding what the effects are in general, it is the number of fields (at different and independent sites) which is important, not the number of quadrats.

All sites were sampled between mid-May and early July 1995. The distribution of sites used is shown in Figure 1, numbered according to the order of sampling. Site names are shown in Table 2, which cross references to Figure 1.

Table 2: Sites and fields sampled as shown in Figure 1		
Site number (Figure 1)	**Site name**	**Field reference from English Nature or original recorder's site card**
1	Upper Beanhall Farm	(Rookery Cottage) Meadows. North field (no. 60)
1	Upper Beanhall Farm	(Rookery Cottage) Meadows. South field (no. 59)
2	Portway Farm Meadows	North Field (no. 554)
2	Portway Farm Meadows	South Field (no. 552)
3	Duke of York Meadow	Flatter area only sampled
4	Rye Street Meadows East field	Area A
4	Rye Street Meadows West field	Areas C & D
5	Trickses Hole Meadow series A	Field 18/44
5	Trickses Hole Meadow series B	Field 18/44 area with *Succisa/Stachys*
5	Trickses Hole Meadow series C	Field 18/38
5	Trickses Hole Meadow series D	Field 18/38 area with *Succisa*
6	Napleton Meadows	Whole site
7	Poolhay Meadows	Field a
8	Penorchard Series A	Field 4/19
8	Penorchard Series B	Field 4/18 MG5 area
8	Penorchard Series C	Field 4/16 short-grazed phase
8	Penorchard Series D	Field 4/16 tall horse-latrine phase
8A	Penorchard (Spring Farm) series A	Field 3/7
8A	Penorchard (Spring Farm) series B	Field 3/22
9	Romsley Manor Farm Meadows Series A	Field 59/104
9	Romsley Manor Farm Meadows Series B	Field 59/108
9	Romsley Manor Farm Meadows Series C	Field 59/128
9	Romsley Manor Farm Meadows Series D	Field 59/127
10	Hurst Farm Meadow	Heavily grazed and poached west end
10	Hurst Farm Meadow	Lightly grazed east end
11	Fox Inn Meadow Series A	Field 2/78
11	Fox Inn Meadow Series B	Field 2/2a south of old drain
12	Leigh Brook Valley	Field 29/34
13	Hawthorn Bush Meadows	Field 604
14	Buckeridge Meadows	Field 510
15	Huntsfield Farm Pasture	Field 588

Table 2: Sites and fields sampled as shown in Figure 1

Site number (Figure 1)	Site name	Field reference from English Nature or original recorder's site card
16	Brotheridge Green Meadows	Field 11/13
17	Feckenham Forest (Parson's piece)	Area with conspicuous *Lotus corniculatus*
17	Feckenham Forest (Parson's piece)	Area with conspicuous *Potentilla erecta*
18	Berry Mound Pasture series A	Field immediately south of 31/34
18	Berry Mound Pasture series D	Field 31/38
19	Lords Wood Meadows	Series A (Slope in field 20/25)
19	Lords Wood Meadows	Series B (Northeast part of field 20/24)
19	Lords Wood Meadows	Series C (Slope south of series B)

3.2 Site environmental factors

In addition to the key factors for investigation summarised in Table 1 above, a number of "environmental" variables were recorded for each site and/or quadrat. These are defined in full in Appendix 1 and summarised here according to three categories.

Management variables include the three critical factors (species of stock, grazing intensity and hay cut) above and other variables which might be expected to have a direct effect on species composition and to be easily manipulated for nature conservation management. The additional ones are the use of a winter or summer rest period in addition to any period when a field is "put up" for hay.

Other biological variables which may have a direct effect but are more likely to be expressions of other management factors or unmeasured environmental variables, or are not amenable to manipulation. Such variables were the time for which a field had received particular management, vegetation height, height range, the amount of bare ground and previous year's litter, and the occurrence of "latrine" areas. Also included here was the total area of grassland belonging to the same community known at a site, which may cause species-area effects in grassland composition and species range (Gibson 1986).

Abiotic variables which, in this study, might affect vegetation and bias the results, but are not amenable to manipulation and could confound apparent effects of more "interesting" variables. These variables were grid easting, grid northing and altitude above sea level, which are likely to correlate with underlying causal variables such as soil types and microclimatic factors.

3.3 Quadrat locations

Once a patch of apparently homogeneous MG5 vegetation had been identified, the following standard procedure was adopted. The system is designed to give a good approximation to a random distribution of quadrats within a patch without the need to grid-survey each site to locate random positions.

1. Pick a random position within the patch from a pair of random distances, walked at right angles into the patch. This becomes the starting point for a random walk.

2. Pick a random distance and a random angle (compass direction from 1 to 8 (north round clockwise to north-west).

3. Travel at this angle for the indicated distance. If an edge is encountered, bounce off the edge as if bouncing light off a mirror.

4. The point found becomes the south-west corner of a quadrat.

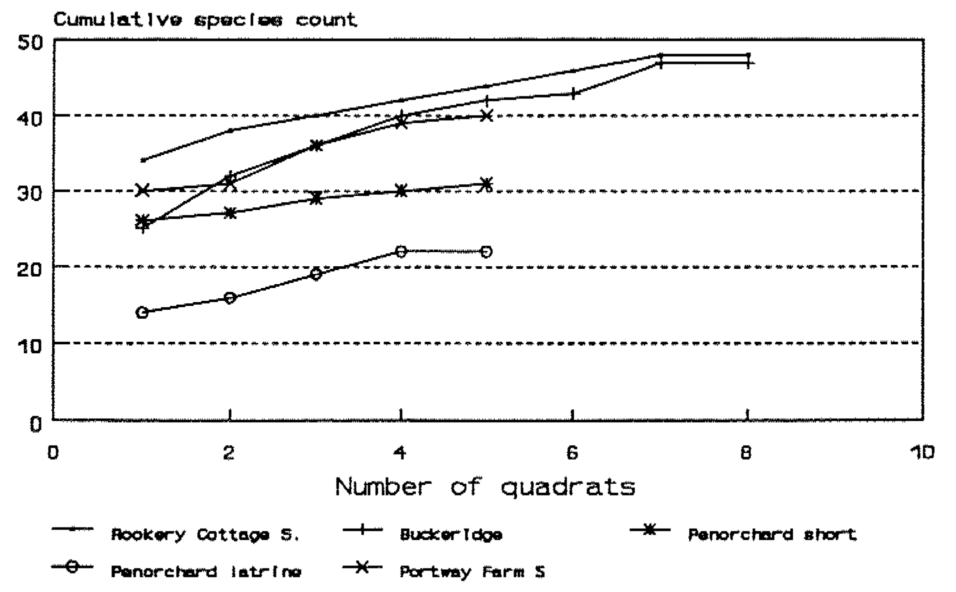
5. After recording the quadrat, pick another random angle and distance to find the next quadrat from the last recorded.

6. Repeat until the desired number of quadrats have been recorded.

7 No quadrat may lie within two metres of another (because of possible interference effects from recording the first one). Should this happen, the random walk continues, ignoring the "illegal" position.

A minimum of five quadrats was recorded in each patch. If there appeared to be continuous variation between quadrats greater than could be described from five quadrats, up to eight were recorded. Examples of the resulting species accumulation curves, shown in the order in which quadrats were taken within each site, are shown in Text Figure 1 below. The examples are chosen to cover the full range of variation in diversity and species distributions encountered. They show that almost all the variation in species composition within a patch studied was encompassed in the sample.

Text Figure 1
Examples of species accumulation curves



3.4 Quadrat recording and data storage

The methods used for recording and storage were developed in 1984 for a long-term research project at Wytham, Oxford. They are described here in full so that the system can be used by others if desired. Bioscan has found the method to be useful and flexible in a variety of grassland and mire vegetation.

The quadrat used was a 1m square divided by fixed wires into 100 cells of 10 x 10cm square. Four such cells were regarded as a unit for recording, giving 25 20 x 20cm cells. These were numbered as shown in Table 3 below. The bottom left cell is the southwest corner of a quadrat.

Table 3. Cell position numbers in a 1m square quadrat

5	10	15	20	25
4	9	14	19	24
3	8	13	18	23
2	7	12	17	22
1	6	11	16	21

On determining a quadrat position, the following sequence of records was made.

1. Three height estimates using a 30cm diameter dropped disc, to the nearest centimetre, positioned separately in a metre square to avoid interference.

2. Place the quadrat, on the ground if the vegetation was short enough to avoid disturbing the lie of the vegetation, otherwise on adjustable stilts placed at the quadrat corners.

3. Make a list of all vascular plants with above-ground parts present in each 20x20cm cell, on a standard data sheet with 25 columns (Appendix 2).

4. Estimate the amount of visible bare ground and litter judged to be remaining from the previous year's growth, each to the nearest 1% (the wired division into 100 cells aids this).

The purpose of using numbered cells is to preserve positional information. Data are stored and retrieved in a manner which allows future analysis at different quadrat scales if required, developed by the author with TA Watt and the late HC Dawkins in 1983-4.

In data storage each species distribution in a quadrat is stored (using a BASIC program) as a decimal integer. For instance, suppose the distribution of *Briza media* in a quadrat was as shown in Table 4 (present in the fifteen numbered squares).

Table 4. Hypothetical distribution of *Briza media* in a quadrat

	10	15	20	
	9	14	19	24
	8			23
	7	12	17	22
			16	21

This distribution can equally well be represented by a string of 0s (for absence) and 1s (presence), placed in the order shown in Table 3 from left to right (reading each column from the bottom up), which in this case would be:

0000001111010111101111110, or the binary number 1111010111101111110

Converted to decimal notation, this is the integer 503,768. This integer is stored, and translated as necessary on retrieval.

The result is to allow the storage of a very large amount of data in a small space. Otherwise, the amount of space required to preserve positional information grows at a rate which is prohibitive even with modern computer systems.

The analyses described in this report are based on the simpler summary of cell frequency in a square metre, ie 15 in the example given above. Full data are given in the Annex volume to this report and have also been copied in electronic format to English Nature.

3.5 Data analysis

Data analyses carried out are described below in the order in which they were done. The order as well as the nature of the analysis is important because it was designed to avoid formal statistical and probability problems as far as possible. These are pointed out where appropriate.

1 Dummy ("passive") NVC samples

Since the point of the study was to examine the effects of management on MG5 grasslands, it was important to relate the results to the NVC. Clearly, different recording methods were used in the NVC to those in this study, but the following translation process has proved adequate in other Bioscan studies and was adopted here. Quadrats recorded by cells almost invariably key to the same NVC community as equivalent DOMIN data. However, there are limits to interpretation which arise directly from the difference between methods. Basically a widespread but sparse species which has low cover will have a low NVC cover score but a high cell frequency (the method used here). Likewise a robust, tussocky species can have a high NVC cover but be present in relatively few cells. To make a translation the following procedure was carried out:

1 Select all species in the NVC tables for MG5 with a constancy of III or more in any subcommunity. Then perform the remaining steps separately for each of the three subcommunities.

2 If a species has constancy V and a Domin cover value of 7 or more, it is assumed to be present in all 25 cells in the dummy sample.

3 For species with lesser constancy or cover, the "cell count" is found by:

(Constancy/5) x (Domin/10) x 25.

The dummy samples do not influence the multivariate analyses described below but can be positioned directly in relation to the real samples from this study. The closer a quadrat is to a NVC dummy sample, the more similar it is to it.

2 DECORANA

DECORANA (also called DCA) stands for detrended correspondence analysis, a standard ordination method originally developed by MO Hill (1979). It describes vegetation in terms of the most important independent patterns (axes) of variability in species composition between samples (here quadrats). By itself, it cannot identify the causes of variability.

Here, DCA was used to explore the data structure and check for anomalies which might suggest the need for data transformation, exclusion of outlier samples or species, or any other modifications.

Using the package CANOCO 3.1 (ter Braak 1987-1992), the environmental variables were then superimposed on the DCA ordination to provide a pictorial check of their likely influence.

Neither of these operations can test the influence of management: they are merely data exploration techniques used to check that the data structure was suitable for subsequent analyses, which used DCCA (detrended canonical correspondence analysis) to test the influence of management.

3 DCCA (detrended canonical correspondence analysis) 1 - testing the adequacy of the data set

Strictly, the sites chosen in this study are not statistically independent of each other. Sources of likely bias include the concentration of horse grazing on the urban fringe, clustering of unimproved sites in areas where the accidents of survival correlate with farming practice, and many other possibilities. Properly, the effects of management can only be tested by an experimental system which would be impossible in practice.

In such circumstances, sites are "blocks" in the statistical sense. In traditional statistics such as parametric analyses of variance, each block would need to contain all treatments and combinations. CANOCO 3.1 however does statistical tests of the effects of variables on vegetation by randomly swapping quadrats and environmental data, extracting an ordination statistic and repeating the process as many times as one wishes (termed Monte Carlo permutation). The permuted (random) ordination statistics (in CANOCO 3.1 an F-ratio) are then compared with the F-ratio from the real data. If the real F-ratio, for example, is larger than that obtained from any of 99 random permutations, the probability of it occurring by chance is a maximum of 0.01.

In the worst case, all variability found between sites would be biased and need to be removed. Only variation within sites, where there was more than one different treatment, would be usable in the statistical sense. In this study, this is unlikely to be true: many of the real effects of management would be discarded with the bias. However, performing the Monte Carlo tests on a design blocked on sites gives a very robust test of whether or not variation due to management is significant.

This test was therefore performed first: effects of the key variables of grazing species, intensity and hay cut were still significant at $p=0.01$ so the analysis proceeded to the next stage.

4 DCCA 2 - investigating the effects of key variables

The core of DCCA is a double ordination in which an ordination of species composition is constrained to devise the most likely relationship between the species composition data and linear combinations of the environmental variables. The following strategy was adopted to gain the best estimate of the relative importance of each key environmental variable and the way in which they affect species composition.

1 *Removal of covariable effects*

The position of the largest nearby city (Birmingham) and associated geology and topography suggest that most variation which could be explained by altitude, easting and northing was likely to be bias, not real management effects. The influence of these variables was therefore taken out of the analysis by using them as covariables in CANOCO. This strategy was adopted as the best practical way of maximising the amount of bias discarded without losing useful information.

2 *Stepwise choice of variables*

CANOCO allows the final estimate of relations between environmental variables and vegetation to be built up stepwise, for instance by first taking the variable with the greatest explanatory power and testing the significance of its effect, followed by repeating the process for each variable in turn. If the effect of a variable is significant, it is retained, otherwise it is left out of the model.

The sequence can be and was modified to take one further factor into account. As in all multivariate analyses, the effects of different variables may be linked. In such a case, it is better to test the variable with the simplest causal link first (e.g. grazing species in preference to sward height). In practice, this made no difference to the final form of the model because all variables with doubt as to their order eventually proved to have significant individual effects.

Variables were only included if they had an individual effect at a significance level of at least 0.01: this superficially "conservative" procedure is the correct one where a sequence of variables is being tested[1].

5 Species, categories and other attributes

By testing ordinations and environmental variables, CANOCO identifies significant effects of variables of interest and plant species and species groups associated with their effects. It is also of interest to demonstrate these effects with reference to simpler aspects of the vegetation, such as species richness, abundance of mesotrophic grassland indicators and similar categories. Strictly, a probability level, and therefore significance tests, cannot be assigned to such effects because testing them is not independent of the statistical tests already carried out by CANOCO. However, if for instance there are many fewer indicator species in heavy grazed sites, this means that such indicators have made an important contribution to the high significance level shown by CANOCO for the effects of grazing intensity on the vegetation. Demonstration of the effects on such categories is therefore illustrative, not formal, but is essential for practical management decisions.

Attributes of the vegetation chosen for such illustration were as follows.

1. Species richness.

2. Life history attributes on a classification originally developed in Grime *et al* (1988).

3. Indicator species scores as supplied to Bioscan by English Nature (Rowell and Robertson 1994), in which species are scored from 1 to 8 with increasing strength of restriction to unimproved mesotrophic grasslands.

4. Indicators of the main axes of environmental influence as derived from CANOCO, taking species strongly biased towards environmental variables (such as grazing intensity) as indicators of their effects.

Where species are grouped in this analysis, such as by life history attributes, the results have been expressed, except where otherwise indicated, as the total number of cell occurrences for all members of the group, i.e. the possible score is more than 25 cells.

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1 For instance, if one does a sequence of 20 tests, an average of one of them would be expected to be "significant" at the p=0.05 (1 in 20) level by chance alone.