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SID 5 Research Project Final Report

Department for Environment Food and Rural Affairs

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Project identification

1. Defra Project code: BD1321

2. Project title: Response of grassland plant communities to altered hydrological management

3. Contractor organisation(s):
Institute of Water and Environment
Cranfield University
Silsoe
Bedford
MK45 4DT

4. Total Defra project costs: £ 97,124.14

5. Project: start date .... 01 July 2002

   end date .... 30 June 2005

6. It is Defra's intention to publish this form.
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(a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

Floodplains constitute a valuable component of the British landscape, not only because of their distinctive grassland communities, but also for their diverse fauna and their important ecosystem processes. In order to conserve floodplain habitats, an understanding of the environmental tolerances of their vegetation is essential. This project aimed to quantify the response of floodplain grasslands to altered hydrology. Such information is required for the UK Government in order to meet its obligations under a number of national and international agreements, but in particular to ensure value for money within the new Environmental Stewardship Scheme.

The project is an extension to project BD1310, which reported in 2002, but which, as a result of the Foot and Mouth Disease outbreak in 2001, failed to achieve its objectives fully. The current project's objectives were to complete work begun in the earlier project and to extend that work at 3 sites (Cricklade, East Cottingwith & Moorlinch), in order to describe the direction of vegetation change over time.

Major findings of the work

- It was possible to simulate the water-table depth across the site at East Cottingwith (N. Yorks) using a hydrological model based on a water-balance approach. This allowed the vegetation responses to be interpreted with respect to the prevailing hydrological regime.
- Over the period of the two projects (1998-2004), the hydrological regime at all sites was more strongly regulated by rainfall pattern than by water-level management. This is an important result in the context of interpreting vegetation monitoring data from environmental land management schemes.
- The exceptionally wet period of 1999-2001, with the highest 36-month total rainfall on record, had a major impact on vegetation dynamics and masked the effect of hydrological manipulations, such that the effect of management could only be seen in the latter years of the project (2003, 2004). This limited the conclusions that could be drawn about effectiveness of hydrological interventions.
- Classification of individual relevés (vegetation samples) to a community type proved a robust method for describing vegetation dynamics. Two contrasting methods of community assignment were used. They gave very similar results in terms of the direction and extent of change within the vegetation, though the absolute numbers assigned to particular categories was dependent on which method was used.
- An experimental intervention to improve the surface drainage efficiency at one site appears to have facilitated the recovery of a species-rich community, but continued monitoring is required to confirm this.
- The implementation of the Raised Water Level Area at Moorlinch appears to have had little impact on the vegetation to date. This is partially because the site's former water regime already approached the raised-water-level targets and partially because the response to the wet period, 1999-2001, masked more subtle responses.
- Comparing correlations between rate of change in community type and the preceding water regime over a variety of time-scales, showed that the vegetation was most strongly related to a cumulative measure of soil wetness over a period of 2 to 3 years prior to survey.
- Taking a 3-year mean value for soil wetness, a regression equation was derived to describe the observed rate of community change at Cricklade. This relationship was then tested at East Cottingwith to see if the water regime could predict the rate of community change. The results were positive.
- The observed rate of loss of a species-rich community was more rapid during years that exceeded a wetness threshold, than the subsequent rate of recovery during years that were less wet.
- At all three sites, ordination techniques were used to explore the changes in community composition over time. In all cases, water regime appeared to be the major variable correlating with botanical variability. The data also suggested that nutrient availability may be an important secondary factor.
- Analysing the data at a species-level, a number of potential indicator species were identified that responded to the prevailing soil hydrology over different timescales. This information will be useful for interpreting monitoring data gathered following hydrological perturbation of sites.

Main implications for policy

- Priority for improved hydrological management should be given to conserving existing species-rich stands over efforts to rehabilitate species-poor stands, as the rate of species loss is more rapid than the rate of species gain.
- Although rates of species gain are low, the data gathered here suggests that substantial increases

in species-richness, and indeed development of a species-rich community can be achieved within a timescale of 10-20 years when a hydrological impediment is removed and therefore some positive results can be expected within the timeframe of an agri-environment agreement.

- Due to the lag time or "inertia" involved in the relationship between hydrological change and vegetation response, it is important to monitor the vegetation at a community level in order to investigate long-term changes. However, the use of relevant indicator species may be appropriate if initial responses to a hydrological perturbation are of interest.
- The response of vegetation to hydrological management is often masked by its response to the variation in rainfall patterns from year to year. It is therefore essential when interpreting vegetation surveys to do so in the context of the prevailing meteorological conditions. The information provided by this and previous Defra-funded research allows that interpretation to be accomplished.

Implications for future research

- The regression model described here for predicting vegetation change requires further testing to check its general applicability and transferability between sites.
- The data gathered have allowed us to describe the response of floodplain grasslands to periods of enhanced wetness, because that was the situation experienced within the time frame of the projects (1998-2004). Continued monitoring is required to describe the equivalent response to drought.
- Interpretation of the data by ordination has reinforced a hypothesis that flood-deposited nutrients are also a significant driver of plant community composition. Further field monitoring of sediment deposition across a range of floodplain habitats would confirm its importance. Such information would be particularly important for future compliance with the European Water Framework Directive.

Follow up actions

The project team intend to develop a technical advice note (TAN) for the Rural Development Service (RDS) summarising the project results. They will also offer a short course for RDS officers to train them in managing soil hydrology on floodplains for biodiversity objectives.

The results are being written up for publication in the scientific literature and on-going collaboration with project BD1322 (re-instatement of surface grips) aims to ensure the understanding gained from this project is used to guide recommendations from that one.

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

BD1321 Response of grassland plant communities to altered hydrological management

1. Introduction

Understanding the environmental tolerances of species-rich floodplain grasslands is important for enabling the UK government to fulfil its obligations under a number of commitments:

- implementation of the European Habitats Directive
- meeting its Public Service Agreement target for nationally important wildlife sites
- achieving the targets set by the UK Biodiversity Action Plan
- ensuring value for money from the Higher Level Stewardship scheme.

It has been established that the composition of floodplain grasslands is highly sensitive to soil water regime (e.g. Gowing *et al*., 1997). Therefore, in order to conserve this habitat in a favourable condition, it is necessary to understand not only the water-regime tolerances of the key plant communities and their component species, but also the rate at which they respond to altered hydrology. The project reported here extends the information presented in the final report for BD1310 (Gowing *et al*., 2002). That project was unable to complete all of its 6 objectives as a result of the Foot and Mouth Disease (FMD) outbreak in 2001.

The data presented here are intended primarily to support the new flexible agri-environment scheme, Higher Level Stewardship (HLS), which allows tailored hydrological management to be incorporated into habitat-enhancement schemes, but they should also prove valuable for meeting the other policy objectives listed above.

2. Objectives

The project had the following four scientific objectives set out in its original proposal and they remain unamended:

1. To validate the conceptual hydrological model that was developed for East Cottingwith Ings, N.Yorks, under project BD1310, using newly collected dipwell data.
2. To complete BD1310 objective 5, "To characterise the relationship between the rate of change in the composition of plant communities and the shift in water regime on hydrologically-altered sites."
3. To describe the trajectories of change observed in the plant community composition at 3 case study sites to provide reference information for managers undertaking similar schemes.
4. To complete BD1310 objective 6, "To develop appropriate methods for interpreting data and designing monitoring strategies for grassland sites subject to hydrological manipulation, such as in wetland ESAs and other agri-environmental schemes involving water-level management."

All of these objectives were met within the proposed timetable. Progress of the project was highly dependent on the prevailing weather conditions, particularly rainfall patterns, as they influenced the water-regime and hence the plant community composition on the sites. One reason why objective 2 had not been completed satisfactorily within project BD1310 was that the years 1999-2001 comprised the wettest 36-month period on record and therefore the effects of altered hydrological management were masked by the extraordinary meteorological conditions. Fortunately, the Springs of 2002-2004 had average or below average rainfall, allowing the effect of the management to be better assessed.

On-going work is still in progress in partnership with the Rural Development Service to format the output from this project into one or more Technical Advice Notes for their advisers.

3. Methods

Three sites were selected for this study:

- Cricklade North Meadow NNR (cSAC), Wiltshire
- East Cottingwith Big Ings, Lower Derwent Ings SSSI (cSAC), North Yorkshire.
- Moorlinch SSSI (SPA), Somerset

All three had previously been investigated as part of the former project BD1310 and their soil types characterised (Table 1). All had originally been selected within project BD1310 on the basis that a change in hydrological management was planned.

At **Cricklade North Meadow**, the project team organised the re-instatement of a blocked culvert in one section of the field, denoted the "treatment"area. This allowed surface water to flow off the area more rapidly. A second area denoted the "control" area was set up to monitor the annual fluctuations in species composition in response to the weather.

East Cottingwith Big Ings was part of a scheme to increase the area of surface water standing on the floodplain of the Lower Derwent Valley, with the objective of increasing the usage of the site by breeding waders (Tim Dixon, English Nature, pers. comm.) Two areas were monitored with the expectation that one would be more acutely affected by the raising of water levels than the other. However, due to the SSSI being denoted a candidate Special Area for Conservation under the Habitats Directive on account of its floodplain meadow (MG4) community, the plan to increase its wetness was abandoned. Indeed, the revised plan for the site, partly as a result of previous Defra-funded research (Gowing *et al*., 1997), involves improving the surface drainage to avoid water standing for prolonged periods. During the lifetime of the project, management has not led to hydrological differences between the two areas; the changes in community composition have nevertheless been interesting, but entirely driven by rainfall patterns.

The site at **Moorlinch** is composed of a large number of small fields. Three of the agriculturally less improved fields were selected for monitoring; two within the area designated to become a Raised Water Level Area (RWLA) within the Somerset Levels and Moors Environmentally Sensitive Area (ESA) scheme and one outside the engineered block to be used as a control. The raised water level regime was implemented in 2001/2002 and the botanical response followed for the next three seasons.

The sites at Cricklade and Moorlinch already had operational hydrological models (Gowing *et al.,* 2002) and East Cottingwith had a provisional one that had not been fully validated due to the outbreak of FMD in 2001 preventing tubewells and stage boards from being monitored.

Table 1. Location and soil type for the three sites used in the study

Site Name	Grid Reference	Soil Association	Soil type
Cricklade	SU096958	Thames	Clay loam over sand
East Cottingwith	SE700420	Fladbury 3	Alluvial clay overlying silt
Moorlinch	ST393362	Altcar 1/Midelney	Peaty clay / peat

3.1 Hydrological modelling

To validate the hydrological model at East Cottingwith, an additional stage board was placed in the back ditch in autumn 2002 and fortnightly readings of it plus eight tubewells within the field were taken by the land-owners, Mr Robert Burnett and Mrs Joan Burnett. Soil hydraulic properties were measured *in situ* and undisturbed cores were taken for laboratory analysis

Meteorological data for all three sites for the period June 2001-May 2004 were purchased from the Met Office and information about river stage levels were sourced from the Environment Agency to supplement earlier data gathered under BD1310.

The information was used to extend the modelling data at Cricklade and Moorlinch up to and including May 2004 and at East Cottingwith to validate the spreadsheet-based water-balance model for estimating weekly water-table depths, developed within the earlier project.

3.2 Botanical recording

All three sites were botanically surveyed in June for each of the three project years: 2002, 2003 and 2004. A total of over 1500 samples were taken from permanent positions, established during project BD1310, to monitor the response of the plant community composition to the prevailing hydrology.

Each sample comprised a full species list of all vascular and bryophyte species found in a 1 m x 1 m quadrat together with a visual estimate of each species' cover on a percentage scale. The recording was undertaken by Ecological Surveys (Bangor), whose two botanists performed all the surveys both within this project and its predecessor, thereby ensuring consistency of method. The botanists regularly compared their cover-estimate scoring to ensure quality control. The quadrat positions were not permanently marked, but were re-located each year using Total Station surveying equipment, which has the ability to pinpoint locations with centimetre accuracy from a single marked position at a site. The accepted error for relocation was ±0.03 m.

The botanical nomenclature used follows Stace (1991) and the data were entered via the Vespan package (Malloch, 1999).

3.3 Community assignment

Two parallel methods were used for allocating each sample (relevé) to a community type. Both methods were based upon the community types described in project BD1310 (Gowing *et al.,* 2002), which drew on a total of 3904 relevés across 18 separate floodplain-grassland sites within England. That dataset represented the largest of its type for the UK and by use of the classification package TWINSPAN (Hill, 1979), 12 distinct grassland community types were identified and then related to the National Vegetation Classification (Rodwell, 1992, Rodwell *et al.*, 2000). These community types are summarised in Table 2.

The first method was to analyse the full time-series data set for each site using the TWINSPAN approach with up to 6 divisions to give tightly-defined clusters of relevés, which were then re-grouped by a subjective interpretation of their synoptic tables. The second method used a dissimilarity metric known as mean character difference (Czekanowski, 1909) to compare individual relevés with the synoptic tables for the communities in Table 2.

Table 2. Community types used within this report and their relationships to those listed in Project BD1310, to alliances used in continental phytosociology and to the British National Vegetation Classification (NVC).

Label used in this report	BD1310 Twinspan Endgroup	Alliance according to continental phytosociology	Community name based on the British NVC
MG4	2	Alopecurion*	*Alopecurus pratensis - Sanguisorba officinalis* grassland, typical community
MG4 spp-poor	4	Alopecurion*	*Alopecurus pratensis - Sanguisorba officinalis* grassland, species-poor variant
MG7C	7	Alopecurion*	*Lolium perenne – Alopecurus pratensis – Festuca pratensis* grassland, species-rich variant
MG8 *Carex*	9	Calthion	*Cynosurus cristatus - Caltha palustris* grassland, *Carex* spp. Variant
Agrostis - Carex distans	10	Calthion	*Agrostis/Carex* grassland, *Carex distans* variant
Agrostis - Carex	11	Calthion	*Agrostis/Carex* grassland, typical community
MG13	12	Potentillion	*Agrostis stolonifera – Alopecurus geniculatus* grassland, *Alopecurus pratensis* variant

*This vegetation has traditionally been regarded as part of the *Cynosurion* alliance, but recent revisions of European classifications (e.g. Schaminée *et al.,* 1996) place it within a separate *Alopecurion* alliance.

3.4 Hydrological interpretation

The previous project, BD1310, had identified the degree of soil waterlogging, as measured by the Sum Exceedence Value (SEV) method (Sieben, 1965; Gowing *et al*., 2002), as the strongest determinant of community composition in floodplain grassland. Therefore, this variable was derived from the weekly data estimating water-table depth beneath ground surface, which formed the output of each hydrological model. The SEV waterlogging figure was calculated for the year 1 June to 31 May, thereby representing the 12-month period prior to each botanical survey.

3.5 Statistical analysis

The trajectory by which the community composition changed with time was investigated using ordination techniques (De-trended Correspondence Analysis) and the role of environmental variables was informed by overlaying the ordination with supplementary variables. The response of individual species to prevailing soil hydrology was assessed *via* correlation matrices.

The utility of the overall approach was tested by using a regression equation derived at one site to predict community response at a second. Predicted and observed values were used to calculate a correlation coefficient which was then tested for significance using a t-test.

4 Results

4.1 Hydrological modelling

All variables required to run a model of the East Cottingwith site were collated and the water-table-depth threshold values for the site were calculated (Table 3).

Table 3. Soil parameters used for hydrological modelling of the East Cottingwith site. Rainfall, evapotranspiration (ET) and soil moisture deficit data taken from Smith and Trafford (1976).

Rainfall (mm)	Potential ET (mm)	Soil moisture deficit at end July (mm)	Topsoil hydraulic conductivity (m day^{-1})	Sub soil hydraulic conductivity (m day^{-1})
643	486	85	0.13	<0.01
Topsoil drainable porosity	**Subsoil drainable porosity**	**Unsaturated hydraulic conductivity exponent (m^{-1})**	**Soil drying threshold depth (m)**	**Aeration threshold depth (m)**
0.13	0.09	3	0.481	0.264

Using the run of field observations from tubewells during the period 1998-2004 (except for the interlude affected by FMD), it has been possible to validate the model output for the East Cottingwith site (Figure 1). A water-balance approach was taken since measurements of lateral seepage in the field indicated that the subsoil was effectively impermeable, which agreed with an earlier soil survey at the site (Palmer and Holman, 2002). A layer of humic, silty soil was found at a depth of over 2 m, which may have high permeability, but it was concluded that this layer was effectively confined by the overlying clay and therefore unlikely to influence the water-regime of the root zone.

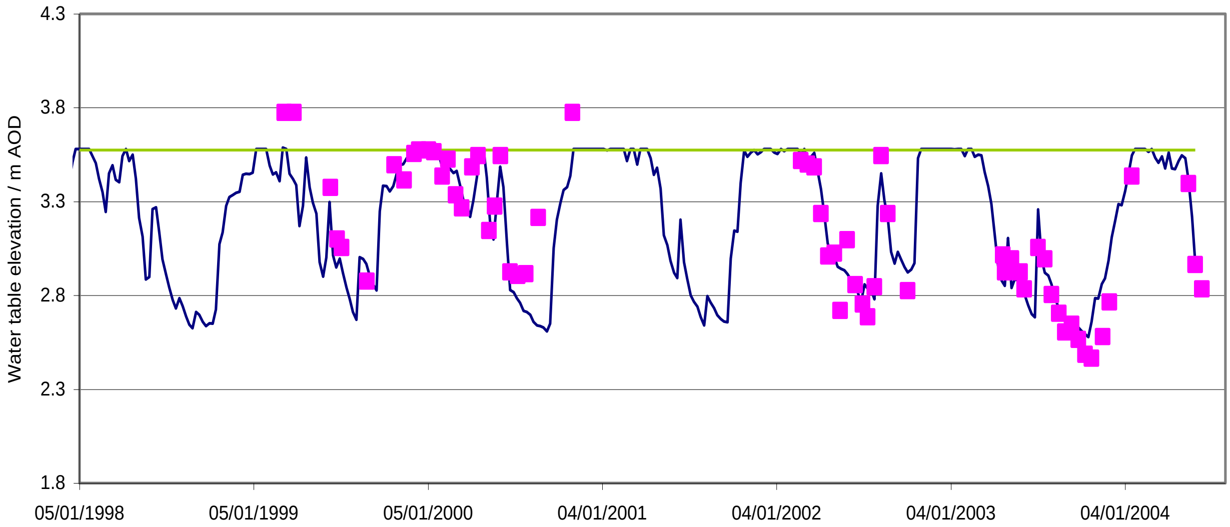


Figure 1. Model output (dark line) for a central tubewell at East Cottingwith compared to field observations for that well (square symbols). The ground surface elevation is shown by the horizontal line at 3.58 m AOD. (Note that the model does not predict depth of surface water).

In order to set the scene in terms of the prevailing meteorological conditions over the lifetime of the project, Figure 2 presents data relating to the rainfall at each of the sites. These meteorological data, particularly rainfall totals during the spring period, were a major driver to the soil water regime, as simulated by the hydrological models.

For the Cricklade and Moorlinch sites, the previously validated hydrological models described in project BD1310 were used to simulate the water-table regime during the period 2001-2004 using weather data purchased from the Meteorological office and water-level data from surrounding watercourses provided by the Environment Agency.

The output from the hydrological model for each site was interpreted in terms of a Sum Exceedence Value (SEV) that cumulates the degree to which water-tables rise above an aeration threshold* and thus creates potential waterlogging stress in the root zone. This parameter of water regime was chosen based on the results of the earlier project (BD1310) which showed soil waterlogging to drive short-term changes in plant community composition. Figure 3 presents the pattern of waterlogging for each site.

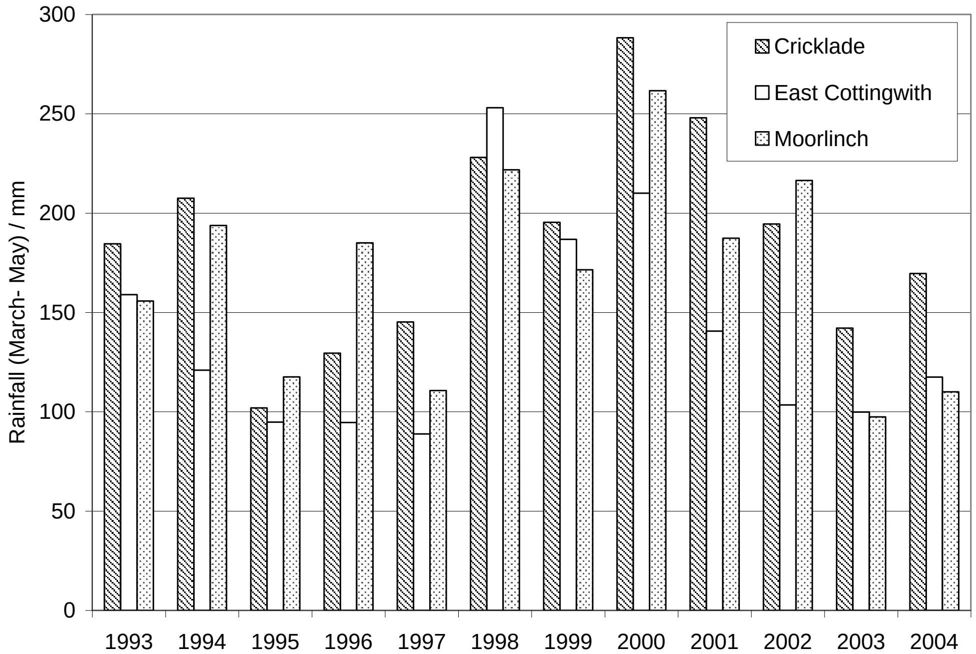


Figure 2. Rainfall totals during spring (March to May inclusive) for each of the three sites.

* The aeration threshold is the water-table depth required to ensure the soil has at least 10% air-filled porosity to a depth of 100 mm. The value is derived from the soil's moisture release characteristic.

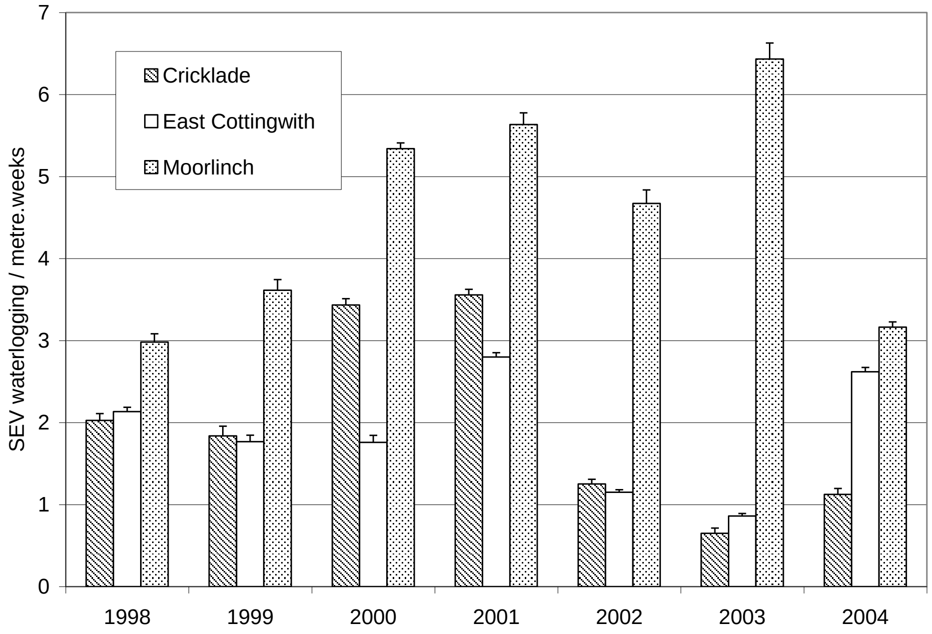


Figure 3. The annual mean Sum Exceedence Value for soil waterlogging at each site over the monitoring period. Error bars represent the standard error of the mean across all positions at each site.

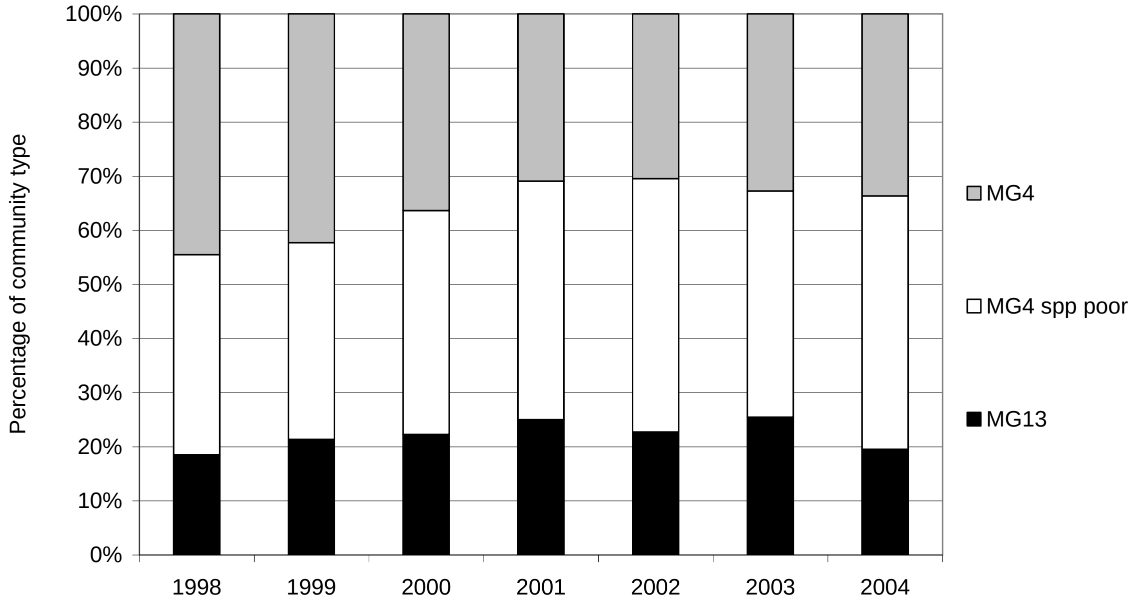
It can be seen from Figure 3 that the waterlogging experienced by the Cricklade and East Cottingwith sites is broadly similar (reflected in their similar plant communities), but that the soil at Moorlinch is substantially wetter during the growing season, giving rise to a different suite of communities. It is also of note that although the broad meteorological pattern was similar across all three sites, the impact in terms of soil waterlogging is different due to differences in site hydrological system and management. Cricklade experienced abnormally wet soil conditions in 2000 and 2001, whilst East Cottingwith had "extreme" events in 2001 and 2004. Meanwhile, Moorlinch experienced 4 wet years in succession, 2000-2003.

The impact of these hydrological variations on each of the three sites, in terms of changes in their plant community composition, will now be considered in turn:

4.2 Cricklade North Meadow NNR

The vegetation at Cricklade was assigned to one of three of the community types described in BD1310 (Table 2): namely MG4 (mean richness of 28 spp m^{-2}), MG4 spp-poor (mean richness of 19 spp m^{-2}) and MG13 (mean richness of 11 spp m^{-2}). Figure 4 illustrates how the extent of these three types altered during the period 1998-2004.

a)



b)

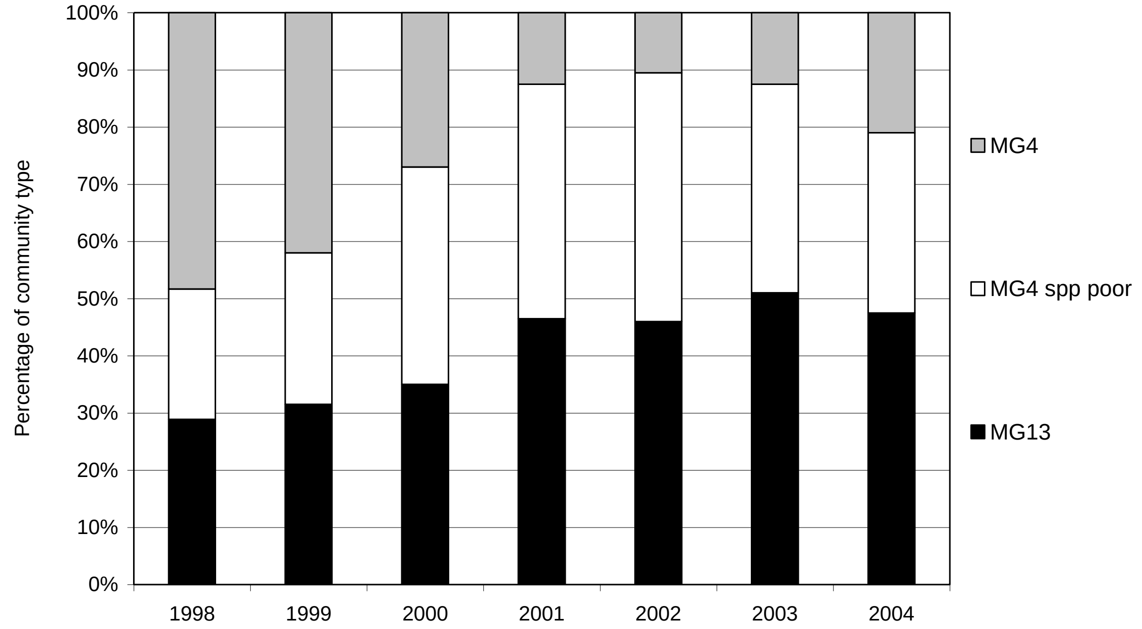
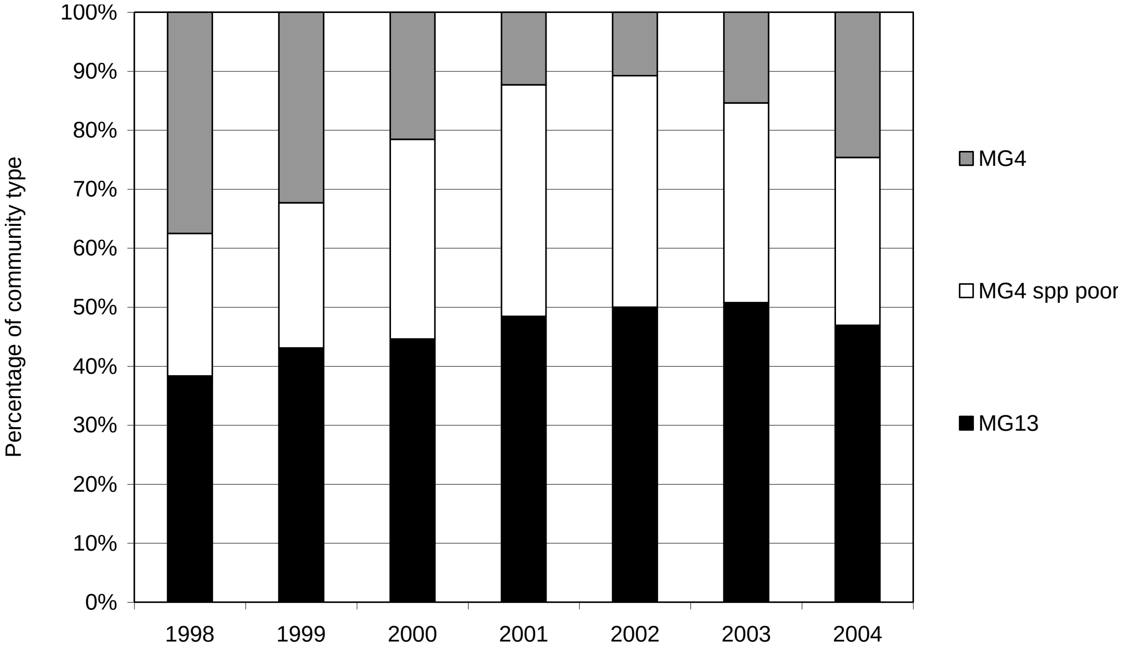


Figure 4. The percentage of samples by community type for each year: a) as assigned by TWINSPAN analysis, and b) as assigned by mean character difference.

The two assignment methods gave slightly different results with the TWINSPAN approach tending to place more samples within the "drier" communities. However, the pattern of change is very similar in both; the wet years of 2000 and 2001 causing a contraction in the area of the "drier," species-rich MG4 community and an expansion in the "wetter" MG13 category. In the analysis below, only results from the mean character difference approach have been used.

Figure 5 reveals the differential response of the two separate monitoring areas at Cricklade. Although both were impacted by the same meteorological drivers, the recovery in the "treatment" area is more marked.

a)



b)

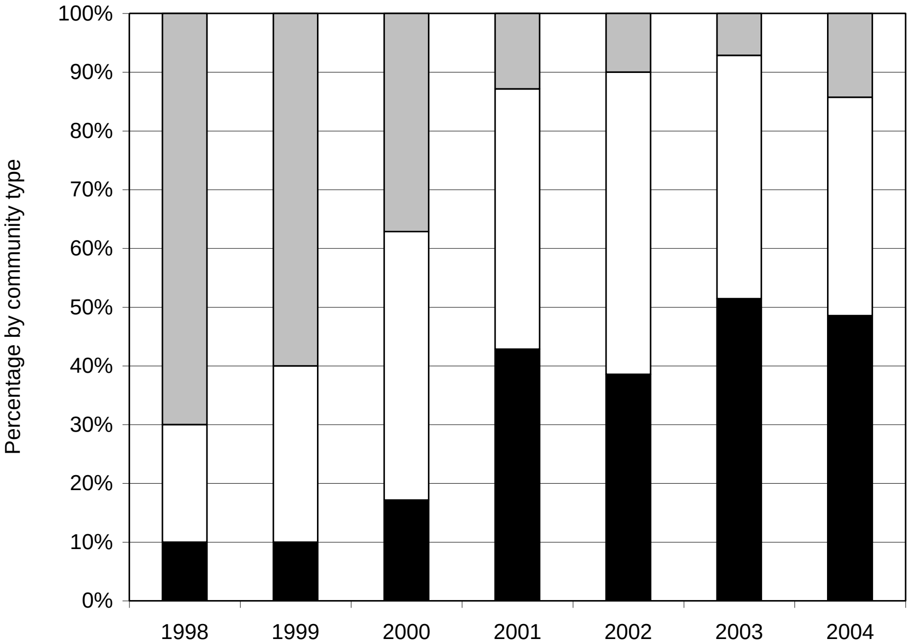


Figure 5. The allocation of samples to community type in the two monitoring areas on Cricklade North Meadow, using mean character difference (cf Fig 4b). (a) Treatment, (b) Control. The same key applied to both charts.

The “treatment” area held the “wetter” vegetation in 1998 and the expectation was that, through enhancement of surface drainage, its community composition would approach that of the “control” area. However, both areas were then affected by the exceptionally wet springs of 2000 and 2001, which postponed the response to treatment. The situation in 2004 now shows both areas to have a similar percentage of the wet MG13 community, but the treated area has the greater proportion of the dry MG4 type. To look at the trajectory of community change over time, ordination methods were used. Figure 6 shows an unconstrained ordination of the relevés recorded at Cricklade, divided into the two areas.

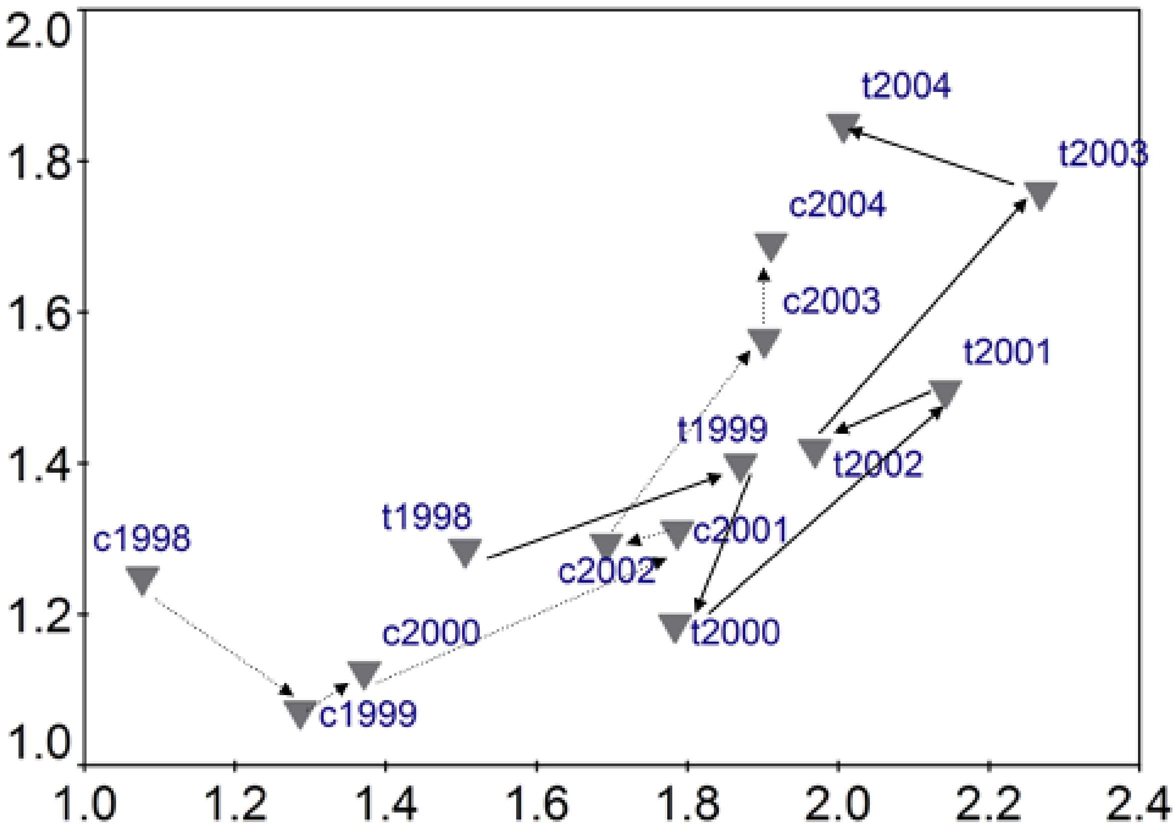


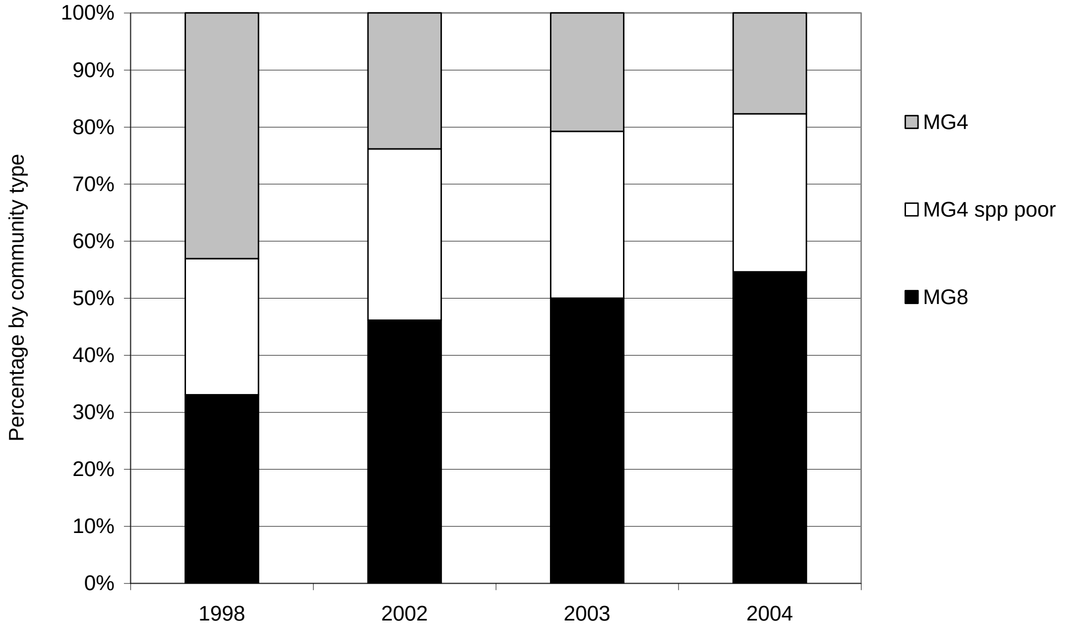
Figure 6. Change in community composition within the two areas on Cricklade North Meadow. The plot shows the centroids for all the samples within one of the two areas on an unconstrained ordination diagram produced by detrended correspondence analysis (DCA). The centroids are labelled with the area ("t" for treatment and "c" for control and the year of survey). The solid arrows denote the trajectory of the treatment vegetation and the dashed arrows that of the control vegetation. The horizontal axis represents Axis 1 of the ordination (eigenvalue 0.57) and the vertical axis is Axis 2 (eigenvalue 0.19). The associated species plot for the ordination is given in Appendix A.

The two areas at Cricklade show similar trajectories during the period 1998-2003 (though slightly displaced due to their different starting positions). The only notable deviation is in 2004 when the treatment area appears to be moving back along Axis 1 (horizontal axis) towards the 1998 baseline position, whilst the control area gives no indication of that trend.

4.3 East Cottingwith Big Ings (part of Derwent Ings SSSI)

The vegetation at East Cottingwith was originally surveyed at 130 permanent quadrat positions in 1998 and then again each year between 2002-2004. Each relevé in each year was assigned to a community type using the same methods as for Cricklade (see section 4.2). The results are presented in Figure 7.

a)



b)

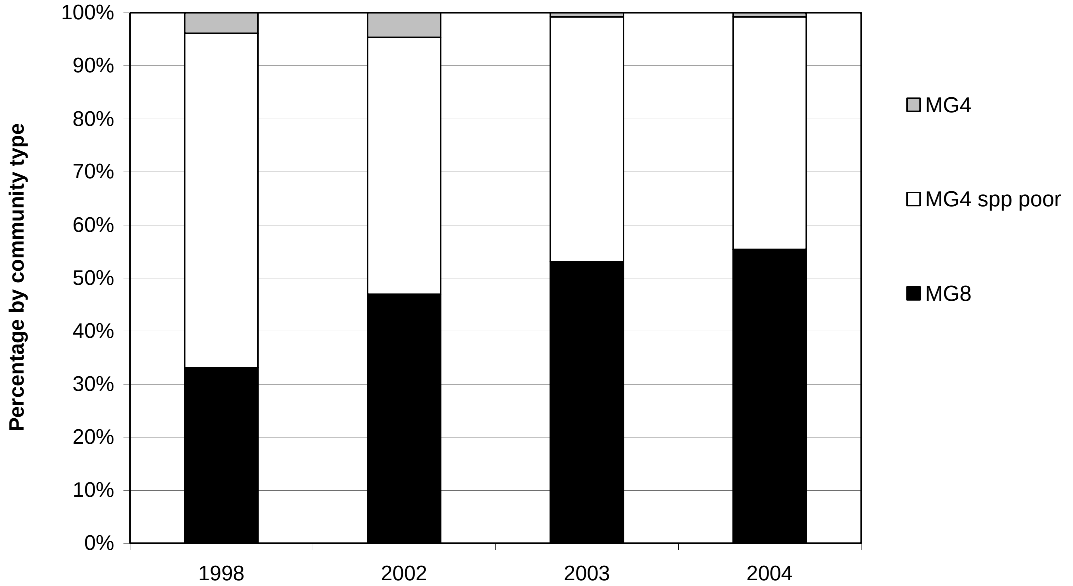


Figure 7. The percentage of samples by community type for each year: a) as assigned by TWINSPAN analysis, and b) as assigned by dissimilarity metrics.

Again the TWINSPAN approach has allocated more relevés to the "drier" communities, but again the pattern of change is the same whichever method is used. The extent of the dry MG4 community has declined steadily over the whole period, until it has all but disappeared if the dissimilarity approach is used. There was no discernable difference in pattern of community assignment between the two blocks (this is as expected given that the planned treatment was never implemented and therefore all the changes observed at the site have been meteorologically driven). This is illustrated by Figure 8 which shows the trajectories of vegetation change for the two areas separately.

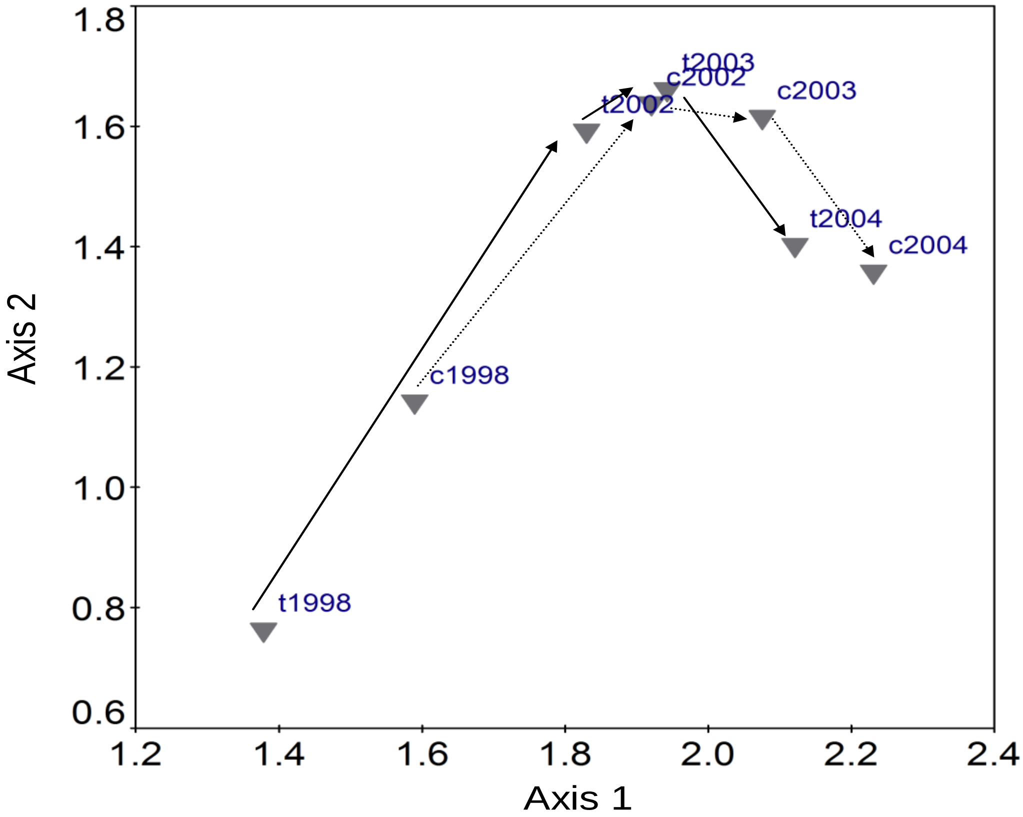


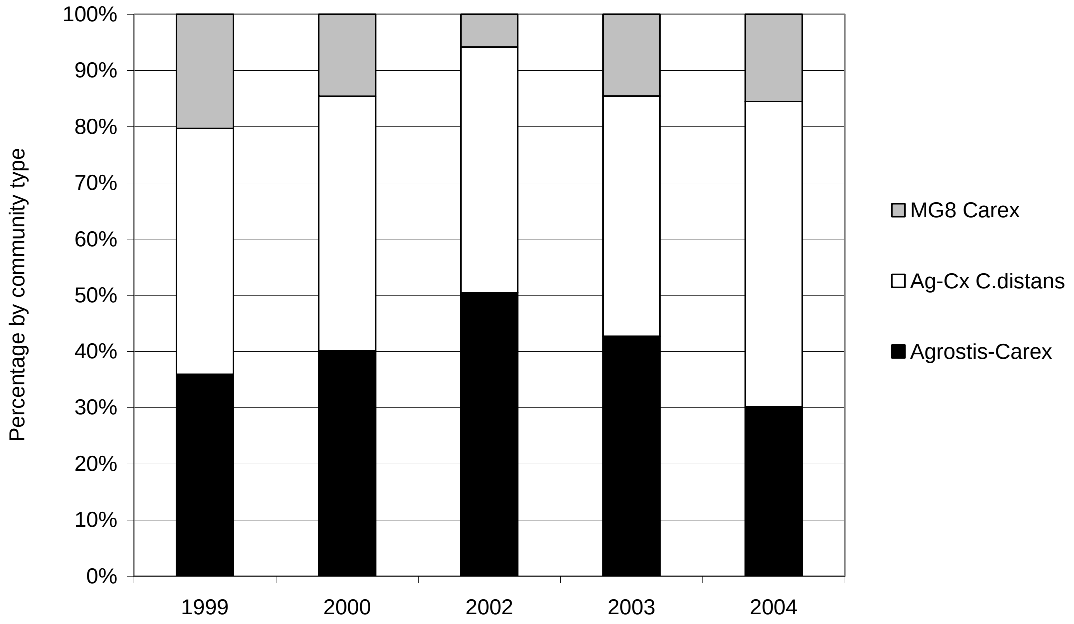
Figure 8. Change in community composition within the two areas on East Cottingwith Big Ings. The plot shows the centroids for all the samples within each of the two areas on an unconstrained ordination diagram produced by detrended correspondence analysis (DCA). Axis 1 has an eigenvalue of 0.53, whilst axis 2 has 0.21. Labelling of centroids is as for Figure 6.

Both trajectories show sustained movement along Axis 1, but a reversal of direction with respect to Axis 2 during the final year.

4.4 Moorlinch SSSI

The vegetation at Moorlinch was distinct from that at the other two sites. This may in part be because its hydrological system maintains water-tables close to the surface throughout the spring (see Fig. 3). Therefore a different set of communities need to be considered for this site. The most species-rich expression is the community labelled MG8 *Carex*. It, in common with the species-rich communities at the other two sites, appears the least tolerant of waterlogging. There is a transitional community, labelled *Agrostis-Carex Carex distans* grassland, to reflect the high constancy of distant sedge (*C. distans*) within the vegetation type. The wettest vegetation conforms to *Agrostis-Carex* grassland; a community not originally listed within the NVC, but subsequently recognised in the UK and occurring elsewhere in Europe (Rodwell *et.al*, 2000). Assignment of the relevés to community type is displayed in Figure 9.

a)



b)

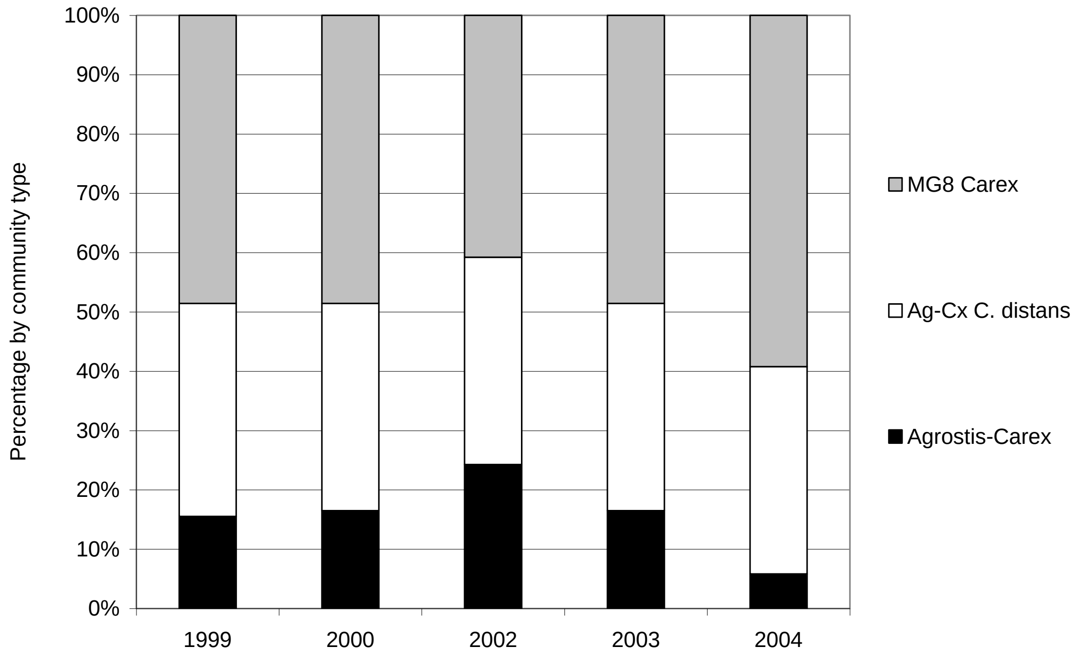


Figure 9. The percentage of Moorlinch relevés by community type for each year: a) as assigned by TWINSPAN analysis, and b) as assigned by mean character difference.

As for the other two sites, although the TWINSPAN approach has allocated more relevés to the drier communities, the two methods are in close agreement in terms of community change. The changes have been less marked than at the other sites, showing an initial movement toward the wetter community, but a reversal in response to the dry spring in 2004.

The implementation of the Raised Water Level Area occurred in 2000, but does not appear to have significantly changed the water regime of the affected fields. It transpired that the previous management of ditches in the area had approached the requirements of the ESA Raised Water Level prescription and therefore formal entry into a scheme had limited effect. The three fields sampled each had slightly different vegetation types, presumably as a result of past management, and similar patterns of community change were found across the treated and control areas. Figure 10 gives the trajectories of change in ordination space.

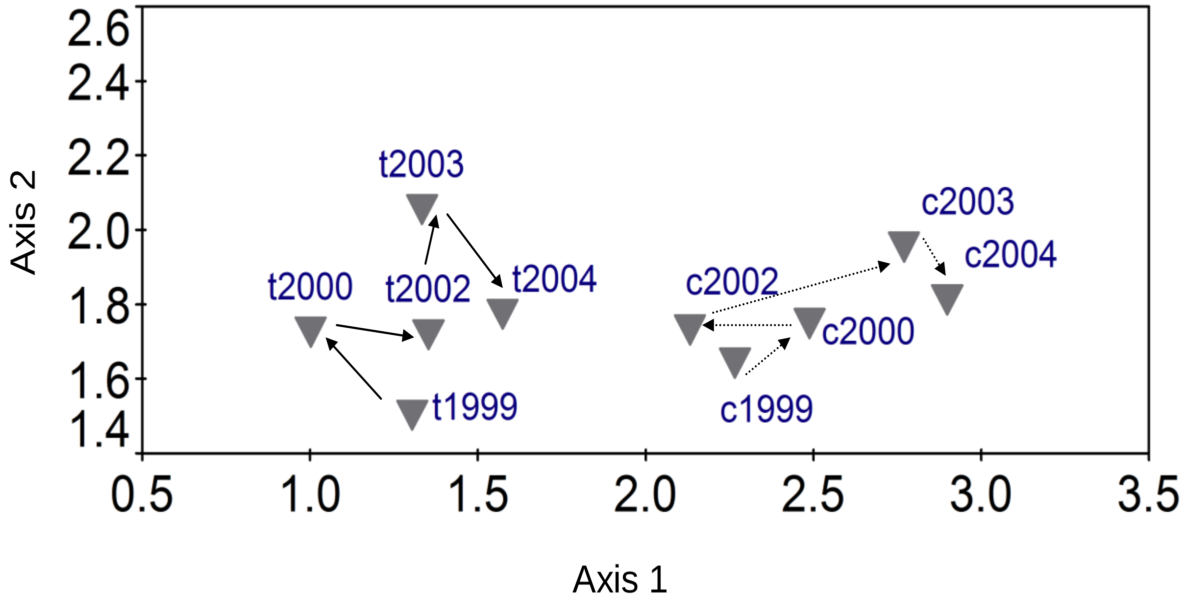


Figure 10. Change in community composition within the two areas on Moorlinch SSSI. The plot shows the centroids for all the samples within each of the two areas on an unconstrained ordination diagram produced by detrended correspondence analysis (DCA). Axis 1 has an eigenvalue of 0.47, whilst axis 2 has 0.33. Centroids are labelled as described for Figure 6.

The two trajectory paths do not show a clear directional change. The offset of the two patterns reflects the different starting points, which may be a result of past management.

4.5 Changes in species abundance

The cover scores of all the individual species monitored as part of the project were analysed to investigate whether changes at a species-level were a more sensitive measure of hydrological change than was community assignment. To achieve this, a correlation matrix was constructed for each site in which correlation coefficients for each species against various measures of soil waterlogging were calculated. Three periods of waterlogging were considered:

1. The 12 months immediately prior to survey in June (WL 12m)
2. The 12 months which ended in the previous June (WL lag)
3. The 36-month period prior to the survey (WL 36m)

This was done to reveal the degree of inertia some species might show to change and whether there are lag effects between a hydrological change and individual species responses. Appendix B holds the matrices of correlation coefficients. To summarise the data set, the species which showed responses to water regime that were both statistically significant and consistent across all three sites were selected and categorised in terms of whether their abundance responded positively or negatively to waterlogging and to which of the three time periods the response was strongest. The results of the categorisation are shown in Table 4.

Table 4. Species whose abundance showed a consistent significant relationship to soil waterlogging across all sites at which it was recorded. If a species could be listed in more than one category, it has been placed in the one where it showed the stronger (or more consistent) response.

Period of waterlogging	**12 months up to survey date (WL 12m)**	**12-24 months prior to survey date (WL lag)**	**Three year period prior to survey date (WL 36m)**
Positive response (increase in cover with increase in waterlogging)			
Species	*Glyceria fluitans* *Carex nigra*	*Agrostis stolonifera*	*Galium palustre* *Myosotis laxa*
Negative response (decrease in cover with increase in waterlogging)			
Species	*Cerastium fontanum* *Lathyrus pratensis* *Rumex acetosa*	*Alopecurus pratensis* *Bromus commutatus* *Bellis perennis*	*Cynosurus cristatus* *Festuca rubra* *Plantago lanceolata* *Ranunculus acris* *Trifolium pratense*

The mean abundance values for six of the species in Table 4 are presented in Figure 11 to illustrate the extent of variation over the timescale of the project.

a)

b)

c)

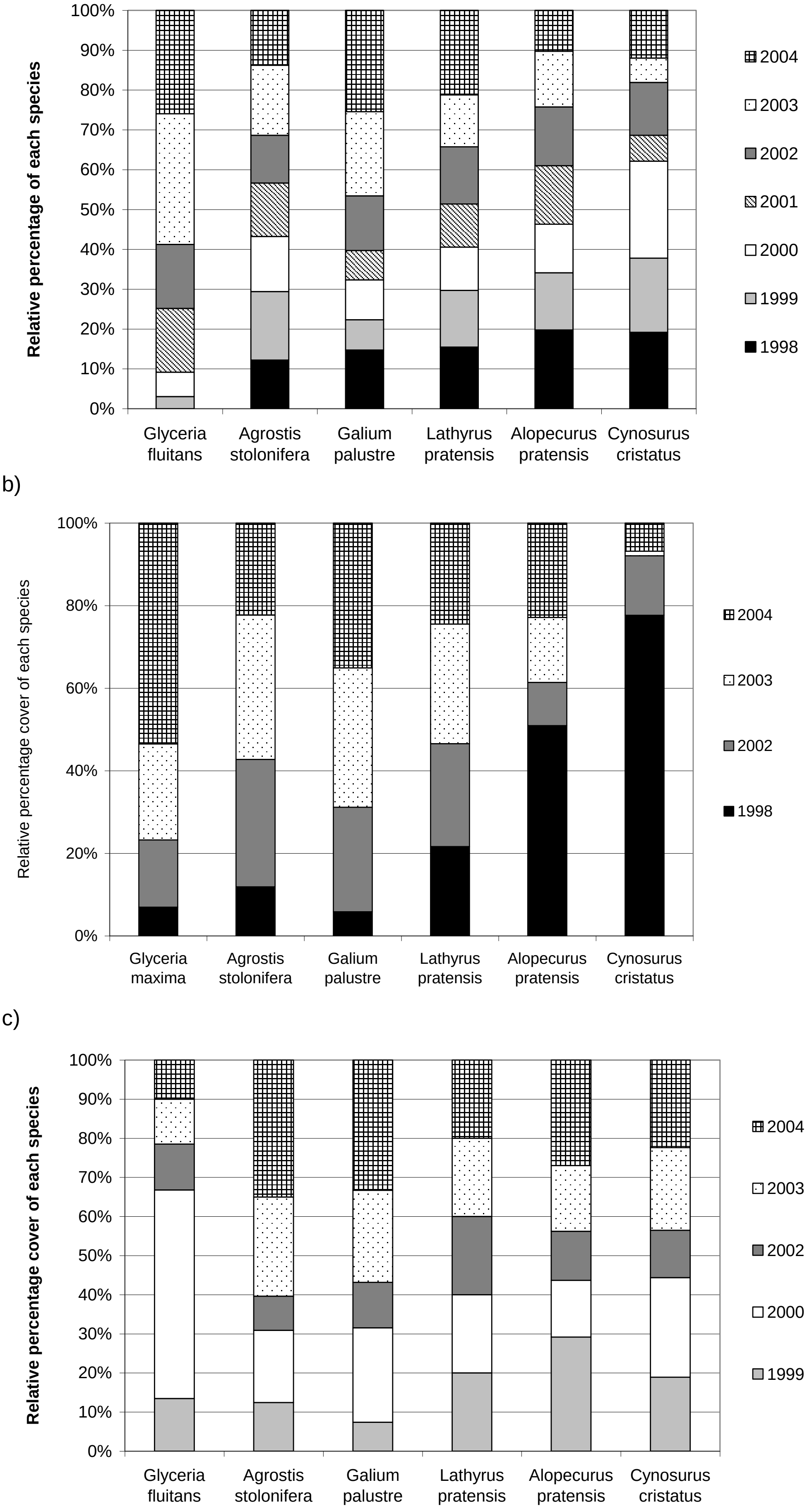
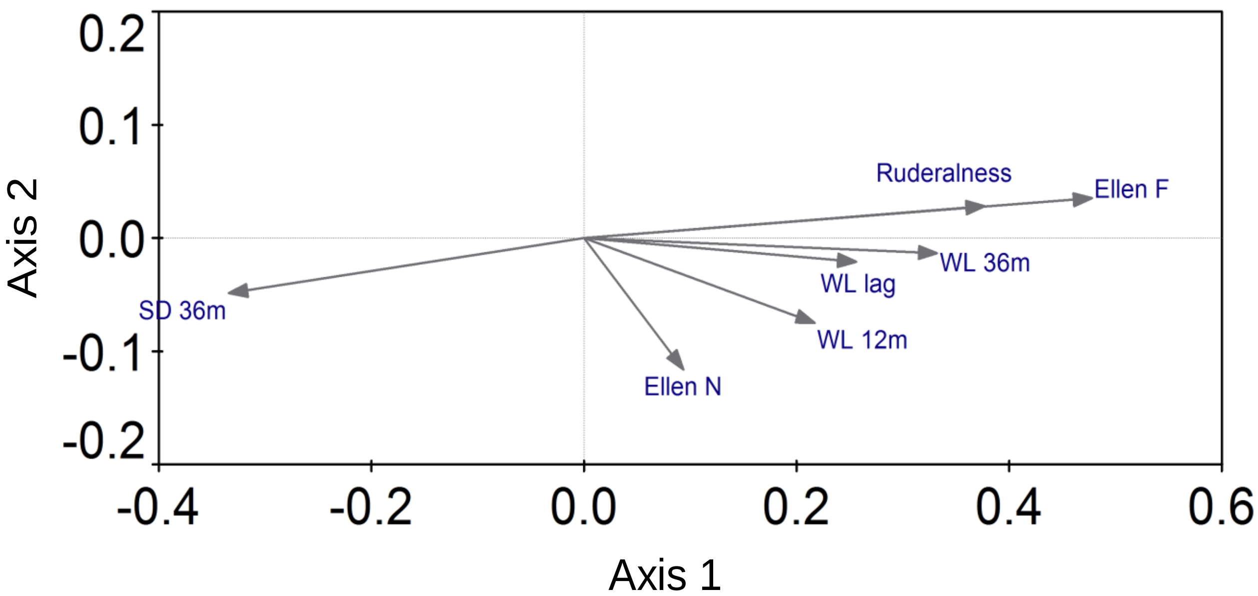


Figure 11. An illustration of the dynamics of potential indicator species between years. The same species (a subset of those in Table 4) are shown for each site: a) Cricklade, b)East Cottingwith and c) Moorlinch. The summed abundance of a species over all the survey years is set at 100%, the relative contribution of each year to that total is then shown, allowing the changes in abundance to be compared. For East Cottingwith (chart b), data for *Glyceria fluitans* is substituted by those for *G. maxima*, *because G. fluitans* was insufficiently frequent to give robust mean values.

4.6 Identifying drivers of change

Earlier reports (e.g. Gowing *et al.,* 2002) have demonstrated water-regime to be the major determinant of plant community composition in floodplain grasslands. Furthermore the utility of the SEV approach has been demonstrated for comparing sites with different soils and different hydrological systems. To explore which of the SEV variables (waterlogging or soil drying) is the more important for driving the community changes observed in this project, an ordination approach was taken. Figure 12 shows the relationship of some water regime variables and mean Ellenberg scores (Ellenberg, 1988) against the pattern of community change at Cricklade North Meadow and East Cotttingwith. Moorlinch was not included in this part of the analysis as it lacked a clear directional change.

a)



b)

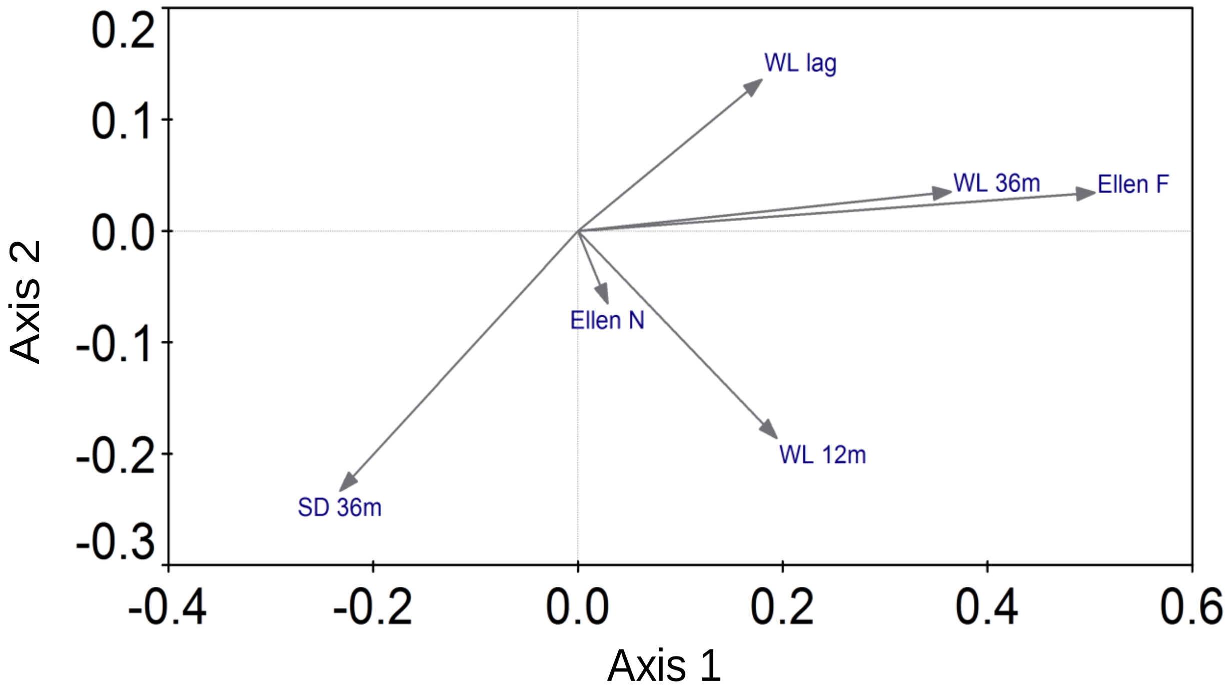


Figure 12. Ordination plots for a) Cricklade data and b) East Cottingwith data showing the position of supplementary variables in relation to the axes displayed in Figures 6 and 8 respectively. As in Table 4, WL_12m is the SEV waterlogging (metre weeks) cumulated over the 12 month prior to survey; WL_lag is the SEV waterlogging in the 12 months prior to that; WL_36m is the 3-year mean SEVwaterlogging. In addition, SD_36m is the 3-year mean SEV for soil drying; Ellen_F is the mean Ellenberg F-score (for moisture) for each quadrat; Ellen_N is the mean N-score (for nutrient availability) and Ruderalness is a measure of Grime's Ruderal strategy on a quantitaive scale. The length of the arrow reflects its explanatory power. Those parallel to Axis 1 are correlated to the factor with the highest degree of variability within the botanical data.

Figure 12 suggests that SEV waterlogging averaged over a three year period prior to survey has more potential explanatory power than any of the other hydrological variables used, because it's corresponding arrow is in both cases the longest and most closely correlated to Axis 1. As shown in project BD1310, there is a strong correlation between this variable (in that case averaged over 5 years) and the Ellenberg F-score. The following section will explore the appropriate length of time over which to consider the water regime.

The arrow labelled Ellen_N suggests that nutrient availability may be correlated with Axis 2 at both sites. The pattern of change at Cricklade therefore suggests that the vegetation has become less indicative of high nutrient status during 2003 and 2004 (years in which the site had little or no flooding), whilst at East Cottingwith, the vegetation may have become more indicative of higher nutrient status in 2004 (this follows some over-bank river flooding in the winter of 2003/4).

4.7 Rates of change

Using Cricklade as the model site because it has 7-years continuous data, the rate of community change as a function of water regime was explored. The transition between the species-rich form of MG4 (for which the site is notified as a candidate Special Area for Conservation under the European Habitats Directive) and its species-poor variant was quantified using the dissimilarity metric. The probability that a relevé classified as "MG4" in year *t* becomes "species-poor" in year *t+1* was calculated, as was the probability that a "species-poor" relevé becomes species-rich "MG4." The difference in these two probabilities then reflects the net change in community type as a function of the community status in year *t*.

This probability may be calculated for each of the 6 transitions for which community type at year *t* and year *t+1* are known. The results can then be plotted against a measure of the preceding 3-year mean for SEV waterlogging in order to investigate the relationship between water regime and rate of change. The treatment and control areas at Cricklade were considered separately as their hydrology was managed differently.

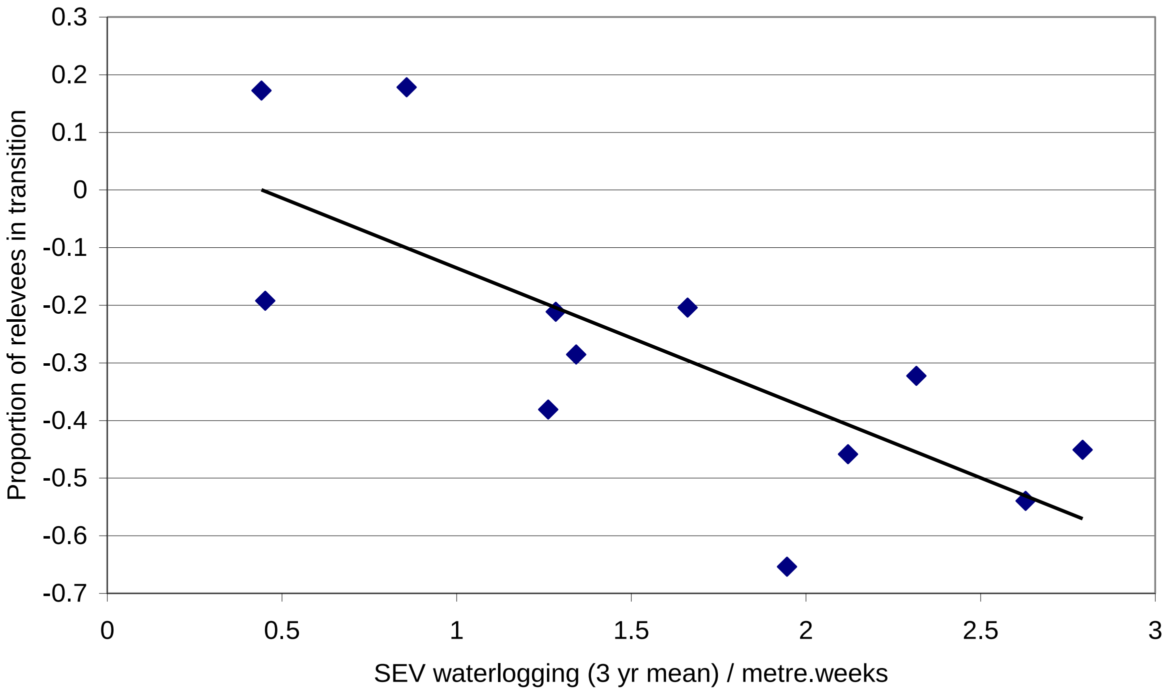


Figure 13. The proportion of relevés sampled at Cricklade changing from "species-poor" to "MG4" (positive values) or from "MG4" to "species-poor" (negative values) in a given year as a function of waterlogging. Line represents best fit by linear regression ($r^2 = 0.57$).

Data from nine separate floodplain sites, collected during project BD1310, enabled the identification of the cross-over point at which the spp-poor MG4 community becomes more frequent than the richer MG4 community to occur at a mean SEV waterlogging of 1.1 metre weeks. The data presented here (Figure 13) is compatible with that value. When the SEV was lower than 1.1, the percentage increase in MG4 averaged 5% per year (standard error of mean = 12%), when above this threshold, the average percentage decrease was 38% (S.E. = 5%). Whilst the standard error for the recovery rate is large (due to lack of opportunities to record it), it can still be stated that the rate of recovery is significantly lower than the rate of loss, even if one allows for the two rates to have different variances. It is also of note that the percentage of relevés changing community type in a single year exceeded 60% on one occasion in one area (control area in 2001).

The data indicate that the probability of a transition between the two community types is a linear function of cumulative waterlogging in the three years prior to survey. The regression equation of the line displayed in Figure 13 is:

$$D = 0.1075 - 0.2429 * W$$

where D is the net change in the frequency of MG4 as a proportion of its frequency at the start of the 12-month period and W is the SEV for waterlogging, expressed as a mean over the three years prior to the survey (WL 36m).

Although 3 years was indicated in the ordination diagrams to be an appropriate time over which to cumulate waterlogging stress, this assumption was tested further by correlating the observed rate of community change with SEV waterlogging variables calculated over a range of timeframes prior to the botanical survey. The results of this analysis are shown in Table 5.

Table 5. Correlation coefficients (n=12) for the relationship between the proportion of relevés in transition between MG4 and MG4 spp-poor and SEV waterlogging (such as shown in Figure 13) across a range of reference periods prior to the survey date. Statistical significance of each correlation is displayed (ns = non-significant).

Reference period prior to survey, over which SEV waterlogging is averaged (years)	Correlation coefficient between degree of change and prior waterlogging (negative values indicate variables are negatively correlated)	Statistical significance	Proportion of variability explained by water regime
1	-0.519	ns	0.27
2	-0.752	P<0.01	0.57
3	-0.754	P<0.01	0.57
4	-0.429	ns	0.18
5	-0.112	ns	0.01
6	-0.010	ns	<0.01

The results suggest that 2 or 3 years prior to survey is the appropriate time over which to cumulate waterlogging stress in order to explain community change. It is noteworthy that cumulating the variable over a longer time period (e.g. 6 years) can result in an almost complete loss of explanatory power.

Using this information from the Cricklade site, it should be possible to predict the changes one would expect at East Cottingwith, where the same community transition is known to occur. The output from the hydrological model of East Cottingwith was used to calculate the “WL 36m” variable for each quadrat holding one of the two communities under investigation. The mean value across the site was then used in the regression equation above to predict D. Table 6 compares the predictions, with the changes actually observed.

Table 6. Comparison of the predicted changes in frequency of MG4 at East Cottingwith (as classified by the TWINSPAN approach) with the observed changes.

Year of survey	Proportion loss predicted by regression equation	Proportion loss observed in survey
2002	0.73	0.74
2003	0.24	0.22
2004	0.22	0.17

Although there are only three periods for which changes in MG4 frequency at East Cotttingwith are known, it is nevertheless possible to calculate a correlation coefficient for the expected versus observed frequencies (0.9986), which is statistically significant (P<0.05; t-test against zero) even with only one degree of freedom.

5. Discussion

The assignment of botanical relevés to community type, whether via a purely objective method (mean character difference) or a partially subjective one (grouping of TWINSPAN end groups), resulted in very similar patterns of community change at all three sites (Figs 4, 7 & 9), in spite of the absolute numbers within the categories varying according to method.

The data have allowed the rate at which communities change in response to soil water-regime to be quantified: recovery rates of species-rich MG4 were observed to be up to 17% per year; whilst rates of loss reached up to 65% per year. These rates are strongly linked to degree of soil waterlogging, as assessed by Sum Exceedence Value. It should be noted that the results were obtained from sites that contained a large stand of the species-rich community, extending beyond the monitored areas, which provided a source of propagules for colonisation. The monitored areas experienced annual hay-making, grazing and flooding, all of which promote propagule dispersal. It is therefore suggested that propagule dispersal was not as limiting in this instance, as it may be in smaller, more isolated stands. The estimated recovery rates need to be viewed in this context.

The trajectories of botanical change as revealed by ordination plots (Figs 6, 8 & 10) were distinct for each site, reflecting local environmental conditions. The main factor affecting community type, on both the sites that showed clear changes during the period of study (Cricklade and East Cottingwith) was water regime in the form of waterlogging stress (Figure 12 a & b). This re-inforces our earlier findings (Gowing *et al.,* 1997 & 2002). However, given a time-series of information, this project has been able to go further and indicate the appropriate time period over which to cumulate stress in order to predict community change. The analysis clearly indicates that a period of 2 or 3 years prior to the survey has the greatest explanatory potential (Table 5). This is in contrast to the 5-year period which was assumed in the BD1310 report (following the earlier work of Noest, 1994 in the Netherlands), but is in line with the results of a recent study in Germany (Leyer, 2005), which relied on a 2-year dataset.

The dataset from Cricklade North Meadow now represents one of the largest, and perhaps longest, runs of botanical data from permanent plots on a floodplain in the UK. Here we have been able to use it to derive a regression line that can be used to predict the response of grassland at other sites to alterations in water regime. The technique was trialled here using data from East Cottingwith and found to give useful results.

Although communities respond to hydrological regime on a 2-3 year timescale, it was apparent that some species such as flote grass (*Glyceria fluitans*) and common mouse-ear (*Cerastium fontanum*) displayed a faster response, with their abundance correlating significantly with water-regime over the preceding year across all three sites. These species are perennial, but they can apparently take advantage of favourable conditions (increased waterlogging in the case of flote grass, decreased waterlogging in the case of mouse-ear) to increase their ground cover in a short time frame. Other species showed little or no response to the previous year's regime, but responded strongly to the year prior to that and to a 3-year mean, including the water forget-me-not (*Myosotis laxa*) and the meadow brome (*Bromus commutatus*). It is notable that these species are annual or biennial in lifecycle, but respond to the hydrological regime more than 12-months prior to their flowering time, suggesting water-regime controls their abundance primarily at the time of seedling establishment or even prior to that in controlling supply of seed and/or the competitive environment the seedlings face.

The supplementary variables on the ordination plots (Fig 12) also reveal information about factors other than waterlogging that may drive community change. SEV for soil drying as a 3-year mean (SD_36m) gives a strong correlation with the botanical data, but the direction of correlation with respect to the other variables differed between the two sites. This suggests its effect is inconsistent. A more uniform response may be produced when drought is a stronger driver of community composition during a run of dry years.

A "Ruderalness" variable based on the classification of Grime *et al.* (1988) was used on the Cricklade plot to investigate whether Axis 2 reflected an increasing presence of short-lived species following perturbation by altered hydrology. However, the direction of increasing ruderalness correlated strongly with the waterlogging variables and Axis 1, but does not appear to have a relationship with Axis 2. Therefore, the movement up Axis 2 in the years after the heavy flooding ceased at Cricklade (2003 & 2004) does not appear to be related to the presence of short-lived species. Instead, the factor most closely correlated to Axis 2 at both sites is nutrient status, as estimated from the mean Ellenberg N value (Ellenberg, 1988). It is negatively correlated with the axis, which is compatible with the suggestion that silt delivery during floods may lead to more nutrient-demanding species in the vegetation (descend axis 2) in the immediate aftermath of floods (summer 2000 at Cricklade, summer 2004 at East Cottingwith) and less of these species (ascend axis 2) following dry winters (summer 2003 and 2004 at Cricklade, summer 2003 at East Cottingwith).

6. Implications for Defra policy

6.1 Rates of loss and recovery of species-rich community types

The data have quantified the rate at which species-rich grassland communities can change. The rate of loss can be rapid with a mean loss of 39% (±5%) per year being observed when a threshold waterlogging tolerance is exceeded. Recovery is slower with a mean rate of just 5% (±12%) per year, when waterlogging stress is below the threshold. It should be noted that this 5% figure is based on just three sets of observations and hence has a large margin of error. Nevertheless, the data are sufficient to state that the rate of observed recovery is significantly slower than the rate of loss.

The implications for this finding to the HLS scheme are that priority should be given to maintaining a suitable hydrological regime on species-rich sites, as this will give better return on investment than trying to rehabilitate a species-poor stand. To ensure this, guidance is required for consultants drawing up Farm Environment Plans (FEPs) and for Rural Development Service (RDS) advisors, in order that they can confidently identify stands of grassland that are particularly sensitive to soil water regime.

To give an idea of timescale for site rehabilitation, if one assumes the estimate for recovery of species-richness is 5% per year, this equates to the area of a species-rich community within a stand of a related species-poor community, doubling in size every 15 years given an appropriate water regime and a supply of propagules. This compares to the area of species-rich vegetation halving in size in just two years, if the water regime is beyond a threshold.

One of the main implications of these results is for the monitoring of schemes and the interpretation of data. A monitoring design that permits stands to be given a community description would provide more robust data than one relying on a few "indicator" species, as the community designation would change more slowly and reflect the longer-term drivers of change. Having said that, appropriate selection of indicator species would allow the impact of a new hydrological scheme to be assessed rapidly. The data presented here allow indicators to be selected for different timescales of response to hydrology.

6.2 Interpretation of monitoring data

One important finding of this research, which has perhaps not been fully appreciated by the conservation community, is the over-riding influence of meteorological patterns on the composition of floodplain grasslands. Variations in the quantity of rain falling in spring (*cf*. Fig. 2) can completely mask the effect of hydrological management operations. All interpretation of monitoring data therefore needs to be in the context of the prevailing meteorological conditions. The information in this report and its predecessor (BD1310) should permit informed judgements about this to be made.

7. Future research requirements

7.1 Full validation: The predictive model used here shows great promise and gave a statistically significant result, but it cannot be regarded as fully tested. Continuation of the monitoring of permanent quadrats at the two key sites (Cricklade North Meadow and East Cottingwith Big Ings) would allow a more complete validation. The addition of a totally independent site (e.g. Portholme SSSI, Huntingdon) would provide a great opportunity to test the general transferability of the model.

7.2 Response to drought: Continued monitoring at these sites would have added value if the UK experiences another period of drought such as that during 1989-1991.It would then be possible to derive tolerances of community types to stresses imposed by soil drying. This has not been possible during the time frame of the current project or its predecessor, because annual rainfall has been generally above average, though 2003 & 2005 have been relatively dry years, so an opportunity to consider the role of soil drying in community determination may be about to present itself.

7.3 Nutrient deposition: Perhaps the most interesting lead to follow up through future research is the role of nutrient availability in determining community change within floodplain grasslands. The evidence presented here suggests nutrient availability may be the environmental driver associated with Axis 2 of the ordination plots. It appears to act independently of water regime to some degree and perhaps on a different time frame. This is an important area of research within the context of the European Water Framework Directive. Our knowledge of the quantity of nutrients being deposited on floodplain habitats during floods is very limited (Gowing *et al*., 2002). Some pilot data has been collected for the sites discussed here, but not for a sufficient range of flood events to draw general conclusions. The maintenance of important habitats in floodplains such as fens and wet woodlands as well as grazing marsh and lowland meadows may be dependent on an appropriate supply of flood-borne sediment, so good ecological status would rely on nutrient management at a catchment scale, but that is only achievable if the habitat requirements are understood. Field monitoring is required to achieve this and it would be essential to do this in tandem with monitoring (or modelling) of soil water regime, so that the two factors can be considered together.

7.4 Remote sensing: Realising the utility of monitoring community type, but given its cost in terms of ground survey, more cost-effective methods for gathering the information should be explored. Remote sensing data from aircraft using hyper-spectral imagery offers a solution, but attempts to train software to recognise community types within grassland have been thwarted by technical obstacles that limit precision. New developments in GIS technology may offer a route to overcome these obstacles and the large dataset on floodplain grasslands compiled through Defra research constitutes a useful resource with which to develop the technique.

8. Actions to be completed

8.1 Technical advice note

David Gowing, in collaboration with both the other project contractors and the Rural Development Service (RDS), will author a Technical Advice Note (TAN) for use by RDS advisors when developing, or commenting on, farm plans under the HLS scheme. The note will guide advisors in recognising grasslands likely to be most sensitive to soil water regime, comment on the design of hydrological schemes for habitat enhancement, suggest an appropriate design and timeframe for monitoring, advise on the interpretation of monitoring data.

8.2 Offer staff development to RDS advisors

To achieve technology transfer effectively, it is proposed that a short course involving field visits, with hands-on monitoring and data interpretation, would be the most appropriate format. Cranfield University has historically run a number of courses entitled "Hydrological management for conservation" for clients such as the Environment Agency, English Nature and Countryside Council for Wales. A costed outline of a course, tailored for the needs of RDS advisors and incorporating the research results summarised here, will be developed and presented to the RDS training co-ordinator for their consideration.

8.3 Publication in scientific journals

A review meeting of all project participants was held in December 2004, at which 4 papers for publication were identified based on the outputs of this project and its predecessor. One has already been submitted to the Journal of Ecology; the others are in preparation and will be submitted during 2005/6.

8.4 Integrate results with "Re-instatement of surface grips" project (BD1322)

Given the understanding of vegetation response to soil water regime revealed in this project, it is important to link that information to research on the management of within-field water regimes, currently being conducted by CEH. David Gowing is a sub-contractor on that project and will endeavour to join-up the outcomes from the two projects in the final report for BD1322. Maximising the potential of HLS for both botanical diversity and breeding bird success through appropriate water management would be the goal.

References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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