

Research and Development

Final Project Report

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Project title

Sustainable livestock systems to conserve key purple moor-grass/rush pasture species.

MAFF project code

BD1318

Contractor organisation and location

Institute of Grassland and Environmental Research,
North Wyke Research Station,
Okehampton,
Devon.

Total MAFF project costs

£ 146 k

Project start date

01/04/97

Project end date

30/11/00

Executive summary (maximum 2 sides A4)

The project aims were to identify management and ecological characteristics of purple moor grass and rush pasture communities of high nature conservation value, to quantify agronomic constraints imposed by maintaining these habitats and identify criteria on which to base restoration of such communities. Twenty one sites were selected, 11 of high nature conservation value, 7 degraded by past agricultural improvement and 3 that had been degraded by lack of management. Eight target NVC communities were represented. Botanical composition, sward structure, soil chemistry and agronomic data were collected at each site.

Management, agronomic output and agronomic constraints for livestock

Cattle grazed all the sites of high nature conservation value, all were grazed during July and August. The start, end and overall duration of the grazing season varied by several weeks between years on most sites. Average weight of livestock carried by sites of high value was c. 25 percent of that achievable from grazed agricultural pastures. Average stocking rate for the high value sites was equivalent to c. 0.4 livestock units (550 kg) /ha per year and ranged from c. 0.2 – 0.8 livestock units /ha per year. The average daily liveweight gain of growing cattle on sites of high nature conservation value was 0.52 kg. Growth rates were particularly poor from mid summer onwards. The estimated average utilized metabolizable energy output achieved from sites of high nature conservation value was 13.6 GJ /ha per year, which equates to c 25 percent of the output that might be expected from grazed agricultural pastures.

No significant relationships were found between stocking rate and sward state of the purple moor grass/rush pasture communities. The presence of mosaics of other vegetation types including drier grassland and scrub at most sites made estimation of the area that was grazed imprecise. Differences in the extent and severity of grazing on these other vegetation types were probable factors influencing the poor relationship between stocking rate and grassland structure. It is concluded that management agreements to maintain good quality sites should be based on sward structural criteria, such as mean sward surface height and/or the proportion of short sward in mid to late summer, rather than on stocking rate. Grazing management agreements should aim to maintain mosaics of different vegetation types and a range of structure in the purple moor grass and rush pasture habitat.

Over 85 % of leaf samples of purple moor grass (*Molinia caerulea*) and the broad-leaved species had sub-optimal P contents for productive cattle. However, although generally sub-optimal in Ca and P content purple moor grass generally provided a satisfactory Ca: P ratio compared with the other grazed forages of these communities. Where broad-leaved and *Carex* species are abundant a supra optimal Ca:P ratio could increase the risk of trace element deficiency occurring. The K content of the forage was generally sub-

optimal for livestock and the severity of deficiency increased during late summer/autumn. Any advantages that the more species-rich purple moor grass and rush pastures offer in terms of supplying trace elements are likely to be offset by other mineral imbalances, such as wide Ca:P ratios and/or low intakes of specific components that would supply adequate trace element requirements. Thus species-richness, *per se*, may not replace the need for some mineral supplementation.

The estimated metabolizable energy (ME) values of leaf samples of purple moor grass in June-July were c. 10% below the value of leaf material obtained from intensively grazed agricultural pastures. The ME value of the purple moor grass declined by c. 20 % between June and October; this decline is unlikely to be offset by higher ME values of other forages due to their low potential intake.

Nutrient redistribution via dung

No significant differences in nutrient content were found between dung from purple moor grass/rush pasture sites where cattle had free access to improved/fertilized pastures and/or mineral licks compared with sites where such “external” sources of nutrients were absent. The risk to the nature conservation value of a site from nutrient transfer via grazing livestock, and in particular phosphorus transfer, within free range grazing systems appears to be small.

Ecological studies

Past agricultural improvement and current abandonment of grazing led to declines in species number and changes in the composition of purple moor grass and rush pasture communities. Loss of biodiversity with agricultural improvement was linked to eutrophication, while lack of grazing led to increases in rank-growing species.

Increased diversity at good quality sites was achieved by packing a greater number of species into the small area encompassed by a quadrat. This suggests fine-scale heterogeneity and low soil nutrient status are important in maintaining diversity. The greater between-site similarity of the good quality sites than of the degraded sites shows that the good quality sites have many species in common. This emphasises the fact that these sites represent a vegetation type that has evolved uniquely in response to common edaphic and hydrological conditions of the sites. Disruption of these communities by degradation causes the formation of more transient communities that will probably be less stable. The changes in species’ abundances between good quality and degraded sites suggests some species could be used as indicators of good quality sites, or, alternatively, to detect if sites are becoming degraded. The classic species of purple moor grass and rush pasture, *M. caerulea*, *Juncus articulatus*, *J. acutifloris* and *Cirsium dissectum*, are therefore not good indicator species. Several sedges, including *Carex flacca*, *C. pulicaris*, and *C. hostiana*, may be better indicators.

Vegetation differences among the good quality sites were determined by some edaphic variables, and, to a large extent, by grazing management. During this study all good quality sites maintained plant communities of high conservation value. Thus the range of grazing regimes were acceptable. Changes in different aspects of the grazing regime would have a range of effects on species composition and the information presented here may be used to guide changes in grazing to achieve certain objectives. However, further work over a greater number of good quality sites is needed to produce more definitive guidelines.

Three key plant species of purple moor grass and rush pastures considered in this study - wavy St. Johns-wort *Hypericum undulatum*, whorled caraway *Carum verticillatum* and meadow thistle *Cirsium dissectum* - showed differing habitat requirements. These related to moisture, vegetation height and soil nutrients, but responses to management were not detected. Full autecological studies of these species, especially in relation to grazing management, are needed. However, these results emphasise that conservation of purple moor grass and rush pastures should consider the different requirements of constituent species.

Purple moor grass and rush pastures comprise a range of NVC grassland categories; scrub vegetation is also important. This is reflected in the different habitat requirements of the key species. There is, therefore, a need to consider the role of the different vegetation types in determining the unique biodiversity status of purple moor grass and rush pastures. The management requirements of these different vegetation types and of individual key species require further study. Site size was a major determinant of whether a site had a population of the marsh fritillary *Eurodryas aurinia*. Abundance and size of the food plant, *Succisa pratensis*, and sward height determine habitat quality. More data are needed on the responses of the butterfly and its food plant to grazing management.

National databases of species’ distributions can be used to produce lists of species that are typical of purple moor grass and rush pastures and can be used to target restoration and management of this habitat. NVC mire communities M16 and M22-M26 provide one source of typical species, but this is not precise because these lists include more generalist species. The data from this project gave a potentially more accurate list of typical species that could be used to map areas of Britain where these species co-occur. This list could help target areas for restoration of purple moor grass rush pastures.

Vegetation maps of Britain derived from the CS90 survey can be used to target restoration at more local scales. Known purple moor grass rush pasture sites differed in the vegetation types which surrounded each site. This information can help determine the ‘landscape quality’ of a site, i.e. the amount of similar vegetation nearby which can act as a source of colonists, or sites to maintain a metapopulation. Similar vegetation types are also more amenable to conversion to purple moor grass rush pasture and so such maps also provide information to help with planning of restoration.

Geographic Information Systems can be used to collate spatial data relating to the distribution, status and management and restoration of purple moor grass rush pastures. This can be used to coordinate actions to meet BAP aims, such as positioning of restoration sites to achieve maximum benefit.

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Edaphic conditions for restoration

Achievement of low soil P availability was found to be the primary criterion for successful restoration of purple moor grass communities of high nature conservation value.

Scientific report (maximum 20 sides A4)

Scientific Objectives

1. Identify the extent and severity of nutritional deficiencies of forages from purple moor grass (*Molinia caerulea*) and rush pastures for productive livestock and examine relationships between management and conservation of key species.
2. Evaluate livestock performance and output from different purple moor grass and rush pastures.
3. Identify whether the use of either mineral supplements or free-range grazing could initiate undesirable vegetational changes to purple moor grass and rush pasture communities.
4. Develop a GIS base for targeting management and restoration effort.
5. Develop criteria for achieving sustainable integrated livestock farming systems that conserve key species of species-rich purple moor grass and rush pasture associations.
6. Develop edaphic criteria for selection of restoration sites.
7. Provide management guidelines for site preparation and the establishment of key plant species.

Scientific approaches

Sites

Eleven purple moor grass and rush pasture sites of high wildlife value, numbered 1-11 from now on, and ten degraded sites, which lacked some or all key purple moor grass and rush pasture species were selected in England and Wales in 1997. The degraded sites, numbered 12 – 18, all had been previously agriculturally improved having received fertilizer applications in the past. Sites 19-21 were considered degraded because they were dominated by tall tussocky purple moor grass (*Molinia caerulea*) due to either a lack of grazing (as at site 19) and/or managed by periodic burning (site 20) or under grazing with sheep and deer (site 21).

Agronomic studies

Management details, numbers, type and breed of livestock and duration of grazing, whether mineral supplements were provided and any veterinary problems at pasture were obtained for each of the eleven sites of high nature conservation value in each of the 3 years, 1997-1999. Growth rates of cattle were obtained from a sub-set of these sites each year. In July and September each year sward surface heights were measured at 50–100 random locations and herbage standing crop was estimated by cutting 5 randomly placed 0.5 m² quadrats per site at ground level. The herbage samples were analysed for dry matter, N, P, K, Ca, Mg and Na content. Pluck samples of the major species or combination of species (purple moor grass, other grasses, forbs, shrub species) that were observed to be grazed by livestock were hand plucked from all sites on 2 occasions during the grazing period each year and analysed for pepsin cellulase digestibility, N, P, K, Ca, Mg and Na content.

Ecological studies

Percentage cover of all higher plant species was estimated within 6 randomly placed 2m x 2m quadrats in July/August 1997 at all 21 sites and again in July/August 1999 at only the 11 sites of high wildlife value. In August 1998 sites containing the key species whorled caraway *Carum verticillatum* and wavy St John's wort *Hypericum undulatum* were visited. Quadrats were placed around all colonies of these two species and cover of higher plant species was estimated. Leaf length and plant height and diameter of devil's bit scabious *Succisa pratensis* were recorded on a random selection of 100 plants at each site during August in 1997 and 1998 and in October 1998. Soil samples of the 0-15 and 15-30 cm depth horizons were taken from the vicinity of each botanical survey quadrat location at all 21 sites in 1997 and analysed for: pH_(H2O), bulk density, total carbon (C), total nitrogen (N), nitrate (NO₃) and ammonium (NH₄), total phosphorus (P), Olsen P, exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na). Vegetation and soil data were analysed by a variety of ordination techniques, using CANOCO software. Site quadrat data were analysed using the MATCH programme in order to assess botanical composition in terms of the NVC classification.

Management effects on nutrient inputs to sites

Nutrient returns/inputs via dung were examined at sites where livestock had free access to agriculturally improved or semi-improved pastures or were set-stocked, with or without the provision of mineral supplementation. Dung distribution was measured by recording the number of dung pats within each pace along two randomly selected 1m wide transects across each site on 2-3 sampling occasions during the grazing season in years 2 and 3. On each sampling occasion, in addition to the dung pat counts five samples of fresh dung (< 24 hrs old) were collected at each site for chemical analysis of N, P, K, Ca, Mg and Na content. The transect data were tested for randomness, after Draper and Smith (1981).

GIS study

Site data and maps were mounted on an ArcView GIS. Two methods were used to derive national maps of potential purple moor grass and rush pasture vegetation for targeting restoration effort. NVC M16 and M22-M26 communities and site data were used to derive purple moor grass and rush pasture species lists. Potential distributions of purple moor grass and rush pasture sites were derived by co-occurrence mapping of distribution of constituent species from BRC distribution maps. ITE land cover classes were also ranked according to their affinity to purple moor grass and rush pastures and used to derive a probability map of distribution of these vegetation types. These land classes were also used to determine the degree of isolation of the survey sites from other purple moor grass and rush pastures.

Restoration experiments

Purple moor grass and rush pasture restoration experiments were sited on an agriculturally semi-improved species-poor/grass dominated rush pasture. Field experiments designed to identify ways of depleting soil nutrient amounts in order to allow key purple moor grass and rush pasture species to re-establish and persist were conducted. Treatments included repeated cutting and removal of vegetation, cultivation, fallowing, topsoil removal and the addition of soil amendments to deplete soil nutrient availability.

Results

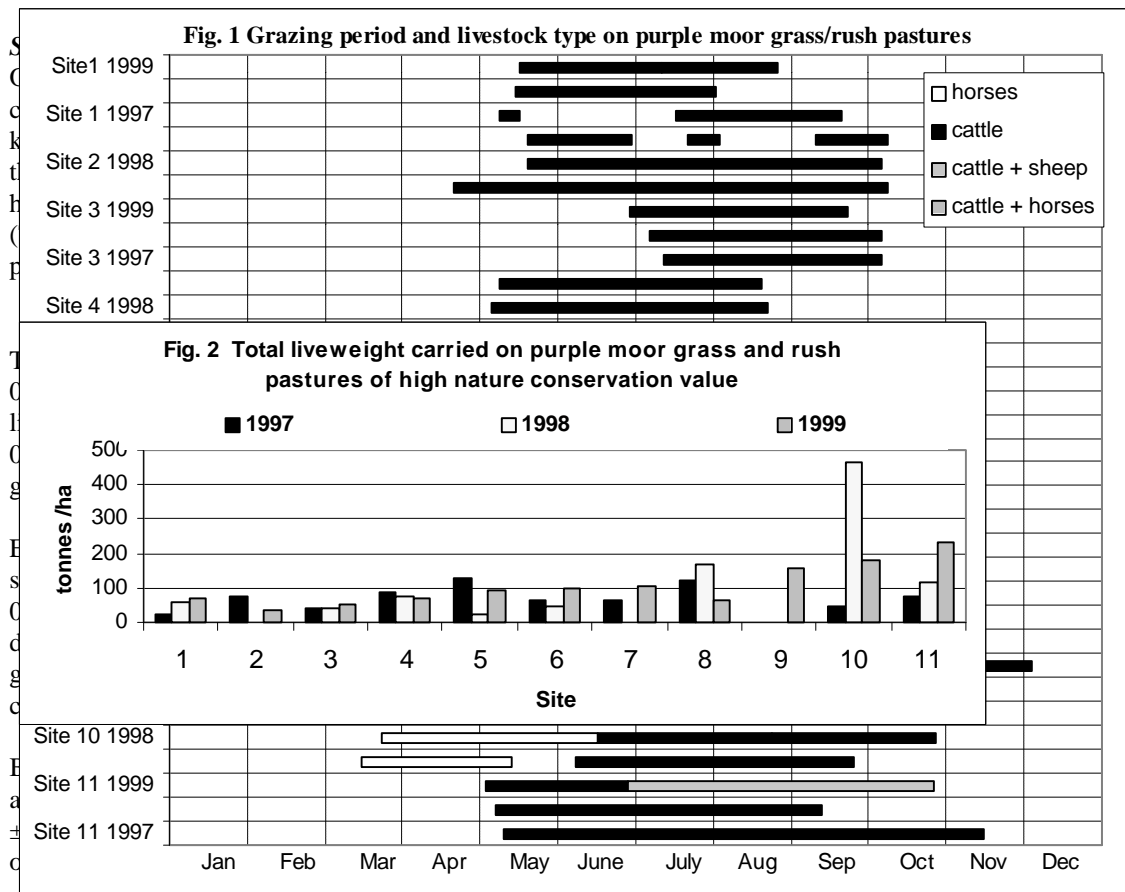
Liveweight carrying capacity of purple moor grass and rush pasture communities

Timing and duration of grazing and type of livestock

All eleven of the sites of high nature conservation value were grazed. The start and finish of grazing and the duration of the grazing season showed considerable variation (Fig. 1). Over the three study years grazing began in May on 45% of sites, in April on 21% and March on 12% of the sites. Winter grazing occurred on one site. Start of grazing varied by 2-6 weeks between years at some sites and was delayed until either June or July on two sites. Average duration of the grazing season was 142 ± 45.1 days per year for all sites. In comparison agriculturally improved or semi-improved permanent pastures on soils with impeded or poor drainage in the same region of south west UK, the average grazing season would be expected to be c. 175 days (Tallowin *et al.*, 1990).

Cattle grazed all the purple moor grass and rush pasture sites of high nature conservation value and all were grazed during July and August (Fig. 1). Two sites were also grazed by horses/ponies and sheep grazed one site in just one year of the study. Some of the sites were used as a strategic forage resource for store cattle, heifers or dry cows with different groups of animals being moved onto the site for c. 4-5 weeks at a time. Only cattle of more than 300 kg liveweight were used to graze the purple moor grass/rush pasture communities examined in this study.

Most purple moor grass/rush pasture sites that were nature reserves were set-stocked, having a fixed number of animals throughout the grazing season. Type of cattle breed varied both between sites and on some sites between years. Traditional breeds of cattle such as Welsh Black or Ruby Red Devon were used on three sites while on the remainder continental cross Friesian/Holstein and Hereford cross Friesian/Holstein store cattle or Friesian/Holstein heifers were used. Anecdotal information from farmers and site managers indicated that the variations in grazing management observed during this project were typical for these type of grasslands.



17 tonnes of liveweight was hectare for store cattle of 450 the same site. In comparison sil type was c. 300 tonnes per fertilizer nitrogen application re sites was, therefore, c. 25

fe value was equivalent to c. per year. The average daily onervation value was $0.52 \pm$ improved pastures during the

is found. Hereford x Friesian between July and September (c. presence of a large amount of tional value of purple moor ce in late summer. Data on

graze the purple moor grass (ME) was estimated to be 13.6 The estimated average UME l., 1990).

Where livestock had access to agriculturally improved or semi-improved neutral grassland they may have been able to compensate, to some extent, for deficiencies in nutritional value of the purple moor grass community. For example, at a hill/upland site in Wales

where c. 2/3 of the area was rank tussocky purple moor grass and 1/3 was semi-improved neutral grassland (MG6 type) cattle of > 300 kg liveweight achieved a growth rate of 0.7 ± 0.19 kg /day over the period May –August. Anecdotal evidence suggests that some farmers involved in managing purple moor grass communities appreciate that improved growth rates of cattle can be expected where there is also access to improved grass swards. The contention that grazing systems that allow free access between improved and unimproved pasture could allow nutrient transfer and eventual eutrophication of the unimproved grassland is examined in a separate section.

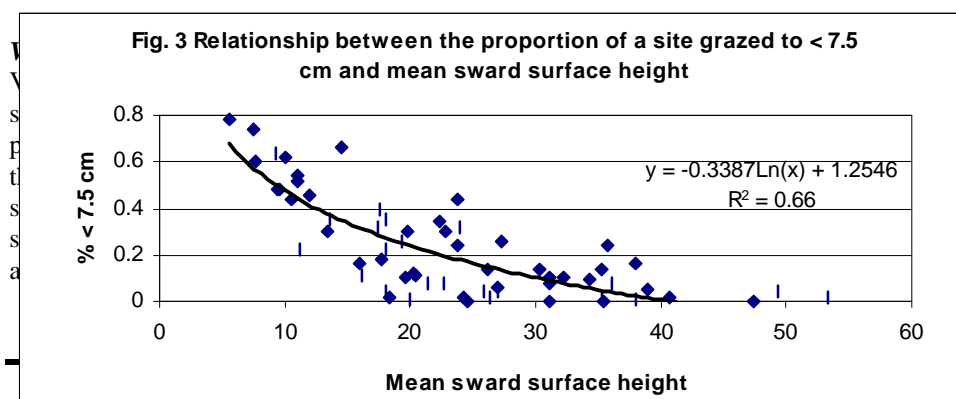
Grazing management and grassland sward height, structure and herbage mass

Table 1 shows the variation in mean sward surface height between sites and within sites both between years and within a year. The large standard errors about the mean values indicate that there was a considerable range in sward height at most sites of high nature conservation value. Although mean sward height appears to be a poor overall descriptor of the grazed structure of the purple moor grass/rush pasture swards there was, nevertheless, a significant relationship between the mean sward height value and the proportion of short grazed sward, with height values of < 7.5 cm (Fig. 3). For sites that had a mean sward surface height of > 20 cm many sites were found to have little or no short sward. Whereas, where sites had been grazed to a mean height of < 20 cm the proportion of short sward showed a significant logarithmic increase. These data indicate that a grazing management that maintains a mean sward surface height of 10 – 15 cm would create short sward conditions on 30-40% of the site area.

Table 1 Mean sward surface heights and standard errors of grazed purple moor grass and rush pastures of high nature conservation value

Site	July/August				September/October					
	1997	1998	1999	1999	1998	1999	1999	1999		
	mean	se	mean	se	mean	se	mean	se		
1	39.0	17.52	9.4	5.31	36.0	22.77	13.4	7.22	18.1	12.43
2	11.20	7.29	9.6	7.62	10.1	9.61	5.5	3.01	11.1	9.45
3	18.1	6.99	31.1	14.52	35.3	22.76	22.6	16.29	35.8	16.29
4	7.7	6.14	9.3	10.56	18.1	15.23	7.5	6.03	23.8	25.30
5	13.6	9.74	20.3	11.46	31.1	24.28	38.0	29.00	22.3	24.02
6	25.8	6.96	47.4	16.70	12.0	12.80	17.4	16.10	14.5	11.23
7	16.2	7.56	19.6	9.36	20.5	13.95	19.4	16.24	23.8	17.74
8	38.04	19.25	24.2	13.09	53.4	24.61	10.6	8.56	19.8	17.69
9	26.94	15.78	32.2	19.76	23.9	19.98	31.1	21.75	30.3	21.31
10	35.44	17.05	26.9	18.51	40.7	23.56	26.3	14.85	22.8	20.80
11	18.1	6.99	24.6	7.96	21.5	15.62	17.7	10.49	34.3	14.32

Data for all the purple moor grass/rush pasture sites of high nature conservation value were analysed together to identify any general relationships between stocking rate, duration of the grazing period or liveweight carried per hectare per year and either sward height or herbage mass. No significant correlations were found between any of the livestock variables and either herbage mass, the mean or median sward heights or the proportion of the sward with a surface height of <7.5-cm. The overall lack of relationship between stocking rate and sward state of the purple moor grass/rush pasture communities was associated with the presence of mosaics of other vegetation types, such as drier neutral grassland, dwarf shrub, scrub and woodland at most sites. These mosaics of different vegetation types made estimation of the area that was grazed particularly imprecise on many sites. Differences in the severity of grazing between the different components of the vegetation and differences in the proportion of each component at different sites probably accounted for much of the variation in sward state between sites and for the poor relationships between livestock numbers per hectare and grassland structure at a particular site. It is concluded, therefore, that management agreements to maintain the wildlife interests of purple moor grass/rush pastures should be based on sward structural criteria, such as mean sward surface height and/or the proportion of short sward in mid to late summer, rather than on stocking rate.



sward structure were characteristics of most management practice between years are controlled/uniform management regime. It is variation in management practice involving increase spatial structural heterogeneity within the future development of agri-environmental

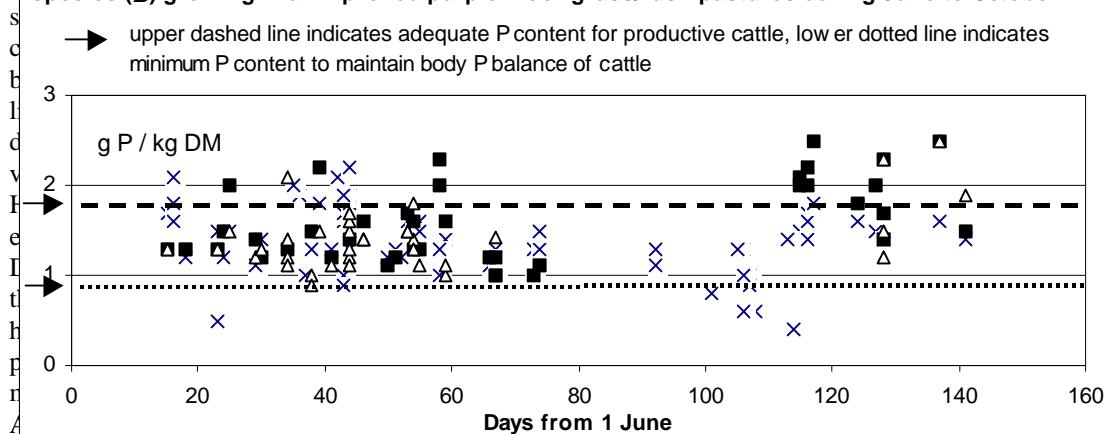
Mineral content of plucked leaf samples from purple moor grass and rush pasture communities

Calcium, phosphorus, potassium and sodium are the four most abundant mineral elements in livestock tissues. Their availability in forages is of major importance for the nutrition of ruminant livestock. Data on the content of these elements in plucked leaf samples of grazed species or mixtures of species were obtained at each purple moor grass and rush pasture site. These mineral content data are reviewed in relation to the requirements for ruminant livestock (Tallowin and Jefferson, 1999).

Seventy three percent of all leaf samples of purple moor grass had a Ca content below 2.0 g kg^{-1} of DM. No significant seasonal or year effects on Ca content were found. The overall mean Ca content for purple moor grass for all sites was $1.7 \pm 0.71 \text{ g kg}^{-1}$ of DM. No leaf samples of dicotyledonous species and only 17.5% of samples of *Carex* species had a Ca content $< 2.0 \text{ g kg}^{-1}$ of DM.

A calcium content of below *ca.* 2.0 g kg^{-1} DM would be sub-optimal for most productive ruminants given an *ad libitum* intake. Some cattle may be able to tolerate this apparent inadequacy but it would be too low for sheep, especially lactating ewes. The risk of deleterious effects due to calcium inadequacy appears to be low if livestock such as dry cows or store cattle have adequate phosphorus supplementation. Indeed there may be some benefit of including low-calcium forage in the feed ration of dry cows. There is now considerable evidence that a low-calcium diet in the later part of pregnancy can reduce the severity of parturient hypocalcaemia and the incidence of milk fever.

Fig. 4 Change in leaf phosphorus content of *M. caerulea* (X), *Carex* species (■) and dicotyledonous species (△) growing in unimproved purple moor grass/rush pastures during June to October



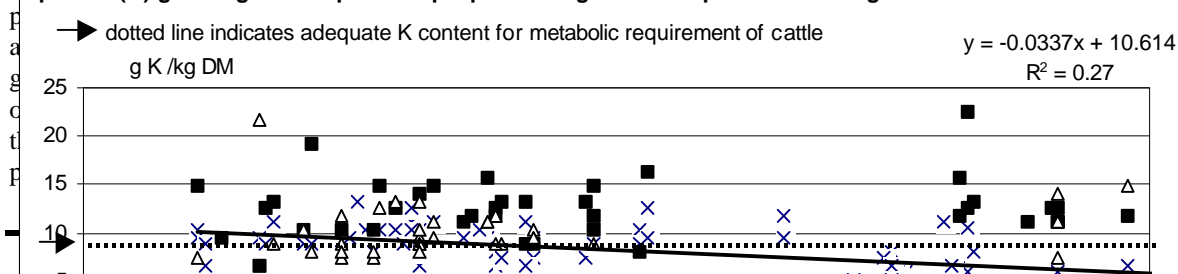
leaf samples from the *Carex* seasonal effect on forage P public requirement to maintain the diet of cattle (of $< 400 \text{ kg}$ contents below 1.5 g kg^{-1} DM the overall feed ration could deficiency in phosphorus supply. t likely to suffer detrimental with very low ($< 0.9 \text{ g kg}^{-1}$ adversely affected. In practice to avoid long-term effects on of mineral supplements with age is also low. Supplements

presence of adequate amounts of vitamin D_3 . There is, however, uncertainty over what constitutes an optimum Ca:P ratio, the general guidance being that a 1:1 to 2:1 ratio is safe. An unusually wide ratio can be as harmful as a deficiency of either mineral by inducing, for example, inadequate utilization of certain essential trace elements.

The overall mean Ca:P ratio for purple moor grass for all sites and sampling occasions was 1.3 ± 0.79 . Less than 10 % of leaf samples of purple moor grass had a C:P ratio that was either below 0.5 or above 2.5. More than 20 % of pluck leaf samples of *Carex* spp. and over 95% of the dicotyledonous leaf samples had C:P ratios in excess of 2.5, the dicots were generally well in excess of 2.5. Thus, although generally sub-optimal in Ca and P content for ruminant livestock purple moor grass generally provided a satisfactory Ca:P ratio compared with the other grazed components of the unimproved communities. Where dicotyledonous and *Carex* species are abundant a supra optimal Ca:P ratio could increase the risk of trace element deficiency occurring.

Intake and performance of cattle are unlikely to be constrained by forage nitrogen content, *per se.*, when it is in excess of 13 g kg^{-1} of dry matter. The average nitrogen contents of leaf samples of purple moor grass, *Carex* species and dicotyledonous species from the unimproved purple moor grass/rush pastures were 23.8 ± 4.27 , 22.2 ± 4.54 , $18.4 \pm 4.88 \text{ g kg}^{-1}$ DM, respectively. No significant change in nitrogen content for any of the sampled species or species groups were found between the mid-summer and autumn. Therefore it is unlikely that the nitrogen content of the forages in the purple moor grass/rush pastures would have affected voluntary intake. The nitrogen content of leaf samples of yorkshire fog (*Holcus lanatus*) and creeping bent (*Agrostis stolonifera*) from unfertilized semi-improved grassland adjacent to the purple moor grass/rush pastures sites was $29.2 \pm 8.82 \text{ g kg}^{-1}$ DM. The nitrogen content of laminae of perennial rye grass *Lolium perenne* from fertilized pastures is generally above 30 g kg^{-1} DM.

Fig. 5 Change in leaf potassium content of *M. caerulea* (X), *Carex* species (■) and dicotyledonous species (△) growing in unimproved purple moor grass/rush pastures during June to October



$3 \pm 0.0062 \text{ g kg}^{-1}$ DM for ruminant livestock samples of purple moor 12 g K kg^{-1} DM. Sub pastures vegetation and t was associated with structure and senescent

component. Adequate potassium intake is particularly important for young growing or lactating animals thus such livestock should not graze these types of community for more than a few weeks in early summer.

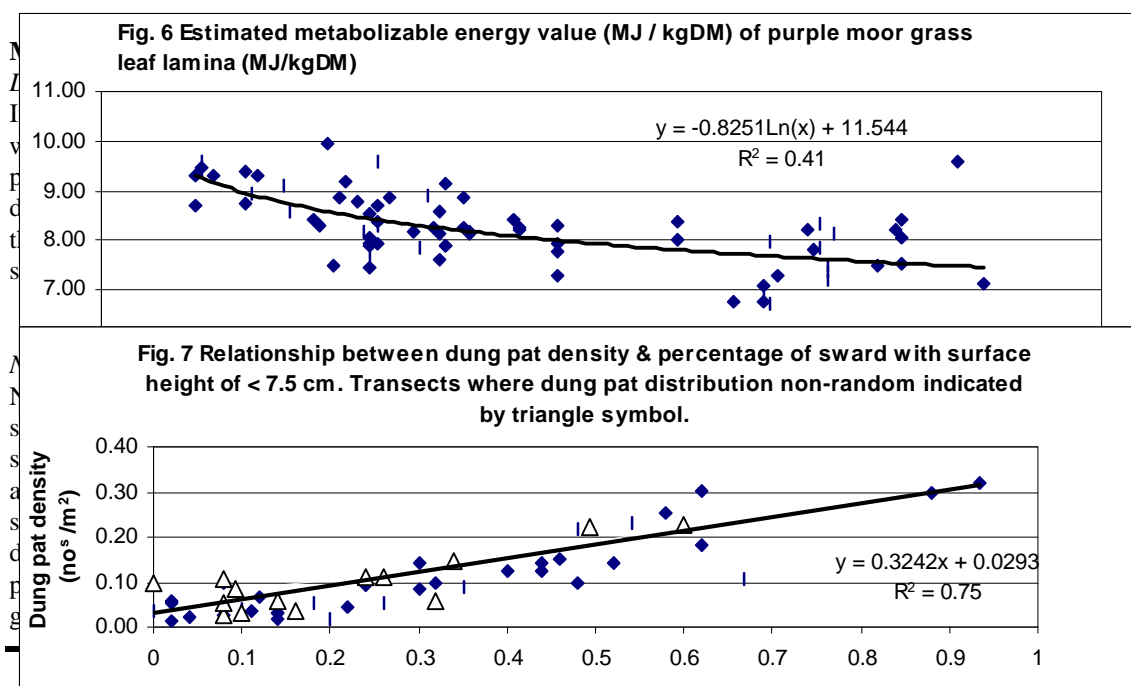
In general forages should contain 1.2-2.0 g of magnesium kg^{-1} DM to provide an adequate dietary concentration for all classes of productive ruminant livestock. Adequacy in the diet will depend, as with other minerals, on the digestibility of the forage and on intake level. Inadequacy in the diet incurs a risk of hypomagnesaemia, particularly in productive livestock. A circumstance where there is a risk of this condition is, for example, with suckler cows being outwintered on low planes of nutrition and especially during cold spells of weather and 2-8 weeks after calving. Over 50% of the plucked leaf samples of purple moor grass from the unimproved purple moor grass/rush pastures were sub optimal in magnesium content ($< 1.2 \text{ g Mg kg}^{-1}$ DM) for productive livestock. The magnesium content of the leaf samples of dicotyledonous species were generally ($> 90\%$) supra optimal. The risk of hypomagnesaemia occurring in late spring/summer calving suckler cows would appear to be low during the summer grazing season on the purple moor grass/rush pastures examined in this study.

A sodium content of $> 0.65 \text{ g kg}^{-1}$ DM appears to be adequate for the metabolic requirements of growing beef cattle of between 200 and 400 kg live weight. For dry and lactating cows values > 0.8 and $> 1.1 \text{ g kg}^{-1}$ DM in the diet, respectively, would be adequate. Higher sodium contents in the diet appear to be required for sheep ($> 2 \text{ g kg}^{-1}$ DM). Inadequacy in the diet can cause inappetence and reduced efficiency of feed utilization. For the purple moor grass/rush pastures examined in this study the sodium content of all the plucked leaf samples were adequate for cattle. However, over 35% of the purple moor grass samples and 10% of the samples from *Carex* species were sub optimal for sheep.

It might be contended that the more species-rich purple moor grass and rush pasture communities could offer advantages in terms of supplying trace elements, through specific differences in uptake resulting in enhanced foliar mineral concentrations compared with species-poor or monospecific intensively managed grassland. However, these advantages are likely to be offset by other mineral imbalances, such as wide Ca:P ratios and/or low intakes of specific components that would supply adequate trace element requirements. Thus species-richness, *per se*, may not replace the need for some mineral supplementation.

Estimated nutritional value of plucked leaf samples from purple moor grass and rush pasture communities

A logarithmic regression model provided the best fit to the estimated metabolizable energy (ME) values for plucked leaf samples of purple moor grass (Fig. 6). The nutritional value, as indicated by the estimated ME, declined ($p < 0.001$) by approximately 20%, from c. 9.5 to c. 7.5 megajoules /kg dry matter between 1 June and October. The decline in the nutritional value of purple moor grass during the June – July was probably related to the cessation in production of new leaves and the onset of senescence in the first series of leaves that were produced at the beginning of the growing season in May. In contrast there were no apparent declines in the ME of plucked leaf samples of *Carex* species or dicotyledonous species growing on the purple moor grass/rush pasture sites. The ME values of the leaf samples of purple moor grass in June-July were approximately 10% below the value of leaf material obtained from intensively grazed and fertilized permanent pasture (Tallowin *et al.*, 1990). It might be contended that the decline in ME of purple moor grass over the mid-summer to autumn period could be buffered to some extent by the maintenance of higher ME values of the other major components of purple moor grass and rush pasture communities. However, any “buffering effect” of particular forages, such as dicotyledonous species with high late summer ME values, could be offset by low availability/abundance leading to low intakes of these components of purple moor grass and rush pasture communities.



ded to occur in certain sites
 significant difference in dung
 re conservation value where
 between dung pat density and
 general indicator of grazing

ple moor grass/rush pasture
 compared with sites where
 .35 g /kg (dry weight). The
 kg P /ha during the grazing
 insect data at the sites where
 sulphorus content of the dung
 naturally improved sites to be
 t was generally found in the

former. The amount of phosphorus cycling via dung deposition on the purple moor grass communities of high nature conservation value is small compared with the amount of phosphorus input that resulted in botanical change to species-rich wet grassland on the Somerset Levels (Tallowin, 1996).

The above indicates that the risk to the nature conservation value of a site from nutrient transfer via grazing livestock, and in particular phosphorus transfer, within free range grazing systems appears to be small. However, because of the limited database, particularly for sites where mineral supplementation was used, it should not be concluded that the risk can be ignored. It is important that early warning indicators of nutrient enrichment of purple moor grass and rush pasture communities are identified to provide a site-monitoring tool for the future.

The grazing livestock redistributed phosphorus and, particularly in the case of cattle and horses, created relatively phosphorus rich patches within sites. The average phosphorus content of cattle dung (3.3 ± 1.35 g /kg dry weight) was c. twice as great as the phosphorus content of purple moor grass leaves (1.31 ± 0.185 g /kg dry matter) indicating that localised phosphorus enrichment could occur as a result of dung deposition. The spatial heterogeneity in nutrient status resulting from the random distribution of dung could be an important influence/driver of community dynamics over time. This contention should, however, be investigated in the context of defining sustainable management practices for purple moor grass/rush pastures of high nature conservation value.

On sites where the distribution of dung pats was non random there would have been an overall net removal of nutrients from the purple moor grass/rush pasture community and localised nutrient enrichment. As both cattle and horses avoid grazing close to their dung, particularly under extensive grazing systems, it is likely that the vegetation of areas of dung concentration would become tall and rank. If ungrazed nutrient enriched patches persist for more than one grazing season then they will develop into scrub. It is possible that such localised "source-sink" nutrient systems have created scrub-grassland mosaics on purple moor grass/rush pasture sites. As the patches of scrub develop and the grazing livestock establish new areas of dung pat concentration the process resulting in successional change is repeated, leading in time to diminution of the purple moor grass/rush pasture resource at the site. Under these circumstances extensive/low-stocking rate grazing systems would be unsustainable for the long-term maintenance of purple moor grass/rush pastures.

Ecological comparison of sites of good quality and degraded sites

The 1997 quadrat data were analysed using Detrended Correspondence Analysis (DCA) to determine vegetation differences among the degraded and good quality sites (Fig. 8). The three sites 19-21 which had been degraded by lack of grazing or undergrazing were grouped on the left of the first axis with the good quality sites 1-11, but separated from the latter on the second axis. Thus the two types of degraded sites had different vegetation both from the good quality sites and from each other.

The separation of sites along the first axis can be used to examine the association of plant species with good quality, previously agriculturally improved or undergrazed sites (Fig. 9). Species on the right hand side of the ordination are strongly associated with improved sites, e.g. white clover *Trifolium repens*. Most sedges were associated with good quality sites. An exception, however, was oval sedge *Carex ovalis*, which was associated with improved sites. Species towards the top of the ordination are associated with the undergrazed sites and include tufted hair-grass *Deschampsia cespitosa*, barren strawberry *Potentilla sterilis* and compact rush *Juncus conglomeratus*. Species towards the left of the ordination including ericoid shrubs, sheep's fescue *Festuca ovina* and green-ribbed sedge *Carex binervis*, are associated with more acidic conditions of wet or dry heath communities. Within the centre of the ordination space there is a cluster of species including flea sedge *C. pulicaris*, and tawny sedge *C. hostiana*, devil's bit scabious *Succisa pratensis*, heath grass *Danthonia decumbens* and bitter vetch *Lathyrus linifolius* that are associated with *Cirsio-Molinietum* fenmeadows of high nature conservation value and thus good indicator species. Species that are separated from this central cluster such as purple moor grass *Molinia caerulea*, jointed rush *Juncus articulatus*, sharp-flowered rush *J. acutiflorus* and meadow thistle *Cirsium dissectum* would not be good indicators of high quality sites as they tend to persist better than the 'indicator' group of species as sites become degraded either through agricultural improvement or poor grazing management.

The seven agriculturally improved sites showed a greater spread in ordination space and thus more inter-site variation than the 11 good quality sites (Fig. 8). Thus, site 17 is close to the good quality sites, while site 18 is very different. This was investigated by calculating the Jaccard similarity index (Magurran 1987) comparing all pairwise combinations of a) good quality sites and b) agriculturally improved sites. The indices were significantly greater for the good quality sites (good quality mean = 0.442, $n = 55$, improved mean = 0.354, $n = 21$, Mann Whitney $W = 2327$, $P < 0.05$), meaning they showed more similarity among sites than did the agriculturally improved sites. This probably reflects differences among the improved sites in the degree of improvement, time since improvement, and species used in re-sowing. However, this also indicates that the good quality sites represent a form of 'climax' vegetation (see Gibson & Brown 1992) community compared to the relatively recently composed communities at the improved sites. Thus the vegetation in the good quality sites has had the time to adapt to the similar physical conditions (hydrology, geology and soils) at the

sites and this has led to a degree of convergence in community composition. Differences among the good quality sites are investigated further below.

In terms of plant species number per quadrat and per site (i.e. over all quadrats), the good quality sites (quadrat mean = 20.4, site mean = 42.8) had higher species richness than the agriculturally improved (quadrat mean = 15.1, site mean = 30.7; ANOVA for quadrats $F_{1,16}=9.5$, $P<0.01$; ANOVA for sites $F_{1,16}=11.5$, $P<0.01$) or laxly managed sites (quadrat mean = 12.7, site mean = 27.3; ANOVA for quadrats $F_{1,12}=11.0$, $P<0.01$; ANOVA for sites $F_{1,12}=12.7$, $P<0.01$). Whittaker's β diversity (see Magurran 1987), the measure of variation in composition among quadrats in a site, was not significantly different between the good quality sites (mean β diversity index = 2.25, $n = 11$) and the improved (mean $\beta = 2.17$, $n = 7$; Mann Whitney $W = 106$, nsd) or laxly managed sites (mean $\beta = 2.34$, $n = 3$; Mann Whitney $W = 76$, nsd). Therefore, the greater species richness at the good quality sites was caused by greater species packing, i.e. more species were packed into the 4m² of each quadrat, rather than a greater heterogeneity in composition among quadrats. This suggests that the good quality sites maintain a high diversity through very fine scale heterogeneity in plant niches (e.g. Silvertown et al 1999).

DCA was used to relate vegetation differences among all 21 sites to soil nutrient data. The first axis explained 9.5% of the variation in the vegetation data and had a 0.745 correlation between the vegetation and soils data. The second axis explained a further 4.3% of the variation in the vegetation data and the vegetation-soils correlation was 0.613. On the first axis P and pH were most important, and agriculturally improved sites were characterised by higher values for these measures. On axis 2 Mg and Na were most important, indicating the laxly managed sites had higher Mg and lower Na concentrations. The level of variation explained by the first axis is high relative to other published data sets and shows that agricultural improvement led to eutrophication and this was the major measured cause of differences among sites. Other unexplained variation would be due to factors such as site history, geographical variation, restricting sampling to only part of a site and the influence of other vegetation types such as dry grassland and wet heaths.

Vegetation differences among good quality sites

The vegetation at each of the 11 good quality sites was characterised by a dominance of *Molinia caerulea*, and high abundance of fine grasses such as velvet bent *Agrostis canina*, sweet vernal grass *Anthoxanthum odoratum*, *Nardus stricta*, *Festuca ovina* and *Danthonia decumbens*, sedges such as carnation sedge *Carex panicea*, glaucous sedge *C. flacca*, star sedge *C. echinata*, common sedge *C. nigra* and *C. hostiana*, and rushes such as *Juncis acutiflorus*, *J. articulatus* and soft rush *J. effusus* (Fig. 10). *Calluna vulgaris*, *Succisa pratensis* and *Cirsium dissectum* were also common. Species which had low cover values, but were found consistently at many sites included heath spotted orchid *Dactylorhiza maculata*, *Lathyrus linifolius*, lousewort *Pedicularis sylvatica*, lesser spearwort *Ranunculus flammula*, lesser skullcap *Scutellaria minor*, saw-wort *Serratula tinctoria*, sneezewort *Achillea ptarmica*, greater birdsfoot trefoil *Lotus pedunculatus*, marsh bedstraw *Galium palustre* and pill sedge *Carex pilulifera*.

MATCH was used to fit National Vegetation Classification (NVC, Rodwell 1992) communities to the quadrat data for each site. The sites fitted best to M25 *Molinia caerulea-Potentilla erecta* mire (sites 1, 4 and 9) or M25b the *Anthoxanthum odoratum* sub-community (sites 3, 5-8, 10 and 11). Site 2 fitted best to M24c *Molinia caerulea-Cirsium dissectum* fen meadow community, *Juncus acutifloris- Erica tetralix* sub-community. The fits were rather poor (median fit = 55.5%, range 46.0-64.9), because the surveys were designed to sample the vegetation randomly rather than by the homogeneous patches recommended for NVC classification. In fact, the open vegetation at the sites contained mixtures of different NVC types, the most common of which were M25, M25b, M24c, M25c (*Angelica sylvestris* sub-community), M16b (*Erica tetralix-Sphagnum compactum* wet heath community, *Succisa pratensis-Carex panicea* sub-community) and, occasionally, M23 (*Juncus effusus/acutifloris-Galium palustre* community) or M15 (*Scirpus caespitosus-Erica tetralix* wet heath).

The NVC analysis showed there were not large vegetation differences among the good quality sites. TWINSPAN was carried on the survey data for both 1997 and 1999 to determine whether there were more subtle vegetation differences. The primary split (Fig. 11) probably indicates differences in moisture levels. The A group (Fig. 11) had preferentials creeping willow *Salix repens*, red fescue *Festuca rubra*, *Cirsium dissectum*, cross-leaved heath *Erica tetralix*, *Calluna vulgaris*, oak *Quercus sp*, western gorse *Ulex gallii* and *Carex pilulifera*. The B group had Yorkshire fog *Holcus lanatus*, *Carex echinata*, bulbous rush *Juncus bulbosus*, heath rush *J. squarrosus*, bog asphodel *Narthecium ossifragum*, deergrass *Trichophorum caespitosum*, *Carex nigra* and cottongrass *Eriophorum angustifloium*. The species in group B indicate wetter conditions than A. There was no suggestion of effects of location on vegetation as the English (3-7, 11) and Welsh (1, 2, 8-10) sites did not separate in the TWINSPAN analysis.

Fig. 11: Results of TWINSPAN analysis of vegetation differences among the 11 good quality sites using the 1999 survey. Relationships among the different groups are shown and the species are the “preferentials” which differentiate each group according to the latest branching

Linear regressions of species number for each site against the soil, grazing and area variables showed no significant predictors of diversity. This was because species number varied little among sites. ANOVA showed species number per quadrat varied significantly among sites ($F_{10,55} = 4.42$, $P < 0.001$), but this was caused purely by two extreme sites. Site 1 (the more upland site) had significantly fewer species than sites 2, 6 and 7, and site 2 had significantly more species than sites 1, 3, 5 and 9 (Tukey multiple comparisons test). No other comparisons showed sites showed significant differences between pairs of sites.

The surveys and visual inspection suggested that all good quality sites remained so in 1999. Therefore while the grazing regime affected the exact vegetation composition, all management practices at these sites were maintaining good quality purple moor grass and rush pasture vegetation. This also means that changes in grazing regime may be used to alter the vegetation structure/composition, providing that individual site management remains within the range observed for the good quality sites. Thus a high sward height in September is associated with *Danthonia decumbens*, *Carex ovalis*, *Pedicularis sylvatica* and *Trichophorum caespitosum* and a high sward height in July is associated with *Calluna vulgaris*, *Molinia caerulea*, heath woodrush *Luzula multiflorum* and *Lathyrus linifolius*, while shorter sward heights in these seasons is associated with a number of sedges, *Carex flacca*, *C. hostiana* and *C. panicea*, and *Agrostis canina*, *Narthecium ossifragum*, *Nardus stricta*, *Scutellaria minor* and *Dactylorhiza maculata* (Fig. 12).

The effects of stocking rate and soil P are difficult to distinguish in the two-dimensional representation of the ordination, but the other ordination axes suggests a high stocking rate is associated with *Achillea ptarmica* and *Succisa pratensis* and negatively associated with *Cirsium dissectum*, *Ulex gallii*, birch *Betula pubescens* and *Salix repens*. Higher soil P is associated with *Festuca ovina* and *Potentilla erecta*, while *Anthoxanthum odoratum* and *Carex nigra* are found more at sites with lower soil P.

Key species

The Habitat Action Plan for purple moor grass and rush pastures names several 'key species' including: two wading birds, curlew *Numenius arquata* and snipe *Gallinago gallinago*, the barn owl *Tito alba*; the marsh fritillary *Eurodryas aurinia* and brown hairstreak *Thecla betulae* butterflies and the narrow-bordered bee hawk moth *Hemaris tityus*; the plants wavy St. Johns-wort *Hypericum undulatum*, whorled caraway *Carum verticillatum*, meadow thistle *Cirsium dissectum*, marsh hawk's beard *Crepis paludosa*, and the greater and lesser butterfly orchids *Platanthera chlorantha* and *P. bifolia*. The birds were not studied, but it should be noted that none of the species are particularly restricted to the purple moor grass and rush pasture habitats. The brown hairstreak feeds on blackthorn *Prunus spinosa* in a range of habitats (Thomas & Lewington 1991), and would be associated with the scrub and hedge element of purple moor grass and rush pastures. The narrow-bordered bee hawkmoth and marsh fritillary both feed on *Succisa pratensis*, and further work was carried out on the performance of this food plant, particularly in relation to the rare marsh fritillary.

Of the plants, *Crepis paludosa* is a northern species and was not found in our sites. Neither were the orchids found at any of our sites. Both butterfly orchids are most associated with MG5 *Cynosurus cristatus*-*Centaurea nigra* grassland (Rodwell 1992) rather than the *Molinia-Juncus* pasture habitat. However, *P. bifolia* is found in base-rich H5 *Erica vagans*-*Schoenus nigricans* heaths on the Lizard (Rodwell 1991). All other key plant species were found at some sites.

Hypericum undulatum was found only in sites 4 and 5, in Devon. Principal Components Analysis was used to compare the vegetation in the quadrats placed around colonies of this species with the vegetation in the 'general' quadrats placed randomly over sites 4 and 5. The general and *H. undulatum* quadrats had different vegetation characteristics at both sites. At site 5 the *H. undulatum* quadrats had more *Ranunculus flammula*, *Angelica sylvestris*, *Holcus lanatus*, *Scutellaria minor*, *Carex flacca*, *Juncus conglomeratus*, *J. effusus*, *J. acutifloris*, and moss, and less *Molinia caerulea*, *Agrostis canina*, *Potentilla erecta*, *Festuca ovina*, *Cirsium dissectum*, and litter than the general quadrats. At site 4 the *H. undulatum* quadrats had more *Agrostis stolonifera*, *Juncus articulatus*, *Cardamine pratense*, *Lychnis flos-cuculi*, *Callitriche stagnalis*, *Glyceria fluitans*, *Myosotis laxa*, *Mentha aquatica*, *Caltha palustris* and *Filipendula vulgaris*, and less *Potentilla anserina*, *Molinia caerulea*, *Carex panicea*, *Lotus pedunculatus* and litter than the general quadrats. This suggests that *H. undulatum* was found in damper and ranker vegetation than is generally found in purple moor grass and rush pastures.

Carum verticillatum was found only at sites 7 and 20. At the latter site this species existed only in a single colony. At site 7 the *C. verticillatum* quadrats had different vegetation composition to the general quadrats. The former had more *Agrostis stolonifera*, *Prunella vulgaris*, *Carex pilulifera*, *Anthoxanthum odoratum*, *Cynosurus cristatus*, *Luzula multiflorum*, *Pedicularis sylvatica* and moss, and less *Agrostis canina*, *Molinia caerulea*, *Erica tetralix*, *Salix repens*, *Ulex gallii*, *Festuca ovina* and litter than the general quadrats. This suggests *C. verticillatum* was found in finer and more mesotrophic vegetation than was found generally at site 7.

These analyses suggest that the environmental conditions and management required by *Carum verticillatum* or *Hypericum undulatum* might not be the same as that which is typical for the general purple moor grass and rush pasture vegetation. *Hypericum undulatum* in particular may be typical of wetter vegetation. The fact that these key species were found at very few purple moor grass and rush pasture sites is cause for concern for the conservation of these species.

In contrast to the other key plant species *Cirsium dissectum* was quite common, being found at eight of the 11 good quality sites, where its percentage cover ranged between <1-5.3%, and five of the 10 degraded sites. Linear regression of the 1999 data for the good quality sites showed that abundance of the *C. dissectum* was not related to any soil or grazing variables except a negative relationship with stocking rate ($r^2=0.44$, $P<0.05$).

The Species Action Plan (SAP) for the marsh fritillary states that the best purple moor grass and rush pasture habitat is that which exhibits sward heights in the range of 8-25cm, has abundant *Succisa pratensis* and large *S. pratensis* plants. Most good quality sites (2, 3, 5-10) had marsh fritillary populations, as did site 20. All sites with marsh fritillary had populations of the food plant *Succisa pratensis*. This illustrates a fundamental habitat requirement for the butterfly, but some sites with *Succisa pratensis* did not have marsh fritillary populations, namely good quality sites 1, 4 and 11 and the degraded site 17. Using only sites containing *Succisa pratensis*, the sites with marsh fritillary populations were compared to those without populations in terms of site size, the average cover of *Succisa pratensis* in the 1997 and 1999 surveys, the average leaf length and plant height and diameter of *Succisa pratensis* as recorded in 1997 and 1998 and August and October 1998, the average July and September sward heights and the average proportion of sward heights <7.5cm in July and September. ANOVA showed only one variable had a significant relationship. Sites with marsh fritillary populations were larger (mean area = 13.6ha) than those without populations (mean area = 4.7ha, $F_{1,11} = 9.4$, $P<0.05$). This relationship accords with predictions of metapopulation theory that size and isolation of habitat patches are important determinants of the ability of butterflies and other taxa to form viable populations in a patch (Hanski 1999). Warren (1994) stated that the small size of many potential habitat patches for the marsh fritillary is a cause for concern in the conservation of the butterfly.

Table 2. Marsh fritillary habitat characteristics of the good quality sites.

Site	Marsh fritillary colony?	Area (ha)	Mean <i>Succisa</i> % cover 1997	Mean <i>Succisa</i> % cover 1999	Length of longest <i>Succisa</i> leaf August 1998 (mm)	Length of longest <i>Succisa</i> leaf October 1998 (mm)	% of sward heights < 7.5cm July	% of sward heights < 7.5cm September
1	×	4.42	0.67	0.85	67.98	57.33	1.22	0.26
2	✓	9.3	14.50	11.33	87.80	49.53	4.83	0.66
3	✓	15.49	5.67	4.50	82.50	86.91	1.34	0.16
4	×	7.46	1.50	0.83	79.55	44.18	12.36	0.59
5	✓	16.87	0.75	0.23	70.00	66.77	7.10	0.25
6	✓	12.88	1.63	3.50	91.70	56.81	1.50	0.49
7	✓	21.99	0.04	0.37	63.08	56.89	2.31	0.25
8	✓	14.88	0.21	0.83	84.15	79.12	0.26	0.37
9	✓	15.54	4.42	5.83	112.10	98.29	1.47	0.12
10	✓	2	12.83	6.17	137.58	99.34	0.03	0.16

11	×	4.86	4.46	3.50	90.20	77.2	0.22	0.14
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Habitat quality is also of prime importance in determining viability of butterfly populations (Warren 1994, Thomas et al. 2000). This analysis did not suggest uninhabited sites were of lower habitat quality than inhabited sites. However, habitat quality will also affect population size. There is poor information on marsh fritillary population sizes for most sites, and because the butterflies show large year-to-year population fluctuations (Species Action Plan (SAP)), such data are difficult to collect. Table 2 shows characteristics of each site that will determine habitat quality for the marsh fritillary according to the SAP. These characteristics varied widely among sites. *Succisa pratensis* cover was generally low, but was highest at site 10. *Succisa pratensis* size (diameter and height both correlated strongly with longest leaf length), was also greatest at site 10, where longest leaf length was double that at some other sites. The percentage of sward heights <7.5cm was generally very low, indicating all the occupied sites had swards which were above the 8cm lower limit required by the SAP. It is interesting that site 4, which was uninhabited despite being quite large, had a much larger proportion of the sward <7.5cm than other sites. Management and environmental factors that affect the abundance and size of *Succisa pratensis* plants will affect the quality of a site as marsh fritillary habitat. The cover abundance of *Succisa pratensis* was negatively correlated to soil total N concentration (cover in 1997 $r^2=0.41$, $P<0.05$, cover in 1999 $r^2=0.29$, $P<0.1$), but not to any grazing variables, while plant size was positively correlated to sward height (length of longest leaf in October 1998 vs sward height in July $r^2=0.48$, $P<0.05$, sward height in September $r^2=0.48$, $P<0.05$). The latter result supports the SAP requirement for a tall sward for good marsh fritillary habitat.

Targeting of restoration using national ecological databases

Two key aims in defining ecological objectives for restoration schemes are to characterise target habitats, communities and species, and to identify appropriate areas for their restoration. The CEH Biological Records Centre (BRC) has a database of the distribution in 10km squares of the Ordnance Survey grid of over 10,000 species of plants and animals. BRC has also developed the Biotope Occupancy database that details habitat associations for a range of plant and animal species. These databases are complementary, and can be used in a hierarchical manner. 1) *Linking species and habitats*: determining which species occur in purple moor grass rush pastures 2) *Local and regional species-pools*: having identified the species that occupy purple moor grass rush pastures, the national biogeographic databases may be used to determine which species occur in the geographic areas of interest. Use of regional species-pools avoids setting inappropriate targets.

Table 3. Preference Index (PI) of British plants for NVC mire communities M16 and M22-M27.

Scientific name	Common name	Constancy within M16, M22-M26	PI
<i>Molinia caerulea</i>	purple moor-grass	4.22	24.88
<i>Lotus pedunculatus</i>	greater bird's-foot-trefoil	1.91	16.83
<i>Juncus acutiflorus</i>	sharp-flowered rush	1.73	16.52
<i>Hypericum tetrapterum</i>	square-stalked st john's-wort	0.60	11.78
<i>Cirsium palustre</i>	marsh thistle	1.89	11.64
<i>Erica tetralix</i>	cross-leaved heather	2.42	11.50
<i>Myrica gale</i>	bog-myrtle	1.17	11.18
<i>Narthecium ossifragum</i>	bog asphodel	1.72	10.88
<i>Potentilla erecta</i>	tormentil	3.88	10.09
<i>Juncus conglomeratus</i>	compact rush	0.49	9.74
<i>Carex echinata</i>	star sedge	1.32	9.25
<i>Achillea ptarmica</i>	sneezewort	0.56	8.62
<i>Galium uliginosum</i>	fen bedstraw	0.83	8.57
<i>Carex panicea</i>	carnation sedge	2.31	8.38
<i>Valeriana dioica</i>	marsh valerian	0.83	8.04
<i>Juncus subnodulosus</i>	blunt-flowered rush	0.99	7.30
<i>Succisa pratensis</i>	devil's-bit scabious	2.19	7.22
<i>Dactylorhiza praetermissa</i>	southern marsh-orchid	0.73	6.90
<i>Juncus effusus</i>	soft-rush	1.56	6.67
<i>Cirsium dissectum</i>	meadow thistle	0.44	6.18
<i>Carex disticha</i>	brown sedge	0.39	6.03
<i>Scrophularia auriculata</i>	water figwort	0.29	5.46
<i>Angelica sylvestris</i>	wild angelica	1.43	5.45
<i>Viola palustris</i>	marsh violet	0.97	5.07
<i>Scutellaria minor</i>	lesser skullcap	0.28	4.93
<i>Trichophorum cespitosum</i>	deergass	1.29	4.89
<i>Carum verticillatum</i>	whorled caraway	0.19	4.40
<i>Lychnis flos-cuculi</i>	ragged-robin	0.74	4.31

Juncus articulatus

jointed rush

1.14

4.08

An objective evaluation of biotope occupancy for vascular plants was developed using the constancy tables from the NVC. Purple moor grass rush pasture is comprised of the NVC mire communities M16, M22-M26. Therefore, these six NVC community types were used to derive lists of the typical species of purple moor grass rush pasture. For each species, the observed frequency in the M16, M22-M26 communities, o , was compared with its expected frequency in all biotopes, e . Species whose constancy was less than 5% in any sub-community were omitted from the analyses. The habitat-specificity of a species was graded by its preference index ($PI = \{(o-e) * abs(o-e)\}/e$). Species defined as most typical of purple moor grass rush pasture were those that showed a high preference index ($PI > 4$) for the six NVC communities assessed (Table 3). The best indicators of these NVC mire communities were predominantly forbs and rushes.

Data collected during the 1997 vegetation survey of the 11 high quality and 10 degraded sites were used to identify a set of species more precisely characteristic of purple moor grass rush pasture. These were species recorded only in or mainly in (i.e. more than half of the records were from good quality sites and there were at least five records for good quality sites) the high quality sites (Table 4).

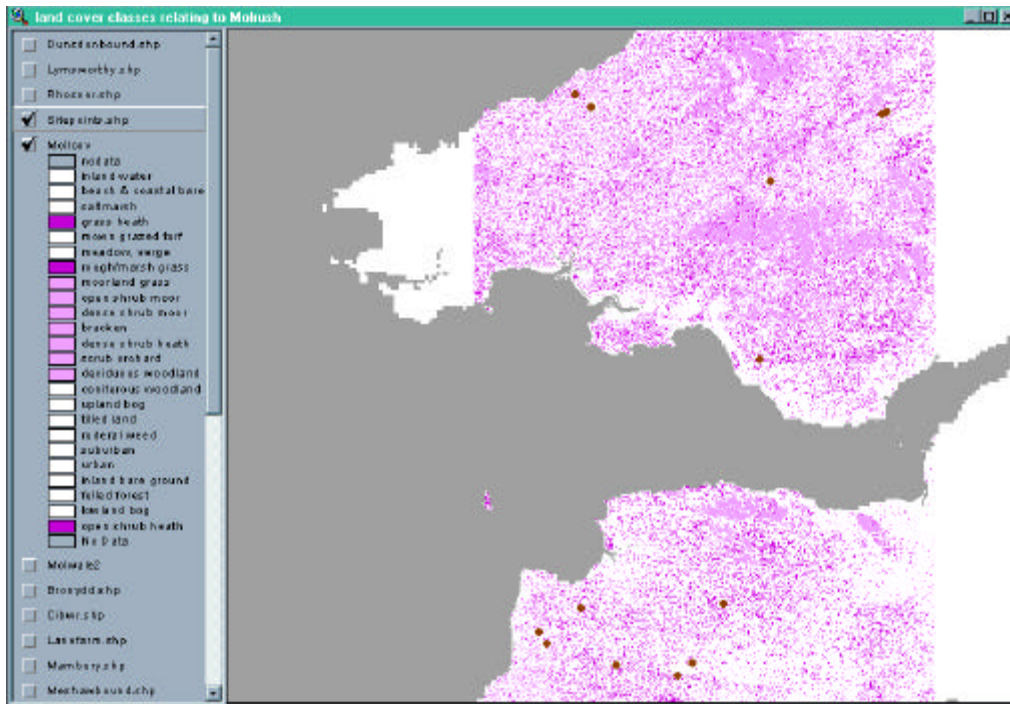
Table 4. Plants characteristic of the high quality sites. Species are ordered top to bottom, left to right according to the number of high quality sites they occurred in, or (from *) if they were also in degraded sites, the degree of preference for high quality sites.

Scientific name	Common name	Scientific name	Common name
<i>Pedicularis sylvatica</i>	lousewort	<i>Trifolium medium</i>	zigzag clover
<i>Erica tetralix</i>	cross-leaved heath	<i>Rumex conglomeratus</i>	clustered dock
<i>Carex hostiana</i>	tawny sedge	<i>Hypericum pulchrum</i>	slender St John's-wort
<i>Carex pulicaris</i>	flea sedge	<i>Vaccinium oxycoccos</i>	cranberry
<i>Calluna vulgaris</i>	heather	<i>Galium saxatile</i>	heath bedstraw
<i>Scutellaria minor</i>	lesser skullcap	<i>Luzula campestris</i>	field wood-rush
<i>Salix cinerea</i>	grey willow	<i>Euphrasia rostkoviana</i>	eyebright
<i>Lathyrus linifolius</i>	bitter-vetch	<i>Hypericum undulatum</i>	wavy St John's-wort
<i>Lotus corniculatus</i>	bird's-foot-trefoil	<i>Athyrium filix-femina</i>	lady-fern
<i>Eriophorum angustifolium</i>	common cottongrass	<i>Hydrocotyle vulgaris</i>	marsh pennywort
<i>Juncus squarrosus</i>	heath rush	<i>Holcus mollis</i>	creeping soft-grass
<i>Mentha aquatica</i>	water mint	<i>Rhinanthus minor</i>	yellow-rattle
<i>Narthecium ossifragum</i>	bog asphodel	* <i>Succisa pratensis</i>	devil's-bit scabious
<i>Juncus bulbosus</i>	bulbous rush	<i>Carex panicea</i>	carnation sedge
<i>Trichophorum cespitosum</i>	deergrass	<i>Danthonia decumbens</i>	heath-grass
<i>Scorzonera humilis</i>	viper's-grass	<i>Festuca ovina</i>	sheep's-fescue
<i>Briza media</i>	quaking-grass	<i>Molinia caerulea</i>	purple moor-grass
<i>Galeopsis tetrahit</i>	common hemp-nettle	<i>Potentilla erecta</i>	tormentil
<i>Carex binervis</i>	green-ribbed sedge	<i>Carex flacca</i>	glaucous sedge
<i>Dactylorhiza maculata</i>	heath spotted orchid	<i>Nardus stricta</i>	mat-grass
<i>Eleocharis multicaulis</i>	many-stalked spike-rush	<i>Luzula multiflora</i>	heath wood-rush
<i>Anagallis tenella</i>	bog pimpernel	<i>Ranunculus flammula</i>	lesser spearwort
<i>Ajuga reptans</i>	bugle	<i>Cirsium palustre</i>	marsh thistle
<i>Equisetum fluviatile</i>	water horsetail	<i>Cirsium dissectum</i>	meadow thistle
<i>Eriophorum vaginatum</i>	hare's-tail cottongrass	<i>Serratula tinctoria</i>	saw-wort
<i>Carex pilulifera</i>	pill sedge	<i>Carex nigra</i>	common sedge
<i>Myosotis secunda</i>	creeping forget-me-not	<i>Juncus articulatus</i>	jointed rush
<i>Valeriana officinalis</i>	common valerian	<i>Ranunculus acris</i>	meadow buttercup
<i>Vaccinium vitis-idaea</i>	cowberry	<i>Prunella vulgaris</i>	selfheal
<i>Vaccinium myrtillus</i>	bilberry	<i>Carex echinata</i>	star sedge
<i>Triglochin palustre</i>	marsh arrowgrass	<i>Achillea ptarmica</i>	sneezewort

The potential distributions of the M16 and M22-M26 NVC community types were assessed by co-occurrence mapping of the distribution of constituent species listed in Table 3. This species-richness map highlights areas of potential occurrence for these communities and thus where restoration could be targeted (Fig. 13). This shows a concentration of potential sites in Wales and the south, west and northwest of England. The species groups derived from site survey data (Table 4) were used to create another co-occurrence map (Fig. 14) which showed a more realistic distribution of potential sites for purple moor grass rush pasture, concentrated in south-west and north-west England, west Scotland and west Wales.

The CS90 survey of the British countryside (Barr *et al.*, 1993) is another national database that shows the distribution of a number of land use classes. Twenty four of these classes are found in south-west Britain and we considered that purple moor grass rush pastures are likely to be associated with three 'high affinity' classes: grass heath, rough/marsh grass and open shrub heath (Fig. 15). A further seven 'medium affinity' classes are likely to be found in or near vegetation containing purple moor grass rush pastures (Fig. 15), while the remaining 'low affinity' have no association with these pastures. The three high affinity land use classes are too broad to allow mapping of purple moor grass rush pastures and associated habitat at the national scale. However the maps can be used to assess the landscape habitat quality of known purple moor grass rush pasture sites and the potential for restoration of the surrounding landscape. For each purple moor grass rush pasture site a map was plotted of the occurrence of high and medium affinity land classes (in 25m pixels) encompassed by the site and the region described by a 1km-wide zone around the site (Fig. 16). The proximity of other purple moor grass rush vegetation to a site may be important to provide sources of colonists to maintain plant and animal populations in a site. This problem has been discussed especially in relation to maintaining metapopulations of the marsh fritillary (Warren 1994). The amount of suitable habitat near a site thus provides a measure of its habitat quality. A strategy to reverse such landscape degradation is to restore purple moor grass rush pasture near to existing sites (see Bullock & Webb 1996). The high and medium affinity land use classes should be more amenable to restoration to purple moor grass rush pasture than low affinity classes. Therefore, these maps illustrate the amount of land near to a site that could be restored, and thus its potential landscape habitat quality. All high quality sites showed good potential for restoration of nearby vegetation (Fig. 16). It is interesting that the three sites with the lowest 'landscape quality' – 1, 4 and 11 – were those with no marsh fritillary populations.

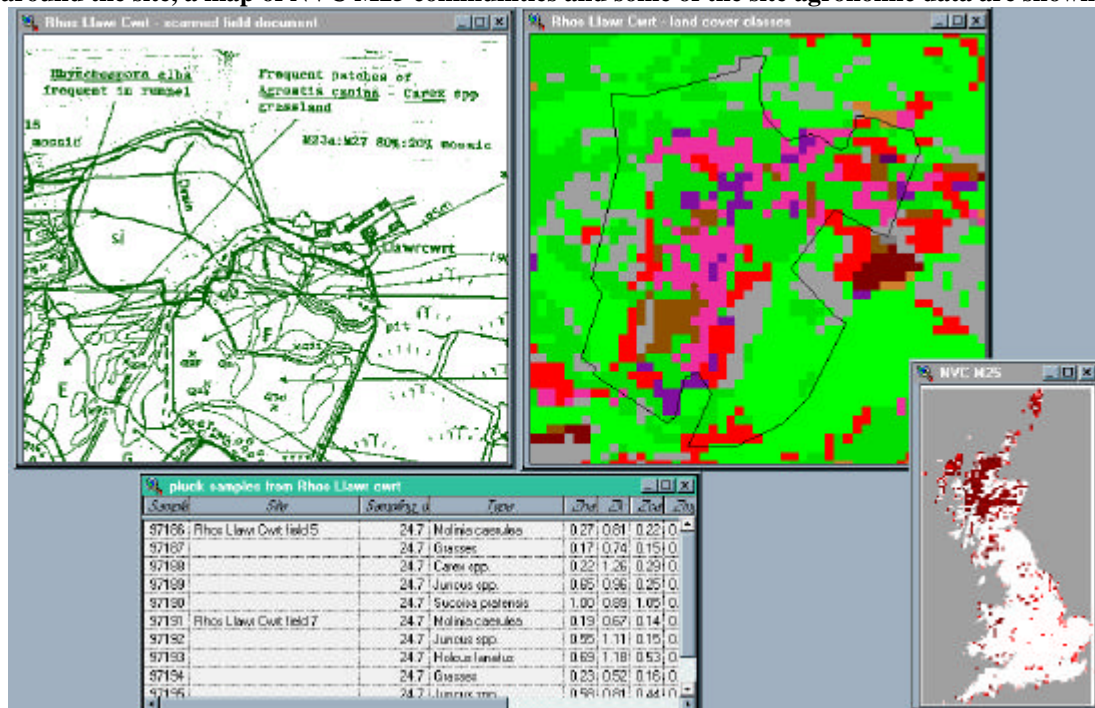
Fig. 15: An ArcView presentation of the distribution of the high affinity (dark purple), medium affinity (light purple) and low affinity (white) CS90 land cover classes in Devon and south Wales, and the positions of the 21 sites (red circles, some sites overlap).



Spatial data for conservation management and restoration of purple moor grass rush pasture

An ArcView GIS was created to hold the project data in a spatially explicit fashion. Site positions were mapped onto a national map, which was also overlaid with the maps of species co-occurrences land cover classes. Information was added for each site which included site maps and ecological, agronomic and soil data (Fig. 17). This illustrates the potential to use a single centralised GIS to hold all data relating to the actions required for a particular BAP habitat. This could include national maps of sites, individual site maps with quadrat locations, species lists, population data for key species, past and current management, spatial relationships to other sites, and surrounding land use. This would allow coordination of efforts to achieve BAP aims to an unprecedented degree. Targeting of restoration, particularly with regard to optimal siting of restoration for metapopulations, would be facilitated.

Fig. 17: An example screen from the ArcView GIS containing the project data. A site map, a map of the CS90 land cover classes in and around the site, a map of NVC M25 communities and some of the site agronomic data are shown.



Restoration of purple moor grass and rush pastures of high nature conservation value.

The objective of this study was to identify soil nutrient availability conditions that would allow the establishment of key species of purple moor grass and rush pasture communities. The restoration site was a species-poor agriculturally semi-improved grass dominated rush pasture that had received no inorganic fertilizer for > 13 yrs and was on the same soil type and locality as an existing purple moor grass/rush pasture site of high nature conservation value. The major edaphic difference between the two sites was in total and extractable soil phosphorus amount, which were over twice as great at the restoration site. Treatments designed to reduce site fertility included: cutting and removal of herbage, cultivation and fallowing, incorporation of straw and/or lignitic-clay and topsoil removal. Purple moor grass/rush pasture species were either sown or planted as seedlings on treated plots.

Neither soil nitrogen nor potassium availability, *per se*, appeared to limit the establishment of purple moor grass/rush pasture species, whereas, enhanced phosphorus availability did. Removal of the top 15-20 cm of soil reduced the total soil phosphorus amount by about 80-85 percent, from c. 2235 to c. 423 mg / kg dry soil and depleted plant dry matter P availability to c. 4.0 ± 2.15 kg P per two years after treatment application and c. 1.8 ± 1.93 kg P per hectare after four years. These harvested yields of P were comparable to the amount, 3.63 ± 0.487 kg P per hectare, harvested from the purple moor grass and rush pasture site in July. Nutrient poor and relatively calcium enriched soil exposed by topsoil removal allowed the development of a community with affinities to species-rich purple moor grass/rush pasture of high nature conservation value. Ordination analysis indicated the existence of marked vegetational gradients within the topsoil removal treatments between the straw and the lignitic-clay amendments. These two amendments did not influence overall mineral nutrient availabilities differently; their effect on edaphic conditions remains unclear. Where the topsoil was not removed the community that developed showed little structural similarity to purple moor grass/rush pastures of high nature conservation value; the abundance of any survivors of the planted purple moor grass/rush pasture species was reduced to trace amounts after three years. Removal of most of the soil organic matter, although drastic, was a practical success in that it did create suitable edaphic conditions for establishment of all planted purple moor grass and rush pasture species.

Details of the restoration experiments are provided in the attached paper (see Appendices) that will be published in the journal *Restoration Ecology* in June 2001.

Conclusions

Sustainable management, agronomic output and agronomic constraints for livestock

Management of all the sites of high nature conservation value was characterised by variation between years in duration of grazing season, stocking density and type of cattle. As a consequence there was between year variation in sward structure within and between sites of high nature conservation value. The only consistent management factors were that cattle grazed all these sites during July and August. Variations in grazing management practice between years are probably important for creating a greater range of regeneration niches than under a more controlled/uniform management regime. It is therefore contended that, where possible (i.e. if the size of a site permits), there should be variation in management practice involving severe, lenient and/or lack of grazing within year as well as between years in order to increase spatial structural heterogeneity within sites. However, more research is needed to underpin such a management policy and thus the future development of agri-environmental agreements for purple moor grass and rush pasture sites.

Estimated output achieved from sites of high conservation value ranged from < 10 to c. 45% of the output that might be expected from grazed agricultural pastures. This range in agronomic “value” needs to be accommodated in agri-environmental support.

Management agreements to maintain good quality sites should be based on sward structural criteria, such as mean sward surface height and/or the proportion of short sward in mid to late summer, rather than on stocking rate. Grazing management agreements should aim to maintain mosaics of different vegetation types and a range of structure in the purple moor grass and rush pasture habitat. However, further research is needed to define the spatial scales of vegetation mosaics for the maintenance of populations of key species, particularly faunal species associated with these communities.

Although generally sub-optimal in Ca and P content for productive livestock, purple moor grass generally provided a satisfactory Ca:P ratio compared with the other grazed forages of purple moor grass and rush pasture communities. The K content of the forage was generally sub-optimal for livestock and the severity of deficiency increased during late summer/autumn. Any advantages that the more species-rich purple moor grass and rush pastures offer in terms of supplying trace elements are likely to be offset by other mineral imbalances, such as wide Ca:P ratios and/or low intakes of specific components that would supply adequate trace element requirements. Thus species-richness, *per se*, may not replace the need for some mineral supplementation.

The estimated nutritional value of purple moor grass was c. 10% below the value of forage obtained from intensively grazed agricultural pastures. Some farmers involved in managing purple moor grass communities contend that improved growth rates of cattle can be expected where animals have access to improved grass swards. However, further studies are required to quantify this.

The risk to the nature conservation value of a site from nutrient transfer via grazing livestock, and in particular phosphorus transfer, within free range grazing systems appears to be small. However, because of the limited database, particularly for sites where mineral supplementation was used, the risk should not be ignored. It is important that early warning indicators of nutrient enrichment of purple moor grass and rush pasture communities are identified to provide a site-monitoring tool for the future.

Non random nutrient returns by livestock within a site represent localised “source-sink” nutrient systems being established with patches being enriched relative to the rest of the site. If grazing pressure is relaxed or ceases, it is likely that nutrient enriched patches that then cease to be disturbed by grazing livestock will undergo more rapid changes in vegetation structure than non-enriched areas of the site. It is probable that patchiness in nutrient returns by grazing livestock is also a factor influencing the development of scrub-grassland mosaics in purple moor grass and rush pasture sites. However, the relative importance of patchiness of nutrient returns by large herbivores interacting with patchiness of grazing at low stocking rates as a mechanism driving successional change needs to be established. It is contended that a fixed low-stocking rate grazing system, albeit designed to maintain the varied wildlife interests of purple-moor grass and rush pastures could, in time, lead to an unacceptable level of scrub development.

Ecological

Degradation by agricultural improvement or lack of grazing led to declines in species number and changes in the composition of purple moor grass and rush pasture communities. Loss of biodiversity with agricultural improvement was linked to eutrophication, particularly phosphorus, while lack of grazing led to increases in rank-growing species.

Increased diversity at the good quality sites was achieved by the packing of a greater number of species into the small area encompassed by a quadrat. This suggests fine-scale heterogeneity and low soil nutrient status are important (the latter in preventing competitive exclusion – see Bullock 1996) are important in maintaining diversity.

The greater between-site similarity of the good quality sites than of the degraded sites shows that the good quality sites have many species in common. This emphasises the fact that these sites represent a vegetation type that has evolved uniquely in response to common edaphic and hydrological conditions of the sites. Disruption of these communities by degradation causes the formation of more transient communities which will probably be less stable (see Tilman & Downey 1994).

The changes in species' abundances between good quality and degraded sites suggests some species could be used as indicators of good quality sites, or, alternatively, to detect if sites are becoming degraded. The classic species of purple moor grass and rush pasture, *Molinia caerulea*, *Juncus articulatus*, *J. acutifloris* and *Cirsium dissectum*, are therefore not good indicator species. Species that are quickly lost from a degraded community, e.g. *Carex flacca*, *C. pulicaris*, and *C. hostiana*, may be better indicators.

Vegetation differences among the good quality sites were determined by some soil and hydrological variables, and, to a large extent, by grazing management. Over the duration of the study all good quality sites maintained plant communities of high conservation value. Thus the range of grazing regimes were acceptable. Changes in different aspects of the grazing regime would have a range of effects of species composition and the information presented here may be used to guide changes in grazing to achieve certain objectives. However, further work over a greater number of good quality sites is needed to produce more definitive guidelines.

Three key plant species of purple moor grass and rush pastures considered in this study - wavy St. Johns-wort *Hypericum undulatum*, whorled caraway *Carum verticillatum* and meadow thistle *Cirsium dissectum* - showed differing habitat requirements. These related to moisture, vegetation height and soil nutrients, but responses to management were not detected. Full autecological studies of these species, especially in relation to grazing management, are needed. However, these results emphasise that conservation of purple moor grass and rush pastures should consider the different requirements of constituent species.

Purple moor grass and rush pastures comprise a range of NVC categories. Scrub vegetation is also important. This is reflected in the different habitat requirements of the key species. There is a need to consider the role of all the different vegetation types in determining the unique biodiversity status of purple moor grass and rush pastures. The management requirements of these different vegetation types and of individual key species require further study.

This study showed variation among sites in terms of suitability of habitat for the marsh fritillary *Eurodryas aurinia*. Site size was a major determinant of whether a site had a population of the butterfly. Habitat quality is determined by sward height and the abundance and size of the foodplant *Succisa pratensis*. However, while this study provided information on these aspects of habitat quality, more information is needed on the responses of the butterfly and its foodplant to grazing management. Key faunal species may need particular conditions or management types.

Restoration

A list of typical species of purple moor grass and rush pastures has been derived, which can be used to map areas of Britain where these typical species co-occur. These maps can be used to target regional areas that are likely to be suitable for restoration of purple moor grass and rush pastures. Vegetation maps of Britain derived from the CS90 survey can be used to target restoration at more local scales. The vegetation types that surround known purple moor grass and rush pastures can be useful in indicating 'landscape quality', i.e. the amount of similar vegetation nearby which can act as a source of colonists, or other sites to maintain a metapopulation. These maps also show vegetation types that could be more amenable to restoration of purple moor grass and rush pastures and thus assist the planning of restoration.

Geographic Information Systems can be used to collate spatial data relating to the distribution, status and management and restoration of purple moor grass/rush pastures. This can be used to coordinate actions to meet BAP aims, such as positioning of restoration sites to achieve maximum benefit.

Restoration and maintenance of soil phosphorus as the primary limiting nutrient is essential where there is a risk of nitrogen becoming non-limiting (see Tallowin & Smith, in press). Restoration should be targeted onto sites where soil phosphorus availability comparable to that found in existing purple-moor grass and rush pastures can be readily achieved. Topsoil removal can be a practical and successful restoration technique. Lack of establishment of key purple-moor grass and rush pasture species from sown seed can be a major problem on restoration sites (see Isselstein *et al.*, in press). Small-scale strategic seedling planting of key species may be cost-effective particularly where these species have been lost from the locality and seeds are very costly and/or scarce to obtain.

Technology transfer

Tallowin, J.R.B. & Smith R.E.N. (1996) Management options to conserve a *Cirsio-Molinietum* and integrate its use into productive livestock systems. In: Vegetation Management in Forestry, Amenity and Conservation Areas: *Management for Multiple Objectives. Aspects of Applied Biology*, **44**, 203-210.

Tallowin, J.R.B. & Smith R.E.N. (1996) Management options to conserve Culm grassland and integrate its use into productive livestock systems. *Culm farmers newsletter*.

Tallowin, J.R.B. & Smith, R.E.N. (1998). Restoration of a *Cirsio-Molinietum* to an agriculturally improved site: a case study. In: *2nd International Conference on Restoration Ecology. Groningen University, The Netherlands, August 1998*.

Tallowin, J.R.B. (1996) Factors that affect the restoration of fen-meadow (culm grassland) associations. Presentation to Culm working group meeting on 16 April 1996

**Project
title**

Sustainable livestock systems to conserve key purple moor-
grass/rush pasture species.

**MAFF
project code**

BD1318

Bullock J.M., Tallowin, J.R.B. & Smith, R.E.N. (1998). Presentation of interim findings on project BD1318 at UK Biodiversity Action Plan meeting for Purple Moor Grass and Rush Pastures .

Tallowin, J. R. B. and Smith, R.E.N. (In press) Restoration of a *Cirsio-Molinietum* to an agriculturally improved site: a case study. *Restoration Ecology*.

Isselstein, J., Tallowin, J.R.B. and Smith, R.E.N. (in press) Factors affecting seed germination and seedling establishment of some fen meadow species. *Restoration Ecology*.

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