ANNEX 3

2.4 The SSSI, turf transplant plot and littered plot: 2x2m quadrat survey - a comparison of their NVC communities

Our initial surveys of the Brocks Farm grasslands indicated that in terms of their NVC categorization they were clearly referable to MG5 (Centaurea nigra - Cynosurus cristatus meadow and pasture) (Leach, 1988). We did not attempt at that time to place the vegetation within a particular sub-community, although other workers had previously suggested it could be either MG5a (Lathyrus pratensis sub-community) or MG5c (Danthonia decumbens sub-community), or perhaps even a mixture of the two.

Of course one of the disadvantages of the RM-Q monitoring system is that the quadrats are too small to be used for NVC purposes. We, therefore, decided in 1994 to record 'extra' quadrats in each of the three monitoring areas, following the NVC sampling protocol (ie. at least five 2m x 2m quadrat samples from more or less homogenous stands of vegetation with species (including bryophytes) recorded using the Domin scale of cover-abundance). These quadrats are presented in Table 9.

Our interpretation of these quadrats has been assisted by use of the computer-matching programs TABLEFIT and MATCH. However, an important disadvantage of these matching programs is that they always put vegetation into a recognised NVC category, even though the 'goodness-of-fit' might be poor or hardly any better than the fit with the 'second-best' community; this means that vegetation probably best regarded as intermediate between two (or more!) NVC categories will always be assigned to a single category. It is thus left to the fieldworker to assess whether the vegetation is 'intermediate' in character.

- The SSSI field

The seven SSSI quadrats point unequivocally to MG5; computer matching suggests that, at sub-community level, some stands were MG5a while others were closer to MG5c, although there was usually very little to choose between them in terms of their 'goodness-of-fit' values.

Several MG5c preferentials are strongly represented in the sward, including *Prunella vulgaris*, *Luzula campestris*, *Danthonia decumbens* and *Carex caryophyllea*. Only two of the 10 MG5c preferentials given in the NVC have not been recorded on the SSSI (although one of these, *Pimpinella saxifraga*, has been recorded by other workers (but note we suspect that this is an error)).

In contrast, of the seven MG5a preferentials given in the NVC only four are present on the SSSI, and only two of these are sufficiently abundant to occur in the RM-Qs (*Lathyrus pratensis* and *Leucanthemum vulgare*). Our conclusion is that while the SSSI does hold a few small patches of each of these sub-communities, the bulk of the grassland is probably best regarded as an 'intermediate' MG5c/MG5a.

In terms of species-richness the SSSI compares very favourably with the figures given in the NVC: mean number of species/sample was 31 (cf. 22 for both MG5a and MG5c in the NVC).

- The turf transplant

The seven quadrats from the turf transplant suggest, as on the SSSI, that the vegetation is best regarded as MG5. In terms of sub-community it is notable that several MG5c preferentials which are class V constants on the SSSI are poorly represented on the turf transplant: for example, in 1994 *Danthonia decumbens* and *Prunella vulgaris* were absent in the RM-Qs, and in the 2x2m quadrats were only present at constancy II. Furthermore, all but one of the MG5a preferentials are present (although only *Lathyrus pratensis* and *Leucanthemum vulgare* occur at the levels of frequency indicated in the NVC). Our conclusion is that, in contrast to the SSSI, the bulk of the grassland transplanted as turves is now referable to MG5a.

There are also a few small patches of grassland/swamp overlying permanently/seasonally waterlogged soils (represented by quadrat no 4 in Table 9) which are clearly not MG5a: one patch near the western edge of the plot is dominated by a mixture of *Glyceria fluitans*, *Ranunculus repens*, *Lotus pedunculatus* and tussocks of *Juncus effusus* (slightly reminiscent of either incipient rush-pasture (MG10) or *Glyceria fluitans* swamp (S22)); while other areas close to the fence (running down the eastern edge) are almost devoid of vegetation, with many of the MG5 species present at the time of transplantation having long since disappeared.

In terms of species-richness the turf transplant is not as good as the SSSI (mean number of species/sample of 25). This is partly explained by an apparent post-transplantation decline of bryophytes. Unfortunately we did not record mosses and liverworts in the R-MQs, and so have not been able to examine in detail the effects on them of transplantation. However, the 2x2m quadrats do show a marked difference between the SSSI and turf transplant in representation of bryophytes: Brachythecium rutabulum, constancy V on the SSSI, constancy II on the transplant; Pseudoscleropodium purum, constancy IV on the SSSI, constancy I on the transplant; Plagiomnium undulatum, constancy III on the SSSI, not recorded on the transplant; and Rhytidiadelphus squarrosus, constancy II on the SSSI, not recorded on the transplant.

- The littered area

The five quadrats here were taken from across the entire littered area, not just that area occupied by the littered plot.

The quadrats highlight the extent to which the littered vegetation has altered: of the 19 class V constants on the SSSI only three were class V on the littered area (Anthoxanthum odoratum, Lotus corniculatus and Prunella vulgaris). As on the turf transplant, bryophytes are also poorly represented. Conversely, several species occur at much higher constancy on the littered area than on the SSSI, including Ajuga reptans, Carex demissa, C.panicea, Cirsium palustre, Juncus acutiflorus, Lotus pedunculatus, Mentha aquatica, Pulicaria dysenterica and Ulex europaeus.

Clearly, 'wetland' species are strongly represented on the littered area (as also shown by the FIBS analysis of the littered plot), reflecting perhaps the extent to which it suffers from surface waterlogging. This is particularly severe following heavy rain (compaction having produced soils with relatively impermeable surface layers), but we have also noted several 'upwellings' of water - both here and in the turf transplant plot - which could be connected to leaking water mains which run along the length of the littered area and turf transplant.

The quadrats from the littered area illustrate clearly the extent to which the littered vegetation now differs from the SSSI and turf transplant. In our opinion it is currently not possible to categorise it in NVC terms. It has yet to 'settle down', but already is beginning to resemble some kind of mire community; the widespread dominance of Juncus acutiflorus suggests the end-community might be closest to M23 (Juncus effusus/acutiflorus-Galium palustre rush-pasture). The early upsurge of Ulex europaeus, on the other hand, indicates that in the absence of management the end-community would probably be some kind of Ulex scrub.

TABLE 9

BROCKS FARM: NVC-STYLE QUADRATS (2x2M) IN THE THREE SAMPLING AREAS, MAY 1994

	SSSI FIELD								TURF TRANSPLANT								LITTER AREA					
	1	2	3	4	5	6	7	CONST.	1	2	3	4	5	6	7	CONST.	1	2	3	4	5	CONST.
Agrostis capillaris	3	3	4	3	3	4	4	V	5	4	3		4	6	3	V		3	2	2	6	IV
Anthoxanthum odoratum	4	4	5	4	4	4	4	V	4	4	5	2	4	5	4	V	3	3	4	2	5	V
Carex flacca	3	3	3	4	8	3	3	V	3				2	3		III		4	2		3	III
Centaurea nigra	3	4	5	6	3	4	4	V	4	3	3		4	3	3	V		2	3	1	5	IV
Danthonia decumbens	3	3	4	4	2	2	4	V		2			1			II	2	1		4	3	IV
Festuca rubra	5	5	6	6	3	5	6	V	7	5	5		8	5	7	V	3	1	4		2	IV
Holcus lanatus	2	2	2	3	2	3	3	V	3	2	2	4	3	3	2	V	2	3	2	2	2	IV
Leucanthemum vulgare	3	4	3	2	2	2	3	V	2		2		2	1		III		3	3	1	4	IV
Lotus corniculatus	4	5	6	6	2	4	4	V	4	3			2		2	III	2	2	3	1	4	V
Plantago lanceolata	4	4	4	4	3	3	4	V	4	3	3	2	4	5	2	V	2		3	1	2	IV
Ranunculus acris	3	3	3	3	3	3	3	V	2	2	2	1	3		1	V	2		2	1	2	IV
Trifolium pratense	4	2	4	2	4	3	4	V	3	2	2		4	1	2	V	1		2		2	III
Brachythecium rutabulum		1	3	3	4	3	3	V					2	2		II			3		4	II
Hypochaeris radicata	3	3	4	3		2	2	V	3	3	2		3	3	2	V		1	2			II
Luzula campestris	3	3	3	3		3	2	V	3	4	3		3	4	3	V	2	2	3		3	IV
Oenanthe pimpinelloides		3	2	3	2	3	2	V	3	2	1		3	3	2	V			1			I
Prunella vulgaris	4	2		2	2	1	3	V	1					1		II	2	3	3	3	3	V
Rumex acetosa	2	1	2	1		3	2	V	3	2	3		2	3	1	V	1		2			II
Achillea millefolium	2	5	2	3			1	V	2	3	4					III						X
Cerastium fontanum	1		1		2	1	1	IV	1		2	1	2	2		IV	1		1			II
Dactylorhiza praetermissa	2			1	1	2	2	IV	1			1	1	1	1	IV	1		1		2	III
Orchis morio	2	1	3	3			3	IV		1	1		1			III					1	I
Potentilla reptans	2			2	2	1	2	IV							1	I	1	2	1			III
Pseudoscleropodium purum		1	2	2	1		2	IV					3			I					2	I
Ranunculus bulbosus	2	3	3	4		2		IV	3	3	2		3		2	IV	2		2			II
Taraxacum agg.		2	2	2	1		2	IV	2		1		3		1	III	1		1	1	2	IV
Carex caryophyllea		2		3		3	3	III		1						I	2		2	1	3	IV
Leontodon saxatilis	1	2		3	3			III								X	1	3		2	4	IV
Ranunuculus repens	1	1				1	1	III				6		3		II		2				I
Dactylis glomerata	1			1			2	III	1					2		II						X
Plagiomnium undulatum				1		2	1	III								X						X
Briza media			2		2			II								X						X
Calliergon cuspidatum			2	2				II								X			2			I
Carex panicea	2					2		II						4	1	II	5	3	3	2	2	V
Crataegus monogyna		1				1		II								X					1	I
Juncus acutiflorus					4	3		II	3		1	5		6		III	5	6	4	2	4	V
Linum catharticum		1		1				II								X						X
Rhytidiadelphus squarrosus	1			2				II								X						X
Rosa sp.		1			1			II								X						X
Senecio erucifolius	1	1						II								X	1		1			II
Senecio jacobea	1			2				II		1	1		1			III						X
Succisa pratensis				1			2	II								X						X

TABLE 9 (continued)

Bellis perennis				1				I								X	1					I
Carex pulicaris					4			I								X	2			2		II
Conopodium majus		1						I								X						X
Crepis capillaris		1						I								X						X
Cynosurus cristatus						2		I								X			2			I
Hypericum humifusum				1				I								X						X
Leontodon autumnalis			1					I		1			2			II			1			I
Lotus uliginosus					3			I			2	5			1	III	2	3	3	1	1	V
Poa pratensis/humilis						2		I	2	2	1		1		1	IV		1				I
Polygala vulgaris			3					I								X						X
Potentilla erecta							2	I								X		1				I
Prunus spinosa		1						I								X						X
Quercus sp.				1				I								X						X
Stellaria graminea	1							I			2					I			1			I
Trifolium repens						1		I	1	1			2		1	III			1			I
Veronica chamaedrys	2							I			1					I						X
Agrostis canina								X								X		6				I
Ajuga reptans								X						2		I		1	1	1	1	IV
Cardamine pratensis								X			1	1		2		III			1		1	II
Carex demissa								X								X	3	3		3	2	IV
Carex ovalis								X								X		1				I
Cirsium palustre								X				1				I		1	1		2	III
Dactylorhiza maculata								X								X		1				I
Equisetum arvense								X					1			I						X
Festuca pratensis								X						1		I						X
Filipendula ulmaria								X						2		I						X
Glyceria fluitans								X				5				I						X
Holcus mollis								X								X					2	I
Hypericum tetrapterum								X						1		I						X
Isolepis setacea								X								X		1				I
Juncus articulatus								X				2				I		1				I
Juncus bufonius								X				2				I						X
Juncus bulbosus								X								X		3				I
Juncus conglomeratus								X	1							I					1	I
Juncus effusus								X				4				I						X
Lathyrus pratensis								X	1					2	2	III			1			I
Mentha aquatica								X								X	3	2		1		III
Myosotis discolor								X					1			I						X
Poa trivialis								X				3				I						X
Pulicaria dysenterica								X						4		I	2	4	2		4	IV
Ranunculus flammula								X				5				I						X
Rhinanthus minor								X			2		3			II						X
Rubus fruticosus								X								X		1				I
Stellaria alsine								X				2				I						X
Ulex europaeus								X								X		1	1	1	1	IV
Vicia cracca								X		1	1			2	1	III			1			I
No. of species	30	33	27	37	26	31	31		27	23	27	18	30	29	23		27	33	39	21	33	

Appendix 5 (EN 10)

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Grassland translocation
Contract No VT5.1M
Brocks farm

March 1997

CWD Gibson

Report No. E0604R1

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1. Summary

1.1 This report presents the results of community analyses of turf transplant and littered transplant treatments of MG5 grassland at Brocks Farm in Devon, compared to grassland not transplanted and used as a control. The control is also a SSSI. The analyses carried out complement analyses of the performance of single species and groups of species in the same grasslands reported on elsewhere.

1.2 Community analysis first used ordination (DCA) to illustrate the full range of variability expressed in nine years of monitoring of the three grassland treatments (turf transplant, litter and control). Canonical ordinations (DCCA) were then used to test the relationships between treatments, time and community-scale vegetation change. These relationships were tested for statistical significance and the amount of change produced was examined to judge the importance of differences produced by littering and turf transplant.

1.3 All treatments have changed over time. Common changes are associated with the reimposition of appropriate management by grazing and cutting after a period of neglect but the litter and turf transplant have also changed in different ways compared to the SSSI.

1.4 The littering treatment produced an immediate large shift in community composition away from the pre-treatment MG5 grassland. This change reduced over the next few years and many species characteristic of MG5 recovered. However, at the end of nine years there remains a substantial "signature" of the littering treatment in the form of species not present in the original grassland. This alien component of the grassland has changed little over the last few years.

1.5 In contrast the turf transplant treatment initially showed little difference from the control, but has since diverged steadily and was still diverging in 1996. This divergence is expressed mainly by the failure to thrive of MG5 species which responded well to the reimposition of management on the SSSI control. A smaller component of the vegetation increased in the turf transplant but not in the SSSI control.

1.6 Both transplant treatments failed to preserve the community characteristic of the original grassland, although many individual species were successfully transplanted. Littering produced an immediate damage followed by partial recovery, but substantial differences remain after nine years. Turf transplant produced damage which appeared small for the first few years but then increased and is still increasing.

2. Introduction

2.1 Background to study

2.1.1 The aim of the study reported here is to provide an objective assessment of vegetation transplanted by two different methods from a MG5 grassland (*Centaurea nigra - Cynosurus cristatus* grassland - Rodwell 1992) known as Brocks Farm in Devon. There has been a wide variety of opinion on the 'success' or otherwise of habitat transplantation, but never before the opportunity to subject a properly controlled and well-monitored operation to rigorous analysis. Previous studies in Britain (Buckley 1989, Byrne 1990) have been short-term and/or not been subjected to full multivariate analysis of vegetation changes and their causes.

2.1.2 The study has assumed a certain degree of urgency in view of proposals to transplant the remaining part of the Brocks Farm MG5 grassland, the part notified as SSSI, in connection with an application for a minerals consent.

2.1.3 Judgement of the success or otherwise of transplantation is dependent on a rigorous definition of the nature conservation value of the original grassland. Although part of this value lies in particular species of nature conservation interest, the key value of species-rich ancient grasslands like the one under study lies at a higher level of organisation. This is at the level of the **plant community**, where a characteristic assemblage of species is able to live together and provide a habitat for all its component organisms. This concept is detailed below because it forms the root of judgement of what constitutes damage to the special interest of the grassland as opposed to mere change.

2.2 The grassland habitat and community - value and the definition of damage

2.2.1 Ecological science has long recognised a level of organisation at which communities of plant species, with the main species present at characteristic and predictable frequencies, recur under the same climatic, soil, and/or management conditions. The development of species-rich communities after disturbance to a state where a balance has been achieved between a large number of species is slow in human terms.

2.2.2 The timescale of community development is at least a century or more for the grassland types which have been studied in Britain (Gibson & Brown 1992, Wells *et al* 1976). Evidence exists that suggests that neutral meadows have been part of the landscape for at least 2000 years (Grieg 1984, 1988). Such species-rich plant communities form the matrix of habitat necessary for supporting both the flora and associated fauna, ie they play an essential role in the conservation of biodiversity.

2.2.3 The importance of these ancient species-rich habitats is acknowledged in national and international law and obligations. The Habitats and Species Directive (92/43/EEC) defines natural habitats as follows: *Natural habitats means terrestrial or aquatic areas distinguished by geographic, abiotic and biotic* *features, whether entirely natural or semi-natural.* (Article 1(b)) (Council of the European Communities 1992). Semi-natural habitats comprise the great majority of European habitats of nature conservation value, including MG5 grassland. The then Nature Conservancy Council, in its *Guidelines for the selection of biological SSSIs* (Nature Conservancy Council 1989), defined such habitats as *semi-natural, that is modified by human activity from its original state but with a vegetation composed of native species, similar in structure to natural types and with native animal communities* (page 10).

2.2.4 Any semi-natural habitat contains a great range of both flora and fauna, but the definition of many habitats rests effectively on a framework of the plant community with which the remainder of the living organisms are associated. As the 1994 United Kingdom Biodiversity Action Plan (Department of the Environment 1994) explains, *ecologists have described habitats most frequently in terms of their vegetation communities. Plants are easier to sample than mobile and often elusive animals, and many plants tend to occur together consistently as well-defined* ***communities*** (page 31 - British Habitats).

2.2.5 The *Guidelines for the selection of biological SSSIs* state that lowland unimproved grasslands have the status of ancient semi-natural communities composed largely of native species (page 91, Lowland Grasslands). MG5 is one such grassland type.

2.2.6 MG5 is distinguished from other lowland neutral (mesotrophic) grasslands in particular by the abundance of a suite of characteristic grass and especially herb species. As Rodwell (1992) in the key to identification of communities in the National Vegetation Classification, states:

There is a complete gradation between rich unimproved stands of the Centaureo-Cynosuretum (MG5) *and the very species-poor swards of the Lolium leys which have been ploughed and reseeded, fertilised and drained (MG7). The above list of dicotyledons* (herbs) *is a generally satisfactory means of separating the Centaureo-Cynosuretum from richer stands of the Lolio-Cynosuretum* (MG6) (partly improved grasslands) *but, in many cases, the best that can be hoped for is to place a stand at particular points along a line of continuous variation.*

MG6 and 7 are not usually considered of sufficient interest for their plant communities to be notified under the SSSI Guidelines.

2.2.7 This means that any assessment of change, or judgement of damage, to MG5 swards must be placed firmly in the context of Rodwell's 'line of continuous variation'. Damage at the community level means that the community has moved from the end of this line represented by species-rich grassland containing many species of high conservation value towards the end represented by species-poor, agriculturally improved grasslands.

2.2.8 Should damage at this level occur, it would affect the fundamentals of ecological interest of a species-rich lowland grassland, because re-creation is so difficult. *The quality of non-recreatability is probably a better integrating measure of nature* *conservation value than any other single factor or criterion. ... Restoring the physical conditions of former habitats is sometimes possible, but it is especially difficult to restore their full and identical range, and even more problematical to replace the full species complement originally present (Guidelines for the selection of biological SSSIs).*

2.2.9 Analyses in this report are therefore directed at assessing the degree and nature of change at the habitat level, by analysis of the community as a whole, as well as examining the nature of that change with reference to particular species involved.

2.3 The grasslands at Brocks Farm

2.3.1 The unimproved MG5 grassland at Brocks Farm originally consisted of two fields. In May 1988, quadrat studies were carried out on both fields using randomly placed 10x10cm quadrats. Some earlier data are available for 1987 but they were gathered too late in the season for a full or compatible assessment of the vegetation (Leach 1988). One field was then transplanted, the other, previously notified as a Site of Special Scientific Interest (SSSI), was left *in situ*. The transplant field was divided into two parts, of which one was transplanted as stripped turf (Turf Transplant) and the other as mixed topsoil and litter (Littered) (Leach *et al* 1992, 1994, 1995a,b, 1997). These operations were carried out with advice on methods from NCC and Bioscan understands that they were done according to the best practice available, including the selection of the best available receptor sites and best practice in moving and establishing the vegetation and turf[5].

2.3.2 Until 1987 (one year before transplantation), the two fields had not been managed for at least 4 years (Annex 1, Leach *et al* 1997). After transplantation, both transplant treatments and the control field had meadow management reinstated, i.e. hay cutting followed by grazing. The manner and timing of reinstatement differed slightly between treatments: these differences reflected the practical consequences of transplant techniques and the suitability of management for the resulting vegetation (Leach *et al* 1997). However, since 1992 all treatments have been managed in the same way, by hay cutting and aftermath grazing by sheep (information supplied to English Nature by the minerals operator).

2.3.3 From 1989 to 1996 vegetation monitoring was carried out in the same way as in 1988 and at the same time of year, with minor differences in the arrangement of strips within which quadrats were taken as an inevitable consequence of the vegetation in turf transplant and litter treatments having moved to a different place (see Leach *et al* 1992 for sampling design). Nine years of quantitative data were available therefore for analysis. Leach *et al* 1992, 1994, 1995a,b, 1997 analysed the Brocks Farm data using categories of life history, function or plant anatomy to characterise species, following Grime *et al* 1988. This report extends the

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[5] It now seems that ECCI are uncertain about the origin of all the littered material and this should be kept in mind when considering the conclusions on the effect of littering (Leach 1997).

analyses given by Leach *et al* by additional methods specifically directed at analysing effects at the community level.

2.3.4 The analyses performed are directed at answering the following questions:

- Do turf transplant and/or littering cause change in the vegetation?
- If so, which changes are provable (ie statistically significant) against a background of natural variation and any changes arising from management? Do provable changes vary with time and if so how and at what speed?
- What is the nature of provable changes. In particular, do they represent damage to the ancient species-rich grassland community?
- Is any such proven damage large enough to be significant in importance as well as merely provable statistically? With enough data, minute changes might be provable: conversely large changes can be difficult to prove statistically without the correct amount and type of data.

3. Methods of analysis

3.1 Introduction

The strategy of analysis has been to concentrate on multivariate methods which examine all aspects of the vegetation simultaneously. Multivariate analyses have been carried out using the computer package CANOCO 3.1 (ter Braak 1987-1992), which incorporates and extends the Cornell Ecology programmes developed by MO Hill (1979). Such methods have the greatest power in defining, detecting and testing change in the vegetation as a whole. Particular categories of species (see 3.6 below) are then examined to illustrate the way in which any proven changes operate in greater detail. In all cases vegetation data were examined as the percentage frequency of species amongst quadrats in a single 'strip', the unit over which randomised quadrats were recorded (see Leach *et al* 1992).

3.2 Detrended correspondence analysis (DCA) - illustrating patterns of variability

The first method used is designed to show the main patterns in variation in species composition observed. DCA (also called DECORANA) stands for detrended correspondence analysis, a standard ordination method originally developed by Hill (1979).

DCA works by arranging the superficially bewildering patterns shown by a large number of samples and species into an objectively logical order based on a technique called reciprocal averaging (Hill 1979). The method does not look outside the information present in a list of species' abundances in different places, so any attempt to explain the patterns produced in terms of environmental variables needs further analysis. Often however the patterns produced by DCA may suggest possible explanations which can then be explored.

The patterns which DCA finds are expressed as scores obtained by samples and the species they contain on a series of 'axes'. The axes are numbered in the order of their importance, which is their relative contribution to the total variability in the vegetation, and each axis is unrelated to all others (independent). Therefore the first DCA axis expresses the most important single source of variation in the vegetation, the second expresses the second most important source, and so on. A large number of axes can be extracted in principle, but in practice the first two or three are usually enough to show any patterns which are important and explainable.

Occasionally, the patterns of variation are so strongly linked to known factors, such as management or soil conditions, that the distinction can be clearly seen on graphs relating the DCA axis scores to each other. One way of testing whether or not these apparent effects are real is simply to relate known factors such as management to the axis scores. This approach is however limited and a more reliable and robust approach is to use detrended canonical correspondence analysis (DCCA - see below) which is specifically designed to test the relationships between variation in the vegetation as a whole and outside factors such as management.

In this study, DCA was used to explore the data structure and check for anomalies which might suggest odd data distributions requiring data transformation, exclusion of outlier samples or species appearing to have a disproportionate effect on the results, or any other modifications. In the event, none were judged necessary. The ordination results are also used to illustrate the more obvious relationships between vegetation and treatment. Testing of these relationships, however, is left to the technique (DCCA) which is designed specifically for this purpose.

3.3 Detrended Canonical Correspondence Analysis (DCCA) - investigating the effects of key variables

DCCA is based on similar underlying principles (ter Braak 1987-1992) to DCA but extends it to consider the 'environmental variables' such as treatments, management or other aspects of the environment which might explain the patterns of variation in the vegetation.

As in DCA, axes of variability in the vegetation are extracted in the order of their importance, but the axes of DCCA are **canonical** axes, constrained to express combinations of the environmental variables measured. The first axis of a DCCA ordination for instance expresses the most important part of the vegetation's variability which can be explained by a combination of the environmental variables measured. The second axis expresses the second most important variation (unrelated to that expressed on the first axis) which can be explained by the same set of environmental variables, and so on. In other words, DCCA looks directly at the variation which is explainable by treatments and other factors measured (such as the treatments of littering and turf transplant) and defines their effect on the vegetation.

3.4 Statistical tests

Vegetation data are notorious for failing to follow the strict assumptions about data which are made by traditional statistical tests. Improvement in techniques of analysis has been made possible by the power of modern computers. CANOCO takes advantage of this power by performing statistical tests which accept the underlying characteristics of the data and operate by generating randomised versions of the data set being considered (Monte Carlo permutations) to see if the variation in the real data could be purely random rather than associated with the effects of the environmental variables. The effects of each variable can be tested in turn and a 'model' built to explain the vegetation which contains only those relationships with environmental variables which would be unlikely to occur by chance. Here, 'unlikely' is regarded as a chance of 1 in 100 (p=0.01) or less that an apparent relationship could have arisen by random effects. Effects which are stronger than this are judged to be proven statistically.

The DCCA models shown in this report have been built by a 'stepwise' testing process which was carried out as follows.

First, CANOCO extracts a statistic (F-ratio) for the effect of each particular variable on its own (derivation in ter Braak 1987-1992). The variable with the largest F-ratio (likely to have the greatest effect) was then chosen to start the model with.

CANOCO then constructs a randomised ('scrambled') version of the real data set (a Monte Carlo permutation) and extracts an equivalent F-ratio for the random data. This was repeated 99 times. If all F-ratios derived from the randomised data set were smaller than the F-ratio from the real data, then the effect of the variable chosen was significant at at least p=0.01 (only one chance in 100 or less of occurring by chance). If significant, the variable was then included in the model. If not significant at p=0.01, the variable was rejected and not used.

With the first variable in the model, the process was then repeated for the variable with the next largest F-ratio, and tested in the same way. The process was repeated until there were no more variables left to include or reject.

3.5 Explanatory models used

Two DCCA models are presented in the analysis. In the first, data from all three treatments (littering, turf transplant and SSSI control) were included. This showed a very strong effect of littering, so strong in practice that it tended to swamp the visibility of the more subtle effects of turf transplanting and the interactions with management over time. Further, the different number of sample units (strips) in the littered plot compared to the other two meant that an explicit test for the way in which changes over time differed between all three treatments was precluded for technical reasons.

Despite the very obvious effect of littering, it appeared from both the DCA plot and the first DCCA analysis that the turf transplant plot was becoming more different from the SSSI control as time passed. Accordingly, a second explanatory model was set up to test this explicitly. Here, only the data from the turf transplant and SSSI control were used.

Further, changes in time which were the same in both treatments (such as weather and accumulating effects from the reinstatement of management) were removed from the model. Technically, the effect of 'year' was removed as a covariable, simultaneously allowing a specific 'repeated measures test' to be performed with CANOCO's Monte Carlo permutations.

In the same model, the interaction between year and time was included as a potential explanatory variable. If this variable were to be significant, this would mean that changes in time were different between the two treatments, ie they were diverging because they started out similar or they started out different and were converging over time.

3.6 Species, categories and other attributes

The proven differences in the vegetation were then illustrated with reference to summary attributes and categories of plants to illustrate the differences and examine their magnitude, i.e. their significance in terms of importance rather than merely their ability to be detected. Attributes and categories examined in this way included species richness and sets of species identified from these DCCA analyses.

3.6.1 Species richness: the average number of species per 10x10cm quadrat.

3.6.2 Indicator species derived from the CANOCO analysis of treatments. This exercise shows directly the magnitude of difference between treatments detected in the CANOCO analysis.

4. Results

In this section, reference is made to species by their English names and acronyms used in the Figures. A full list of species in the data sets used, with acronyms, English and Latin names, is given in Appendix 1. Scientific nomenclature follows Clapham, Tutin & Moore 1987).

4.1 DCA of Brocks Farm data

The most important source of variation in the vegetation (Axis 1 in Figure 1) clearly contrasts the effects of littering and turf transplanting. The second (vertical) axis expresses change which was similar in all treatments over time.

In Figure 1, each point represents the data from a strip in one year. Apparent changes are illustrated by joining all the points within single years and indicating the polygon so formed according to its treatment. Not all years are shown in this manner for clarity, but all points from every year are shown by different symbols for each treatment. However, the average position over all strips in each year is shown. Arrows join polygons to show the directions of change.

The three polygons for 1988 show that the areas subject later to turf transplant and left as SSSI control were closely similar. The future littered plot overlapped with the other treatments but contained one outlier point well separated from the remainder.

Littering however produced an immediate and massive shift in the vegetation, followed by a recovery which appears to have become slow because there has been little movement on axis 1 in recent years.

The managed SSSI control has not moved at all on axis 1 but, like all treatments, has fallen on axis 2.

Turf transplants have changed less than the littered treatment but in 1996 were completely separate from the SSSI control (polygons for the two treatments for 1996 do not overlap).

The main species defining this overall pattern of change are shown in Figure 2, although not every species could be labelled for reasons of space. Species in the top left, judging by the position of strips on Figure 1, appear to be characteristic of littered plots in early years. Bottom left species are littering species from later years, bottom right late turf transplant species and top right are turf transplant species characteristic of early years.

The species involved confirm the findings reported in Leach *et al* (1997). It appears that early littering species are those commonly associated with disturbance such as creeping buttercup (RANREPE) and scarlet pimpernel (ANAGARV) and also species of open wet vegetation such as toad rush (JUNCBUF) and bristle club-rush (ISOSETA). Later on, coarse grass and shrub species appear such as gorse (ULEXEUR) and creeping soft grass (HOLCMOL), and at the extreme bottom left two MG5 species: heath grass (DANTDEC) and ox-eye daisy (LEUCVUL).

The change in turf transplant is more difficult to identify in this purely descriptive analysis. Early on there are large-seeded and other coarse species which often persist (tufted vetch (VICICRA), meadow vetchling (LATHPRA)) or increase (the species pair smooth meadow grass/spreading meadow grass POAPRAT) in semi-improved as opposed to unimproved grasslands. Later on corky-fruited water dropwort (OENPIMP) appears. This is usually associated with unimproved grassland but in south-west England can also be found in semi improved grassland (MG6) (Stewart, Pearman & Preston 1994).

The main characteristic of the pattern is however the massive displacement associated with littering, followed by the changes in all vegetation types over time. These effects appear to swamp any other changes.

Connection of these causes to the species and sampled areas (strips) can only be tested however by using DCCA.

4.2 DCCA of all Brocks Farm data

Figure 3 shows the strength and nature of the effects of each 'environmental' variable which proved to be statistically significant. Variables are shown by arrows: the longer the arrow the stronger the effect. The horizontal axis is the most important (canonical axis 1), the vertical axis the next most important (canonical axis 2). The most important contrast is clearly between the opposing effects of littering (to the right of axis 1) and turf transplanting (to the left). More quadrats happened to be taken in the littered treatment than elsewhere: hence the number of quadrats taken within a strip (Nquads), included for completeness, matches with that associated with littering.