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Flood embankment vegetation management trials – final report

Science project SC030228/SR1

Flood and Coastal Erosion Risk Management Research and Development Programme

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Steve Killeen

Head of Science

Executive summary

This report is the culmination of a five-year monitoring programme aimed at improving our understanding of the effects of vegetation management on the performance of the flood embankments, especially along lowland rivers. The flood embankment vegetation management trials were part of a suite of operational trials within the engineering theme of the joint Department for Environment, Food and Rural Affairs (Defra) and Environment Agency (Environment Agency) research and development programme. The results of the study will contribute to a decision support framework for determining the optimum vegetation management regime for the maintenance of flood embankments that considers engineering, operational and environmental attributes.

The trials consisted of the selection of three sites in Lincolnshire and Cambridgeshire (Billingborough, Reach Lode and Ely Ouse). Each site was subjected to a series of management techniques over the five-year period including:

- using a range of cutting frequencies (varying from none to six cuts per year);
- removal of mown arisings;
- treatment with herbicides;
- application of aquatic dredgings.

Important indicators of embankment performance such as soil strength and erosion resistance, soil macronutrients, soil moisture and organic content, floral and faunal communities were monitored to assess the effects of the different management techniques.

Qualitative and quantitative analysis revealed that the three trial sites were substantially different in terms of their history, location in the landscape and other environmental characteristics. Subsequently, statistical analysis of the survey data was undertaken on each site separately, with an overview of comparisons between the sites.

Analysis of the data showed that vegetation management had a strong affect on a number of indicators of bank performance. The main relationships are summarised below.

- Cutting frequency strongly affected vegetation composition and was found to be the overriding factor determining the plant communities found at two of the three sites (embankment face was found to be the overriding factor at the third site, with management secondary). The most species-rich communities were recorded where treatments included at least three cuts per year, with species-poor communities recorded where treatments received only one cut or less per year.
- Cutting frequency affected the dry weight of arisings collected, with the greatest weight of arisings collected in those treatments receiving three or more cuts per year.
- Cutting frequency can affect surface soil strength, with the greatest soil strength found in those areas with a short sward (i.e. cut three times a year or more). The absence of any mowing proved poorest in terms of both surface soil strength and erosion resistance.
- Cutting frequency was not found to significantly affect soil strength at depths of 0.3 m. Instead, the material used in the construction of the bank appeared to be the overriding factor, with peat soils proving especially weak.

- There was some evidence that a greater frequency of cutting resulted in greater invertebrate diversity, but this was not consistent across all three sites.
- Application of weed wipes had very little effect on vegetation composition, soil strength or erosion resistance, and when combined with a single annual cut, led to species-poor communities.
- Application of growth retardant resulted in reduced production of arisings at two of the three sites, but at the third site, was found to be reliant on appropriate timing of herbicide treatment in order to counteract invasive annual species such as Charlock.
- Collection of arisings after mowing was generally found to have little effect on vegetation composition, particularly where only one cut per year took place. One of the sites showed some evidence that, where vegetation was cut more frequently (i.e. three times per year), removal of the arisings benefited plant diversity.
- Some evidence was found that collection of arisings improved surface soil strength indirectly through soil moisture (i.e. the presence of large quantities of arisings led to increased soil moisture leading to reduced surface soil strength), but it was found to have little effect on erosion resistance.
- Invertebrate populations were larger both in the more productive areas (i.e. where a greater weight of arisings were collected) or where leaf litter cover was high (i.e. where arisings were not collected).
- Deposition of aquatic arisings and channel dredgings on the bank (during annual watercourse maintenance) resulted in species-poor vegetation communities. No noticeable difference was recorded even where aquatic arisings were removed after one week.
- Deposition of aquatic arisings and channel dredgings proved detrimental to surface soil strength, though no discernable effect was found at depth.

Many other factors were found to affect vegetation and invertebrate composition including:

- embankment face;
- starting condition of the sward and the availability of a diverse seed rain;
- the presence of invasive species;
- soil nutrient levels and moisture content;
- exposure to fire events, trampling and other forms of disturbance.

In the majority of cases, these variables affected the vegetation composition as a secondary factor in addition to the overriding influence of management.

The report also makes use of the results of a complementary study testing the erosion resistance of vegetated floodbanks. The combined results suggest that the substrate used in bank construction appears to be the overriding factor affecting soil strength (particularly at depth). The degree of compaction experienced through the access of maintenance machinery and localised effects of mammal activity were additional factors that strongly affected soil strength and erosion resistance.

Four tables are presented outlining which management technique is most appropriate given a series of environmental scenarios. Scores are given for categories such as bank strength, erosion resistance, cost, health and safety, floral and faunal diversity. The treatments that generally scored highest are those cut more than once a year with the arisings left on. However, it is likely that individual sites may require particular emphasis on certain criteria (e.g. bank strength where flooding risk is high, plant diversity where rare species are present, etc.).

Certain background information must be available before the most appropriate management can be selected (through the use of a simple standardised form to be completed prior to management selection). Development of a weighing system by Environment Agency is also essential to differentiate between the effectiveness of each management treatment at sites with particular relative priorities. For example:

- Sites near designated conservation areas should give a higher weighting to conservation criteria such as plant diversity and invertebrate diversity (partly because the banks could provide migration routes for species between protected areas and partly because the nearby seed source may result in diverse swards establishing on the banks).
- Sites that contain an element of peat in their construction should give a higher weighing to flood risk (leakage can often occur).
- Sites regularly exposed to events such as fire, fly-tipping, etc. should give a higher weighting to health and safety.
- Sites with marginal wetland vegetation on the river face should give a higher weighting to conservation criteria. This face may contain protected species such as water vole and otter as well as a more diverse range of plant and invertebrate species.
- Sites with low nutrient status should give a higher weighting to conservation criteria because it is more likely that a diverse plant community can be established on these sites.
- Sites that receive frequent trampling by the public may override any effects of management in terms of plant community establishment.

Further research into alternative maintenance techniques and grass mixes is also recommended.

Contents

1 Introduction

1.1 Background

This report describes Stage 4 of the Flood Embankment Vegetation Management Trials.

The trials aim to provide an improved understanding of the effect of management interventions on the performance of the flood embankments, especially along lowland rivers under service conditions. For this purpose, three sites (Ely Ouse, Reach Lode and Billingborough Lode) were selected during Stage 2 of the project (see Section 2.1).

Stage 4 was conducted over a period of five years and is part of a suite of operational trials within the engineering theme of the joint Department for Environment, Food and Rural Affairs (Defra) and Environment Agency Flood & Coastal Erosion Risk Management research and development (R&D) programme.

The outputs from the project are expected to feed into continuous development of best practice via the Environment Agency's Agency Management System (AMS) and to provide general guidance to the wider land drainage community. The need for these trials was supported by the recommendations of *Operations and Maintenance Concerted Action Report* (Environment Agency 2002).

This report contains analysis of all data collected over the past five years (Table 1.1). Because of the volume of information collected, raw data are included on the accompanying CD 1. All photographic evidence is provided on accompanying CD 2 while CD 3 contains the results of data analysis to establish possible relationships and correlations between variables.

The statistical analysis focuses on datasets that are likely to show the most meaningful results (e.g. datasets from Years 1 and 5). Intermediate datasets (such as those of Years 2, 3, and 4) have been used where further detail was necessary.

Table 1.1 Stage 4 data collection periods.

Data collection period	Period within Stage 4 of the trials
January–December 2003	'Year 1'
January–December 2004	'Year 2'
January–December 2005	'Year 3'
January–December 2006	'Year 4'
January–December 2007	'Year 5'

1.2 Objectives

The objectives of Stage 4 of the project were to:

- provide and review information on the effects of various options for vegetation management on the standard of vegetation cover (leading to improved national guidance on maintenance practice in the Environment Agency's Agency Management System);
- contribute to a decision support framework for determining the optimum vegetation management regime – considering engineering, operational and environmental attributes – for the maintenance of flood embankments.

The assessment was based principally on monitoring key indicators of embankment performance that are affected by vegetation management options.

1.3 Direct performance indicators

Following a literature review and consideration of the effect of grass management on embankment performance, the characteristics listed in Table 1.2 were judged to be the most significant and cost-effective to measure. These indicators were monitored by Ecology, Land and People (ELP) (research contractor) as performance indicators of three important considerations:

- vegetation;
- soil;
- habitat utilisation (by invertebrates, mammals. etc.).

Table 1.2 Performance indicators.

Consideration	Performance indicator measured
Vegetation	• Species composition. • Sward structure including vegetation height, total vegetation cover, extent of ground covered by leaf litter, extent of bryophytes and extent of bare ground. • Quantity: dry weight of cut vegetation left after mowing (termed 'arisings' throughout this report).
Soil	• Biological parameters including root quantity, root size, soil moisture content and soil fertility through measuring levels of available macronutrients. • Geotechnical parameters including soil strength measurements and the extent of cracks and holes.
Habitat utilisation	• Species composition and frequency of invertebrates. • Recording of other wildlife interest such as mammals, fish and reptiles.

The timing and methods used in the field trials were designed to take full account of the need to ensure the continued integrity of the embankments at all times.

1.4 Other monitoring requirements

Additional monitoring of environmental and local conditions was carried out in order to interpret the data from the direct performance indicators. The details and frequency of monitoring are discussed in Section 2. Monitoring included:

- temperature (air and soil);
- rainfall;
- water level;
- light;
- humidity;

- wind speed;
- extent of public, animal and vehicular traffic.

The Environment Agency provided an ongoing record of this information to ELP as required (see Section 2.5).

1.5 Approach to site trials

The development of the site trials was informed by:

- experiences of the project team during Stages 1 and 2;
- knowledge obtained from a literature review.

The extent of the work was based on the requirement to:

- observe changes to the embankment vegetation cover and surface geotechnical structure, and hence embankment performance caused by a change in the management of the vegetation;
- ensure observations are taken at appropriate times of the year;
- obtain adequate monitoring information to enable a scientific assessment of the results;
- maximise the use of the available knowledge base and ensure value for money.

A partnering approach to ensure value for money through the combined expertise of the project group continued throughout the five year period. The project group included:

- the Environment Agency team led by the Environment Agency project manager and a project steering group made up of Area and Regional flood defence and environmental staff;
- the ELP team led by the ELP project manager;
- Dr Laurie Boorman of L A B Coastal in the capacity of scientific advisor.

The Environment Agency's Operations Delivery team (formerly known as the Environmental Work Force) carried out all vegetation management activities as outlined in Section 2.

The Environment Agency provided information to ELP each year on:

- vegetation management works carried out;
- timing, extent and cost of each treatment;
- observations and issues of concern or efficiency.

The Environment Agency's Operations Delivery team reported any occurrences or concerns that could affect the trials to the project group via the Environment Agency project manager. Decisions on such issues were then taken collectively by the project group.

In the final year of the trials, a separate study was set up by L A B Coastal and the Environment Agency to monitor the erodibility of the vegetation cover on each of the trial sites. The study involved the development and testing of a portable erosion measurement device (EMD), which was then used to test the erosion resistance of the vegetation within the various treatments by subjecting small areas to running water (Environment Agency

2009). The data gained will supplement the findings of this report to ensure any recommendations are comprehensive.

2 Methodology

2.1 Trial sites

Suitable sites for the vegetation management trials were selected under Stage 2 of this project. The sites were as follows:

- **Site 1:** right bank (facing downstream) of the Ely Ouse, Queen Adelaide, Ely, Cambridgeshire (TL 567820 to TL 570832).
- **Site 2:** left bank (facing downstream) of the Reach Lode, Upware, Cambridgeshire (TL 549691 to TL 556678).
- **Site 3:** left bank (facing downstream) of the Billingborough Lode, Neslam Road, Billingborough, Lincolnshire (TF 165325 to TF 150332).

Figure 2.1 shows the general location of the three sites within East Anglia (more detailed maps for each site are given in Appendix 3).

The three sites were selected to ensure the trials were representative of the range of typical embanked watercourses within the Anglian Region. The outputs of this project are therefore expected to be generally applicable to long lengths of watercourses in the Anglian Region and other similar lowland flood embankments.

The selection criteria and a full description of the sites are given in the Stage 2 report (as specified in the Site Selection Summary by Posford Haskoning Ltd, 2003).

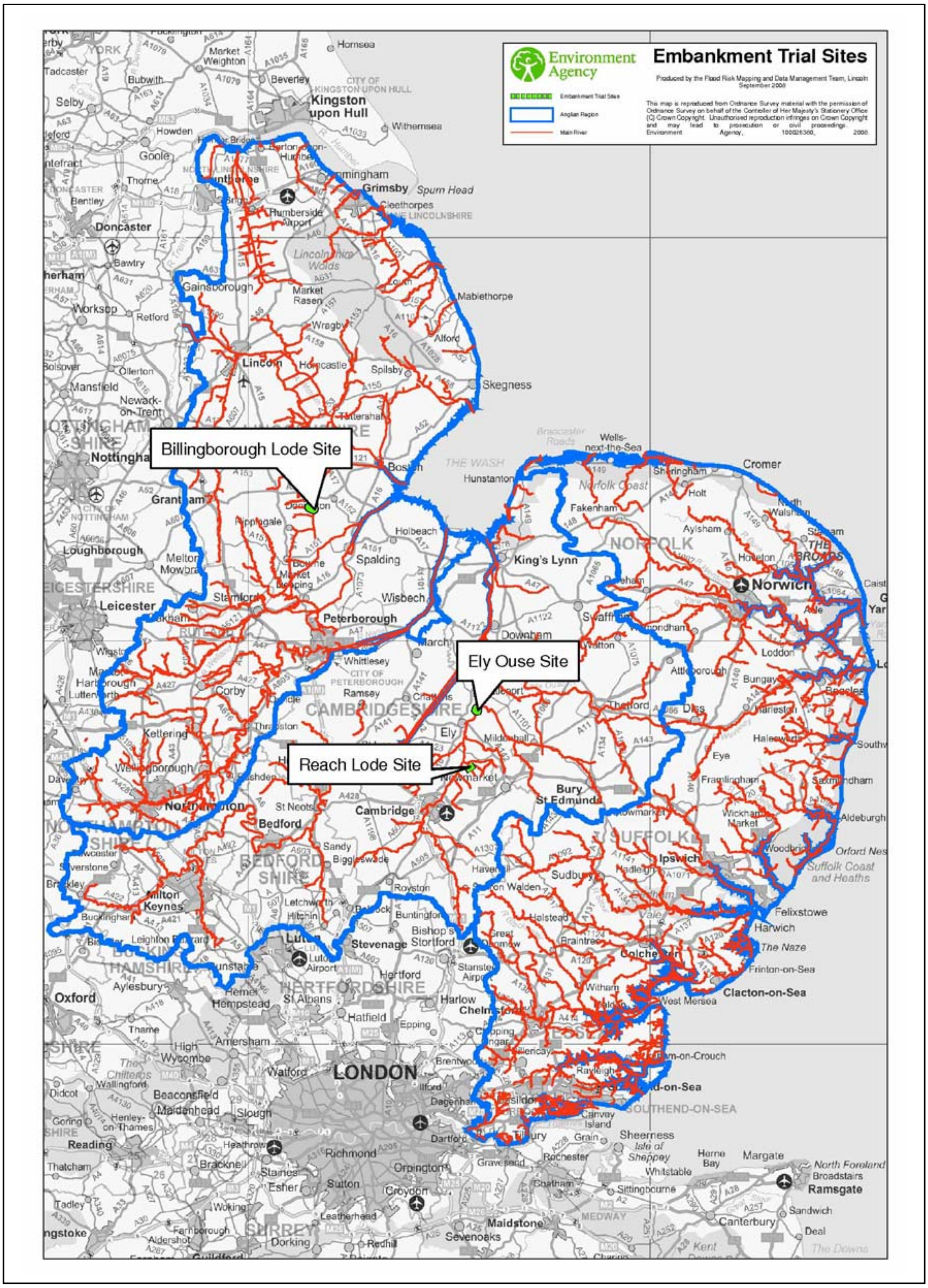

Figure 2.1 Locations of trial sites in Environment Agency's Anglian Region.

2.2 Experimental treatments

2.2.1 Treatment options

The original design report identified 11 different experimental treatments for the vegetation trials. These included 10 different cutting and/or chemical application techniques and one control treatment (Table 2.1). The Operations Delivery teams of the Environment Agency carried out the maintenance at predetermined times as detailed in Table 2.1.

Table 2.1 Treatment options used in the vegetation management trials[1].

Treatment Option	Method	Timing during the year
1	Cut six times per year and leave arisings	April, May, June, July, August and September
2	Cut three times per year and leave arisings	April, July and September
3	Cut twice per year and leave arisings	July and September
4	Cut once per year and leave arisings	August
5	Cut three times per year and remove arisings	April, July and September
6	Cut twice per year and remove arisings	July and September
7	Cut once per year and remove arisings	August
8	Growth retardant and weedkiller plus Treatment 4	Spray in April, cut in August
9	Control of weeds by the use of a weed wipe plus Treatment 4	Wipe in April and June, cut in August
10	Arisings from aquatic weed cutting placed on the bank (as with all treatments on the Reach Lode site only) but removed in this treatment after one week, plus Treatment 4.[2]	Cut in August.
11	Control option, no grass cutting during the five-year trials.	

Notes [1] Treatment options shaded in grey were excluded from vegetation and soil monitoring.
[2] It was not possible to apply aquatic weed cuttings from Ely Ouse embankment for operational reasons. Although aquatic weed cuttings were applied at Billingborough, there was insufficient aquatic material to cover the whole bank and therefore much of the recording plots remained uncovered.

All 11 treatments were marked out and baseline data collected during Stage 3 (April 2003). But due to funding limitations, the Environment Agency decided to remove three of the treatments (marked in grey in Table 2.1) from all forms of vegetation and soil monitoring.

- Treatments 3 and 6 were removed on the basis that cutting twice yearly would not provide sufficiently different data from the once yearly and thrice yearly cutting to justify the additional cost involved in monitoring.
- Treatment 8 was removed as it is considered environmentally unsustainable as a broad management tool.

Sufficient funds were available to repeat some of the soil geotechnical monitoring in Year 5 of the trials.

The three excluded treatments continued to be managed in the specified way for all five years of the trial, with arisings sampled and walkover examinations conducted on each year so that soil monitoring in Year 5 of the programme could take place.

2.2.2 Methodology of treatment operations

The height at which the vegetation is cut has a crucial effect not only on the nature of the sward but also on the ability of the vegetation to reduce the vulnerability of the embankment structure to erosion. The cutting machinery used determines this height and it may vary from site to site. Therefore all reasonable steps were taken to standardise the height of cutting across the three sites at approximately 50 mm.

All treatments were carried out by the Operations Delivery teams and sub-contractors employed by the Environment Agency during the same time of the year over the five-year trial period.

The detailed methods and timings of each treatment option, including those not monitored, are outlined below. A diagram of a typical cross-section of an embankment is shown in Figure 2.2.

- **Treatment Option 1** was cut six times a year using a tractor and flail during the third weeks of April, May, June, July, August and September. Samples from the grass cutting arisings were collected and weighed.
- **Treatment Option 2** was cut three times a year using a tractor and flail during the third weeks of April, July and September. Samples from the grass cutting arisings were collected and weighed.
- **Treatment Option 3** was cut twice a year using a tractor and flail during the third weeks of July and September. Samples from the grass cutting arisings were collected and weighed.
- **Treatment Option 4** was cut once a year using a tractor and flail during the third week of August. Samples from the grass cutting arisings were collected and weighed.
- **Treatment Option 5** was cut three times a year using a tractor and flail during the third weeks of April, July, and September. Samples from the grass cutting arisings were collected and weighed. The arisings from the grass cutting were removed using a hand-rake as soon as cutting and the collection of samples was complete, and disposed of away from the embankment.
- **Treatment Option 6** was cut twice a year using a tractor and flail during the third weeks of July and September. Samples from the grass cutting arisings were collected and weighed. The arisings from the grass cutting were then removed using a hand-rake as soon as cutting and the collection of samples was complete, and disposed of away from the embankment.
- **Treatment Option 7** was cut once a year using a tractor and flail during the third week of August. Samples from the grass cutting arisings were collected and weighed. The arisings from the grass cutting were removed using a hand-rake as soon as cutting and the collection of samples was complete, and disposed of away from the embankment.
- The growth retardant and weedkiller for **Treatment Option 8** were maleic hydrazide (MH) and 2, 4-D respectively. The same products were used for the three trial sites. They were applied in the third week of April of each year on

Treatment Option 8. They were mixed together and applied with knapsacks or other suitable hand application method (same method at all three sites) in accordance with the manufacturer's instructions. In addition to the chemical treatment, Treatment Option 8 was cut once a year using a tractor and flail during the third week of August. Samples from the grass cutting arisings were collected and weighed.

- The weed wipe for **Treatment Option 9** was glyphosate. The same product was used for the three trial sites. Although glyphosate is harmful to grass, it was selectively applied here with hand-held wipe applicators (in accordance with the manufacturer's specification) to tall, broadleaved weeds only. Glyphosate was applied twice (once in the third weeks of April and once in the third weeks of June) to ensure application to early and late growing weeds. In addition to the chemical treatment, Treatment Option 9 was cut once a year using a tractor and flail during the third week of August. Samples from the grass cutting arisings were collected and weighed.

- **Treatment Option 10** was carried out successfully at Reach Lode and Billingborough (but see footnote 1 to Table 2.1). The grass on Treatment Option 10 was cut once a year using a tractor and flail during the third week of August. The arising from the aquatic weed cutting carried out during August/September was placed randomly on the embankment face (landward face for Reach Lode) of all treatments and removed after one week on Treatment Option 10. Treatment Option 10 at Ely Ouse was removed from the management trials due to the proximity of Clayway Farm and because no routine aquatic weed cutting is carried out from the bank on the Ely Ouse.

- **Treatment Option 11** (control) remained uncut throughout the period of the trials. The only cutting was to maintain public footpaths along the crest at the Reach Lode and Ely Ouse sites.

To alleviate disposal costs for the Operations Delivery teams, arisings on the Ely Ouse site were placed along the riverside berm for those treatments that required arisings removal.

During treatments, all vehicles entering the treatment areas were instructed to keep to the existing tyre ruts wherever possible to prevent disturbance to the monitoring area on the crest of the banks.

In addition to the treatments, routine vermin control and bank inspections were carried out by the Operations Delivery teams as usual to maintain embankment integrity. Particular note was made of any change in vermin activity within the treatments. Information gathered during inspections was included in the annual report, together with a note of any subsequent action taken (e.g. to exclude vermin).

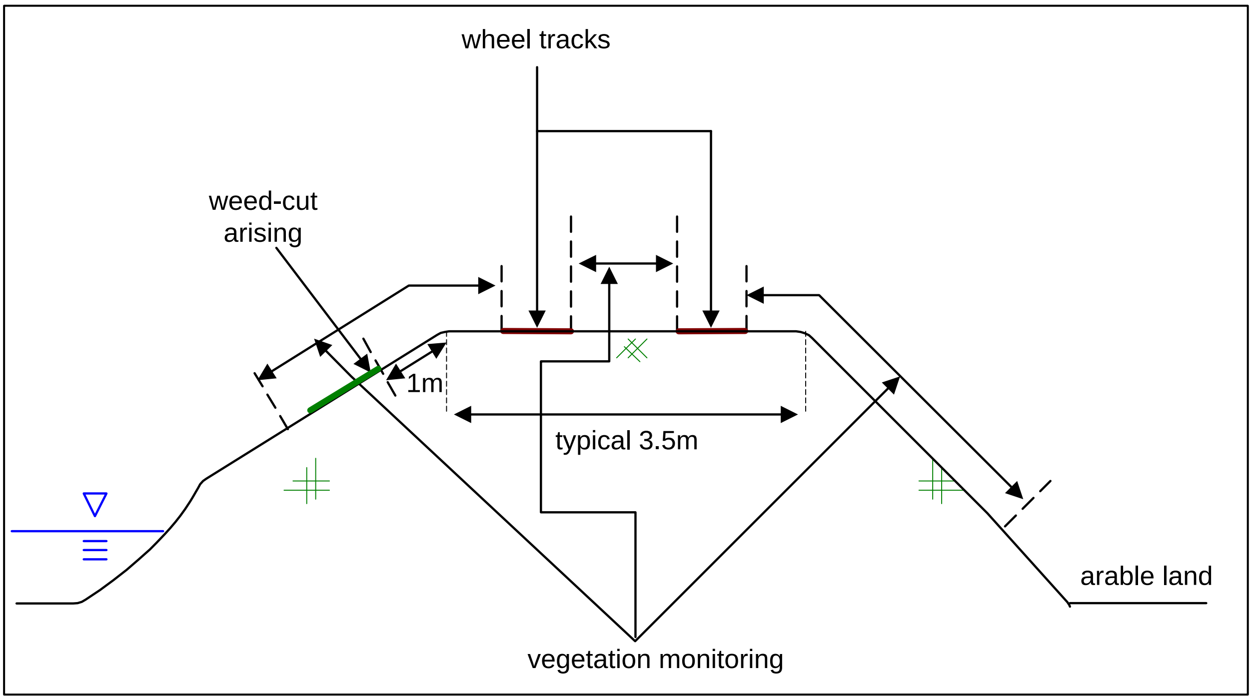

Figure 2.2 Typical cross-section of a trial embankment.

2.2.3 Additional cutting for public footpaths and/or to reduce fire hazards

Both trial sites in the Environment Agency's Central Area (Ely Ouse and Reach Lode) have statutory public footpaths along their crests. To ensure the use of the footpaths was not compromised while minimising the impact on the trial, the following additional cutting was carried out.

- **Reach Lode.** Cutting of the part of the crest between the landward tyre tracks and the landward edge of the crest was conducted at frequencies agreed with Cambridgeshire County Council. These cuts were conducted for all but Treatment Option 1, where six cuts per year were already being carried out.
- **Ely Ouse.** Cutting of the part of the crest between the two tyre tracks was conducted at frequencies agreed with Cambridgeshire County Council, with the crest of Treatment Option 11 being cut in August only. In order to reduce the risk of the treatments being affected by fire incidents, a strip of vegetation was regularly cut at the base of the bank next to the road (approximately 1 m below the feno-markers – see Section 2.3.2) to provide a fire barrier.

These additional cuts are illustrated in Section 3.4.

2.2.4 Operational, health and safety, and environmental considerations

The need to cut the embankment, including its crest, at set times of the year was crucial to the success of these trials. But this resulted in conflicts with the Environment Agency's standard cutting times and with procedures agreed within the Environment Agency or external bodies for health and safety and environmental reasons. These issues included:

- cutting at different times of year from those agreed with environmental bodies;
- increased likelihood of disturbance to birds' nests due to timing of cuts for some treatments;
- the use of chemical additives adjacent to water (a licence was required for Treatment Options 8 and 9);
- the health and safety risk of tall vegetation for access and inspection, as cuts would not occur before July/August in some treatments, and no cut at all for Treatment Option 11. The particular risk of falling or overturning vehicles from non-identification of the edges of embankment crests was noted.

The Environment Agency's Operations Delivery teams identified management practices to deal with these risks and the revised methodology in this report incorporates these management practices. Specific operational issues identified during the five years of these trials are considered in a supplementary report prepared by the Environment Agency project manager (Appendix 1).

2.3 Layout of experimental treatments

2.3.1 General layout

The laying out and marking of the experimental treatments was carried out by Posford Haskoning under Stage 3.

Each of the three trial sites had similar experimental layouts.

At each site, a strip of embankment approximately 93 m was set out for each of the 11 different treatments. The only exception was the Ely Ouse site, where there were only 10 treatments ('Treatment Option 10: aquatic weed cutting' was not carried out at this site).

The arrangement of the treatments along the embankment at each of the three sites was not in numerical order but was designed to facilitate the cutting process (i.e. treatments requiring the most regular grass cutting were typically nearest the entrance to the site). An example of the layout of the treatments is shown in Figure 2.3.

Each treatment was sub-divided into eight sections 12 m long, termed 'replicates' throughout the report (see Figure 2.4) to allow for any variation across each treatment.

In the baseline survey (Stage 3), five of the eight replicates in each treatment were randomly selected using random number tables for monitoring each year during the five years of the trial (leaving three unmonitored replicates as spares).

In subsequent monitoring after the baseline survey (undertaken in Stage 4), only the first three of the five selected replicates were recorded in order to meet funding limitations.[1] This method continued for the remaining four years.

The individual treatments were separated by typically 10 m to allow for the adjustment of the machinery used for mowing. The gap between treatments was increased where necessary to avoid unsuitable areas of bank (e.g. areas of excessive shading by trees, access bridges, culverts or areas with major vegetation differences).

[1] Examination of the data obtained during the baseline survey and comparable situations suggested that three replicates would still provide adequate information for the statistical analysis required.

Each replicate was 9 m long with a gap of 3 m between each to allow for access to the replicates for data collection with a minimum of disturbance to the replicates themselves.

Three recording plots were set up within each monitored replicate including one on the river face, one on the crest and one on the landward face (see Figure 2.4). The width of the recording plots was constrained by the almost universal presence of wheel ruts along the crest of the bank. These ruts have a clear space between them of about 1.3 m, which limited the width of the recording plots to 1.2 m.

The first 6 m of each recording plot was used to measure the vegetation parameters (see Figure 2.5) and the next 2.1 m was used to record soil parameters. This left a length of 0.9 m at the end of each recording plot, as a spare area for other testing that might be required.

The gap between the recording plots on the top of the bank and those on the sides of the bank varied depending on the dimensions of the embankment. The gaps also served to avoid the physically and biologically variable areas across the wheel ruts on the crest and over the break of slope on each side of the crest of the bank. Occasionally the width between the ruts on the crest of the slope was less than 1.2 m. In these circumstances, the recording plots were located so that the undisturbed area between the ruts was positioned centrally within the recording plot.

The total length of each replicate was therefore 9 m.

The actual layout of the different treatments at each of the trial sites is shown in Appendix 3.

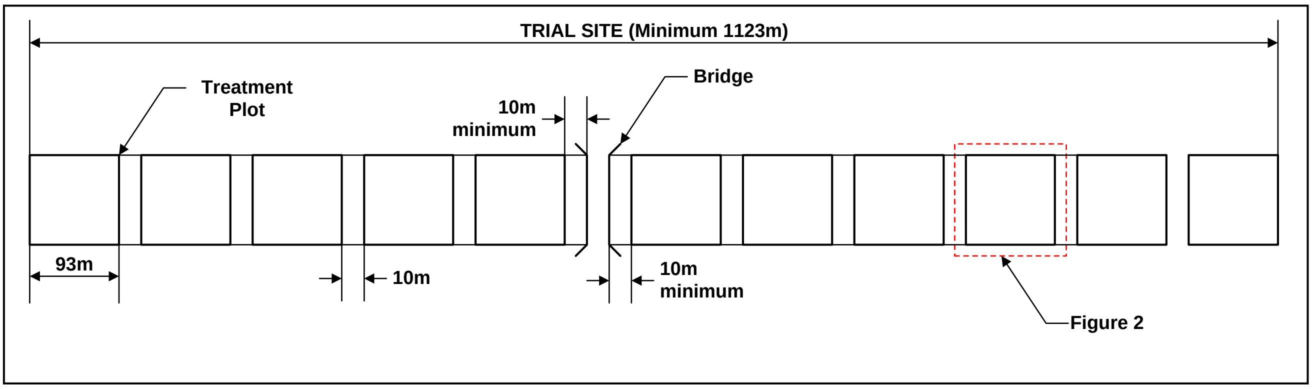

Figure 2.3 Typical trial site.

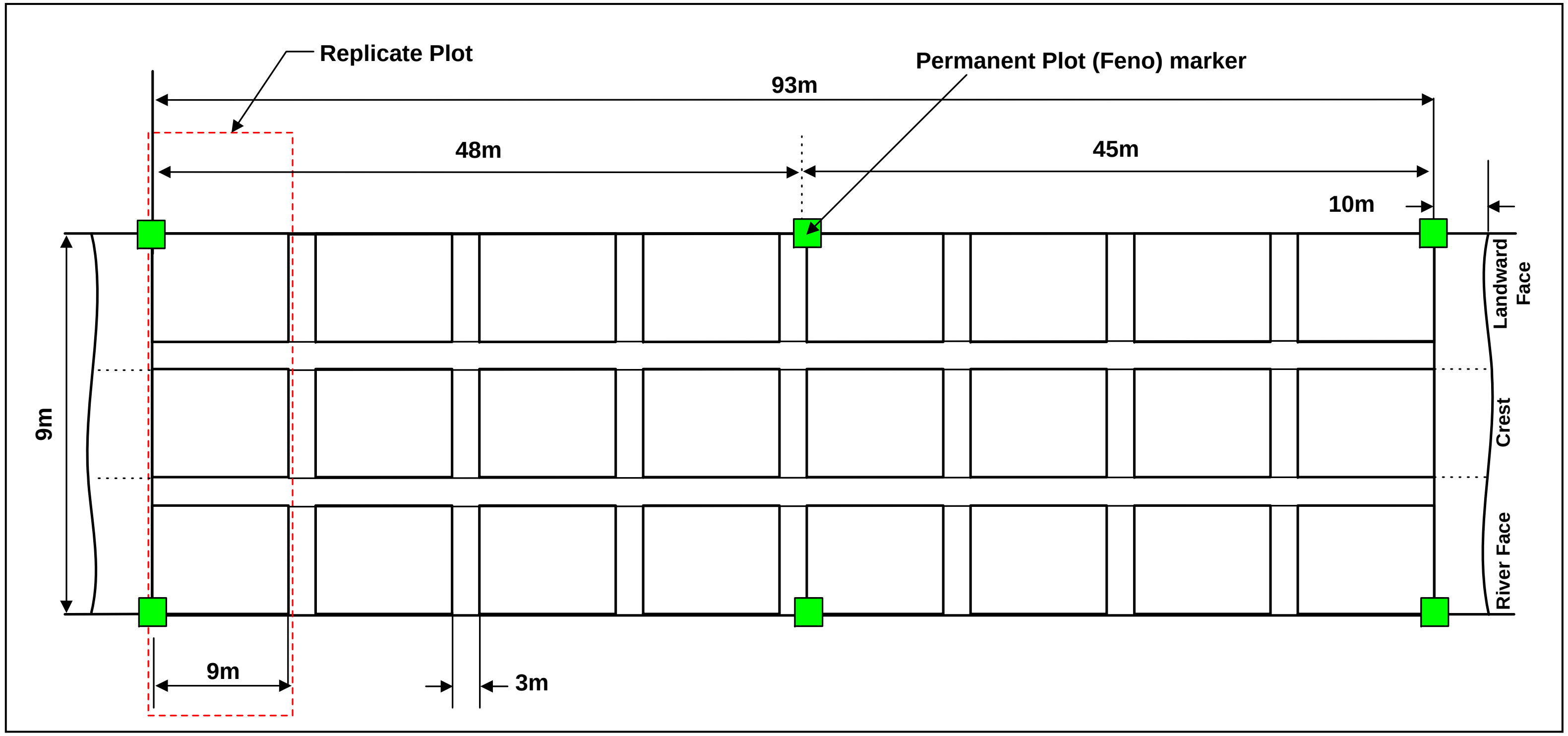

Figure 2.4 Typical treatment layout.

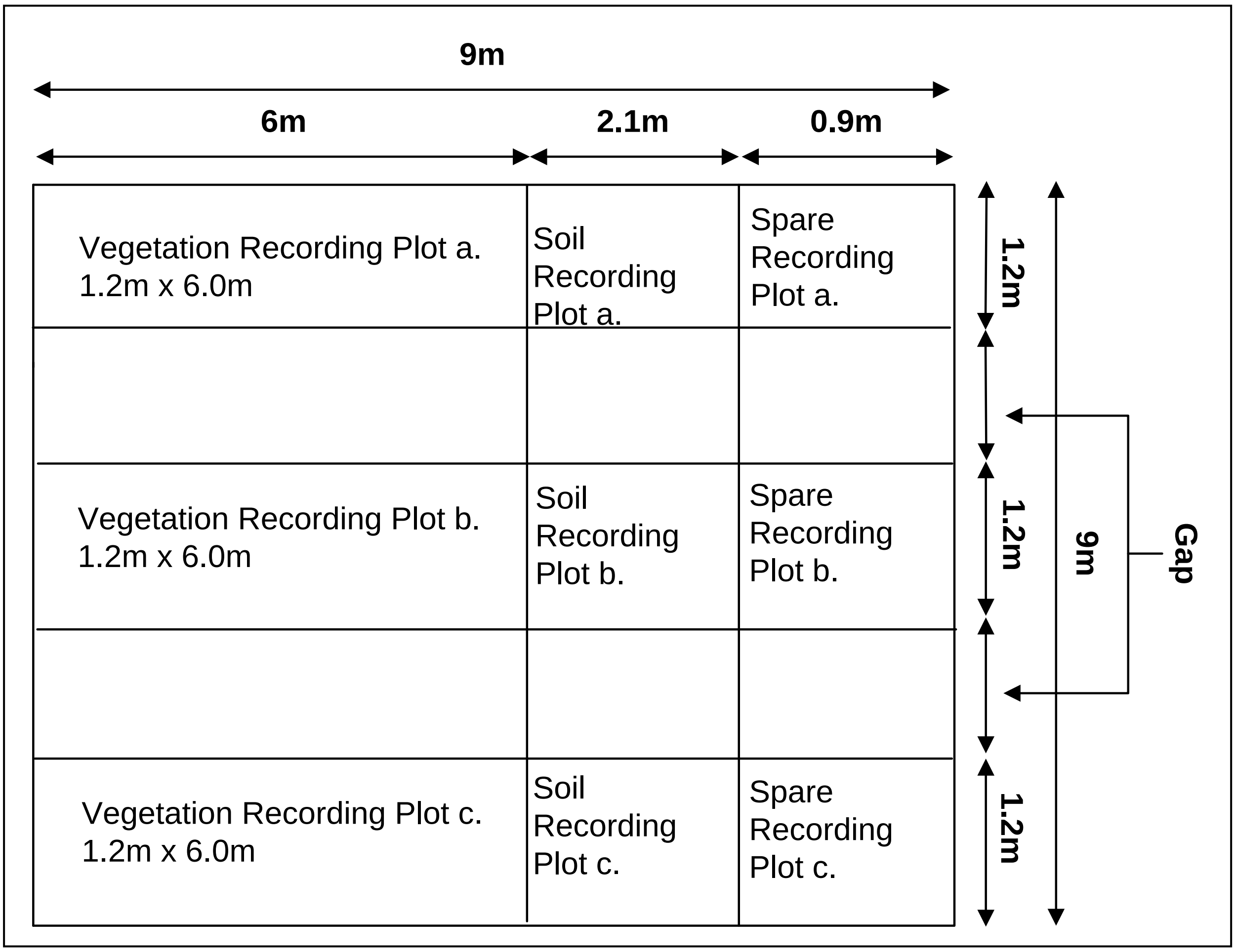

Figure 2.5 Generalised layout of a single replicate plot showing location of individual recording plots for vegetation, soil and the spare plot.

Note: There is a 3 m gap between each of the individual replicates within each treatment.

2.3.2 Marking of treatments

The precise location of each treatment was marked with a permanent feno-marker (a 0.6 m spike with an aluminium head flush with the soil surface).

One feno-marker was positioned at each of the four corners of the treatment and two further markers about midway (48 m from the eastern end and 45 m from the western end of the treatment). Each feno-marker was marked with the treatment number and a serial number (as specified in the Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report by ELP, 2004).

Metal detectors were used to re-locate the feno-markers before monitoring took place.

Individual recording plots were measured out from these permanent treatment markers and marked temporarily, using bamboo canes, during field recording. This was essential to prevent previously disturbed soil samples from being re-sampled and vegetation monitoring discrepancies.

The Operations Delivery teams provided, erected and maintained:

- cross signs (informing passers by about the works);

- treatment demarcation posts (located at either end of each treatment and labelled to inform the maintenance teams which management type was required).

The Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report (ELP, 2004) gives full details of the positioning of these markers.

2.4 Recording of key parameters

This section outlines the methods used in the vegetation, soil and habitat utilisation monitoring carried out over the five year period. A full account is given in the Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report (ELP, 2004).

2.4.1 Recording of vegetation

The recording plots were used to monitor all necessary parameters for changes in the vegetation under the various treatments. Particular emphasis was given to those vegetation parameters (e.g. percentage cover of bare ground) considered during the selection of the performance indicators to be monitored to affect the erodibility of the bank either directly by river flow during flood periods or by overtopping (with supercritical flow) down the reverse (landward) embankment face.

Recording was conducted two times within Year 1 of the trials (once as part of the baseline survey in April by L A B Coastal and once by ELP in September). ELP conducted all recording in Years 2–5 as set out in Table 2.2. Plans for a further December vegetation monitoring round (which would have provided information on the vegetation when the water levels in the lodes were at their highest and the plant cover at its lowest) were removed from the trials due to financial constraints.

Table 2.2 Schedule of vegetation recording of the flood embankment.

Month	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Year 1	Baseline				*	+			
Year 2	+		+						
Year 3	+		+		+				
Year 4	+		+						
Year 5	+		+		+				

Notes * Year 1 August recording was postponed to September due to Environment Agency operational delays.

Each recording session was conducted during the first and second weeks of the month to ensure all surveying was completed before cutting commenced in the third week. This timing of the monitoring enabled recording of the maximum levels of the vegetation growth consistently across the sites and facilitated the identification of plant species.

As previously stated, the vegetation of each treatment was recorded using three replicates (within which lay separate recording plots). The vegetation parameters recorded included:

- **Vegetation height** using the disk method devised by Dr Laurie Boorman (NCC 1986, EFU 1991).

- **Plant species composition** (grasses and herbs) of the sward using the Domin scale of cover/abundance (Table 2.3) and assignment of values for each species within the 6 m × 1.2 m (area 7.20 m^2).[2] Only living plant material was recorded within the Domin value for each species (i.e. the dead stalks of species still present within the area were not included within the overall Domin value for that species). Additionally, living specimens present underneath a cover of grass arisings were included within that species score.

Table 2.3 Domin values.

Domin value	Cover
10	91–100%
9	76–90%
8	51–75%
7	34–50%
6	26–33%
5	11–25%
4	4–10%
3	<4% with many individuals (scattered)
2	<4% with a few individuals (clumped)
1	<4% with 1–2 individuals

Source: Dahl and Hadac (1941).

- The **extent of bare ground and leaf litter** (including both dead plant material attached to living plants and arisings left after cutting) were recorded as percentage cover. A separate percentage cover value was assigned for aquatic plant litter (i.e. dead plant material sourced from the cutting of wetland vegetation at the margins of the watercourse which has been placed on the embankment during maintenance procedures). The extent of bryophyte (moss and liverwort) cover was also estimated using percentage cover.
- The **extent of shading and details of any other factors** that could be affecting plant growth were also recorded on a standard form during what was termed a 'walkover survey'.

Some of the sward variables (including leaf litter cover, aquatic litter cover, bare ground cover, bryophyte cover and total vegetation cover) were only estimates by eye rather than measured variables. Therefore they may be up to ±10 per cent error between surveyors (though surveyors were trained together).

Similarly, plant species cover was estimated using Domin values rather than actual measurements. However, as Domin classes are specifically designed to reduce the potential of surveyor disagreement, the error of assigned Domin values is likely to be small (one size class at most for the smaller Domin values, with little chance of error in the larger Domin values).

[2] It was originally proposed that nested quadrats would be used to monitor the vegetation within each recording plot and these were recorded in the baseline survey of Stage 3. However this was later adapted to one set of data for the entire recording plot as it was felt that nesting provided unnecessary duplication of results on what was essentially a series of rather species-poor plant communities.

For all sward variables, the large number of vegetation recording plots sampled and the rotation of surveyors across bank faces and treatments mean the likelihood of a significant correlation between two variables being recorded due purely to error between surveyors is considered very small.

A full photographic record of each of the vegetation recording plots was taken during the baseline survey (Posford and L A B Coastal 2003). A further set of photographs showing the landward slope and the riverside slope of each treatment was taken by ELP during the September 2003 survey; this was repeated at every vegetation monitoring visit for the remaining four years of the trials.

These sets of photographs provided a useful visual comparison of the result of different management techniques between treatments (all photographic evidence is provided for reference on CD 2).

A record of the weather conditions was made for each day of recording. The plant names used for the vegetation recording are in accordance with *New Flora of the British Isles* (Stace 1997).

2.4.2 Recording of soil

The taking of soil cores and other similar soil monitoring could not be repeated at the same spot within the recording plot each year and provision was made for sufficient area to allow for repeated soil monitoring. A detailed record was kept of the location of each soil core taken at each monitoring round to avoid interference with subsequent monitoring.

The soil monitoring programme can be divided into two sections covering the geotechnical parameters and biological parameters respectively. To minimise the variability of soil characteristics, the geotechnical and biological monitoring were carried out within the same replicate for each treatment.

The soil monitoring replicates were selected by using the first replicate for each treatment (to coincide with the first vegetation replicate). The same replicate was used throughout the five year trials to maximise consistency of the results.

Each chosen soil monitoring recording plot (1.2 m × 2.1 m) is divided into 28 grids each 0.3 m × 0.3 m. These girds are used for the biological and geotechnical monitoring, testing and sampling. Each square grid was used only once for monitoring during the trials.

Geotechnical parameters

Soil monitoring for geotechnical parameters was designed on the basis that the effect of grass management (as opposed to tree/shrubs) on the flood embankment reduces significantly with depth. To monitor below 0.3 m or to have permanent instrumentation for the direct recording of soil suction and other strength indicators was considered beyond the scope of the research.

The geotechnical parameters observed and recorded were:

- the presence, orientation and dimensions of cracks and micro-fissures;
- shear strength at the soil surface and within the top 0.3 m depth;
- removal of undisturbed soil samples and laboratory testing for classification and moisture content at 0.075 m and 0.3 m depths.

Cracks and micro-fissures

The detailed recording of cracks and micro-fissures was carried out as specified in the Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report (ELP, 2004). Recording was carried out on the crest, landward and river faces of the vegetation recording plot in April, and on the landward face only in August (as this was felt to be embankment face most vulnerable to destabilisation).

Each recording plot was surveyed using a survey frame, with all cracks over 1 cm wide and greater than 10 cm in length recorded.

The crack width recorded represents only the surface dimensions and does not take into account any expansion/contraction of the crack width below the surface. The width of most cracks varies along their length and therefore it is the average crack width which was recorded. Similarly where cracks were particularly long, several depths were taken along their length and depth variation was indicated (e.g. 40–60 cm depth).

Soil strength

The following strength monitoring was carried out at each soil recording plots (as detailed in the Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report (ELP, 2004) in the following order:

1. Three pocket penetrometer (PP) readings at the ground surface.
2. One surface soil temperature.
3. Three proving ring penetrometer (PRP) probe readings (0, 0.15 and 0.3 m depth).
4. One hand vane (HV) reading at the ground surface (0 m) adjacent to the sample hole (S) location.
5. Removal of the top of the sample area (approximately 0.075 m deep to ensure grass and matted roots are removed) from above sample hole location.
6. Recovery of an undisturbed sample from 0.075 m to 0.3 m – recording the number of blows required to fill the sample tube. The percussive action of collecting the sample is considered to be a good indication of the character of the ground.
7. Two pocket penetrometer readings at the top and bottom of the sample (0.075 and 0.3 m).
8. Labelling and storing of the samples.
9. One soil temperature reading at the base of the sample hole (0.3 m).
10. One hand vane reading at 0.3 m depth.
11. Backfilling of the hole with material similar to that removed.
12. Replacement of the turf.

The soil samples were sealed undisturbed and were later extruded in a laboratory (with the soil described in accordance with BS 5930: 1999 *Code of practice for site investigations*). Separate moisture content tests were then carried out in accordance with BS 1377: 1990 *Methods of test for civil engineering purposes* on soil from the top and bottom of the extended samples, giving moisture content readings at approximately 0.075 and 0.3 m depths.

The geotechnical monitoring schedule is shown in Table 2.4. The timings were chosen to coincide with the month where maximum cracking of the soil was expected (first and second weeks of August) and the month at the end of winter high flows where vegetation growth was not at its maximum (first and second weeks of April).

As previously stated, resistance trials were also performed in Year 5 on the river face at the three trial sites by L A B Coastal in partnership with the flood embankment management trials. These trials were conducted in winter and summer to determine the rates of soil erosion under different management practices. For a full description of the methodology see *Testing the Erosion Resistance of Vegetated Floodbanks* (Environment Agency 2009).

Table 2.4 Schedule of geotechnical monitoring and testing.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 1	Baseline					+			
Year 2									
Year 3	++				+				
Year 4									
Year 5	++				+				

+= landward slope only, ++=landward, crest and river face monitored.

Biological parameters

Within the soil recording plot, one soil sample was taken to a depth of 0.15 m for macronutrient analyses.

The sampling in June covered the period of maximum vegetation growth and plant cover. The April sampling provided a direct comparison with the baseline survey.

All April monitoring (including the baseline in Year 1) were carried out on the crest, landward and river faces of each selected soil monitoring recording plot. Other monitoring rounds were only carried out on the landward slopes (Table 2.5). All monitoring was carried out within the first two weeks of the month.

The growth of the vegetation is controlled by both the soil moisture content and the mineral nutrient status. Cutting the grass with the removal of arisings (Treatment Options 5, 6 and 7) may significantly reduce the soil nutrient status and limit future plant growth. The main nutrients that affect vegetation growth include nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg). If there is an adequate supply of three of these, the fourth will become the limiting factor. Hence, although generally nitrogen and phosphorus are the most likely to determine plant growth, either potassium or magnesium can also become the controlling factor.

A second soil sample (identical in depth and adjacent to the first soil biological sample) was taken for root content analyses. Root soil samples were then analysed by accurately weighing out 25 g of soil[3] taken from the centre of the root sample (i.e. approximate 0.075 m down from the top of the sample). The roots were then teased out of the 25 g sample, recording any details regarding orientation in the process. The roots were then separated into three size classes (<0.5 cm width, 0.5–1 cm width, >1 cm width) and counted. Once separated, the roots were dried at 105°C until a constant weight was reached (taking

[3] 25 g is the weight of soil as it comes out of the sample tube (i.e. no water added or removed).

approximately one hour) and weighed using analytical scales to ascertain the dry weight of each size class.

In the original design of the methodology, it was intended that a cube of soil would be taken from the sample and that root counting would be conducted on each of the sides of the cube to record root orientation. This was not possible due to the friable condition of the soil.

During each visit, tests were conducted by ELP on the extruded samples listed above to obtain the following information for each of the treatments:

- root content in terms of the number, size and general orientation;
- average soil sample moisture content – dried at 105°C and expressed as a percentage on a dry weight basis;
- soil organic content – percentage loss on ignition based on the difference between 220 and 440°C;
- soil fertility – levels of available macronutrients P, K, Mg, nitrate (NO_3) and ammonium (NH_4);
- soil pH – expressed to 0.1 units;
- soil salinity – recorded in micro-siemens in the baseline survey only.

In the baseline survey of Year 1, this recording was undertaken by Posford Haskoning.

Table 2.5 Schedule of soil biological sampling.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 1	Baseline					+			
Year 2			+						
Year 3	++		+		+				
Year 4			+						
Year 5	++		+		+				

+=landward slope only, ++=crest, landward and river faces.

2.4.3 Recording of habitat utilisation

The available habitat utilisation was assessed within the trial sites to provide a context for the vegetation management. The schedule for the surveys is outlined in Table 2.6.

The following surveys are conducted for each of the treatments for all three trial sites.

- Walkover survey of each site undertaken in April to include notes on evidence of mammal, bird or reptile activity, shading influence from trees, adjacent land use, trampling pressure, etc.
- Walkover checks for birds' nests – due to the grass covered areas of the floodbanks potentially being used by birds for nesting.
- Invertebrate surveys – undertaken as shown in Table 2.6 and detailed in the Anglian Region Vegetation Management Trials: Methodology Review and Monitoring Report (ELP, 2004). The procedure broadly involved taking standardised sweep net samples from each treatment. Samples were taken

along the crest, landward and river faces of the treatment and the data pooled as one result for the entire treatment. Invertebrates were then removed and stored in alcohol for laboratory examination.

Table 2.6 Schedule of habitat and species surveys.

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Year 1	Baseline (E)					Baseline (I)			
Year 2	E + B		B						
Year 3	E + B		B + I			I			
Year 4	E + B		B						
Year 5	E + B		B + I			I			

E= walkover ecological review, B= bird's nest survey, I= invertebrate survey.

2.5 Meteorological and river condition monitoring

The project also required the monitoring of data relating to local environmental conditions for each site. The Environment Agency provided the following meteorological or local river condition data on an annual basis (every January for the past 12 months):

- air temperature (daily maximum, minimum and mean);
- rainfall (daily total);
- wind speed and direction (daily means, and maximum gust wind speed);
- humidity (daily means, minimum and mean from wet and dry bulb temperatures);
- radiation (total and net solar).

The data for the Ely Ouse and Reach Lode sites were taken from Denver weather monitoring station (Environment Agency). Data for Billingborough Lode were taken from the Cranwell and Waddington weather monitoring stations (Met Office).

In addition to these weather data, water levels (daily mean and maximum level) were recorded by the Environment Agency using existing telemetered local level monitoring stations.

3 Site background

3.1 Site history

3.1.1 Billingborough

The main bank construction works at this site were undertaken during the 1930s and locally sourced material (scrapes from fields, materials removed from the channel during widening/dredging, etc.) would have been used. It is not known if the banks were seeded after the original construction. Localised improvements were undertaken in the 1960s and 1970s.

A regime of six cuts per year was in place only for a year or two before the trials. Before that the maintenance regime would have been monthly crest cuts (April–September) and one or two cuts of the landward and river faces, with a single late channel weed cut undertaken from the opposite bank. No arisings from weed control were ever dumped on the trial bank prior to the trials (Brown J, personal communication, 2007).

3.1.2 Reach Lode

It is not known when the river embankments at Reach Lode were created. The last major bank improvement works during 1989/1990 resulted in the bank profiles that exist today. The material used during these works was clay and topsoil, which would have been sourced locally from clay pits – probably at Ely Ouse or Sutton. The banks were seeded following the improvement works (the seed mix is not known).

The management regime prior to this trial was biannual grass cutting of the whole bank in July and September (R Ely, personal communication, 2007).

3.1.3 Ely Ouse

The date of creation of the embankments at Ely Ouse is unknown. During 1960 major bank improvement works were undertaken to create the current profiles. Material used in the bank modifications was locally sourced clay and topsoil. The banks were reseeded following the works, but the seed mix is unknown.

Prior to these trials, the management regime would have included mowing all faces of the bank, once in July and once in September (R Ely, personal communication, 2007).

3.2 Location in landscape and site observations

3.2.1 Billingborough

The Billingborough trial site is surrounded by private arable farmland and contains no public pathways, though there is a private path along the ridge used by the adjacent farm. There is a farm road access across the site near Neslam Bridge Farm.

There is only one small tree on the western end of the site, which began to have a small shading effect on some monitoring plots from Year 3.

Cattle were observed within the trial site in September of Year 1 but were immediately removed. Spray drift was also apparent at the base of the landward face of treatments in Year 1 and to a lesser extent in Year 2. This is due to the close proximity of the landward face to the arable fields.

Vehicle access was evident on the crest of the bank, necessary for management purposes.

Trampling was recorded on the crest along the route of an informal footpath, particularly in treatments at the eastern end of the site in Year 4. But as trampling was present on the crest of all three trial sites, the trials remain highly comparable.

Substantial areas of bare ground were also present on the river face in those treatments containing abundant charlock. This species was present (although in smaller quantities) in the baseline survey and was also observed frequently on the embankments immediately outside the trial site. This was not the case at Reach Lode or Ely Ouse, where charlock was largely absent.

This site showed the most mammal activity of the three trial areas. An otter slide was observed on the north bank during 2006 (L Boorman, personal communication). The burrows of small mammals (most probably field voles) were present in the swards of several treatments, as were small amounts of rabbit droppings. A badger latrine was recorded in Treatment Option 7 in all years. Fox scats were present on the crest of Treatment Option 10 in Years 1 and 2. It was therefore likely that differences in soil strength and erosion measurements at this site would be more pronounced due to the increased mammal activity (particularly voles).

A reasonably diverse aquatic flora was observed in the watercourse and, in conjunction with some areas of exposed steep bank on the opposite side of the watercourse, provided good habitat for water voles (though none were observed). Old otter spraints were also recorded in Year 3. Kestrels and barn owls were seen using the bank for hunting and moorhens were nesting in the watercourse within the trial section.

3.2.2 Reach Lode

Reach Lode is also adjacent to arable land. Between the trial site and the crop, however, there is an access track and a discontinuous hedge. A public footpath runs along the length of the embankment crest. The land to the east of the study area (on the other side of the lode) is part of the Wicken Fen National Nature Reserve (renowned for its diversity of vascular plants, invertebrates and birdlife). Reach Lode is therefore likely to receive a greater diversity of seed rain than would be expected if it were purely surrounded by arable land.

Several trees can be found within the hedge, which may occasionally shade the base of the landward face. Treatment Option 6 contains some small bushes, which may cause minor shading.

There were vehicle ruts on the crest (necessary for management purposes). Some trampling of the vegetation had occurred through public use of the site during Years 3 and 4. There were also signs of horse riding across some of the crest in Year 4.

From Year 3 onwards, undercutting (as a result of natural erosion) was occurring on the river face (slightly reducing the width of some replicates).

Seepage was observed only at a single location (in Year 3 within Treatment Option 7) where water was leaking from the landward face onto the adjacent track. However, similar seepages were observed outside the treatments at this site and demonstrate that this bank is more prone to leakage than Billingborough or Ely Ouse.

Swans and geese use the crest and river face of the embankment as resting areas in several recording plots, although no nests were found within the study area. In Year 3, heron and moorhen were also seen using the river faces, while green woodpecker and pheasant were recorded on the landward face of the site. In addition to those birds seen in previous years, yellowhammer, goldfinch, reed bunting, swifts, swallows and coots were sighted in Year 4. There was evidence of the continuous presence of voles using the site (tunnels and runs in vegetation) as well as moles and fox signs in Years 3 and 4.

For a period of time, tethered horses were grazed just south of the embankment although they were unable to access the recording plots.

3.2.3 Ely Ouse

Once again, this trial site is adjacent to arable land to the east beyond a busy, potentially hazardous road. A train line cutting through grassland is adjacent to the Ouse on the opposite side of the river.

A number of trees at the site may create some minor shading to monitoring plots.

The Ely Ouse site receives the largest amount of public use of all three trial sites; walkers were observed on several occasions using the crest of the bank. Numerous tracks through the vegetation were also evident (some of which cut through replicates). These tracks appeared to lead to fishing points but did not seem to be routes taken regularly and therefore the impact on the vegetation was likely to be minimal. Equipment used for maintenance had also created significant rutting on the crest of the embankment – as on all sites.

Due to the close proximity to the main road, this site is vulnerable to, and has been affected by, isolated vegetation fires during the summer months. This is mitigated for by cutting the lower 2 m of the bank adjacent to the highway (but outside the trial area) on a regular basis. This technique has reduced the frequency of fires but has not prevented them entirely. This is an environmental factor that is likely to influence the plant communities found but which is not shared by the other trial sites.

Ely Ouse had the least amount of bird and mammal activity of the three sites probably due to the greater amount of use by the public here and adjacent to this site. Small mammal burrows (most likely vole) and molehills were observed throughout the treatments but no clear evidence of water voles was found. Juvenile and adult frogs were seen on the river face in Year 3.

During Year 2 surveys, reed buntings were observed nesting in the tall reed bordering the watercourse but were not sufficiently close to any replicate to be disturbed by surveying.

Swans were observed nesting on the riverside berm (Treatment Option 3, Year 1) but later abandoned the nest. Cormorant and mallard were seen using the Ouse, but only kestrel, swan and reed buntings were actually observed on the bank itself.

3.3 Soils

3.3.1 Billingborough

The soils in the area immediately adjacent to the embankments at Billingborough fall into the general classification of Wallasea 2 (813g) by the Soil Survey of England and Wales (1983). This soil is described as:

> Marine Alluvium. Deep, stoneless, clayey soils, calcareous in places. Some deep calcareous silty soils. Flat land, often with low ridges, giving a complex soil pattern. Groundwater controlled by ditches and pumps.

Further assessments have revealed that the embankment soils have a slightly different composition than those surrounding them. The embankments at Billingborough generally consisted of stiff, dark brown to orange brown clay with occasional fine roots (soil classification CH) across most of the treatments. There were intermittent patches of sandy clay and organic matter. Occasionally areas of gravel consisting of sub-angular chalk and flint were also found. The pH was generally around 8.0–8.5 yet pH levels did drop as low as 5.5, possibly due to the sandier component of the soil.

At Billingborough, phosphorus was recorded at levels below the target for agricultural grassland; potassium and magnesium were not recorded as limiting factors. The embankment at this location generally had the highest levels of measured nutrients of all the sites. This was likely to influence the plant communities recorded as it would favour competitive species able to utilise the available nutrients rapidly over diminutive species able to tolerate impoverished soils. However, available soil nitrogen was the lowest of all the three sites.

3.3.2 Reach Lode

The soils in the area immediately adjacent to the embankments at Reach Lode fall into the same general classification as those at Ely Ouse, Adventurers' 1 (1024a) by the Soil Survey of England and Wales (1983). The pH was generally around 8.0–8.5.

The soils within the study area's embankments consisted mainly of stiff, dark brown, slightly gravely clay with fine roots and sometimes an organic element (soil classification CV and MV). Where gravel occurred it was generally of siltstone or limestone.

The soil at Reach Lode was found to be more organic on the whole than Billingborough and even contained some brick and coal in addition to fine shell fragments. Sandier patches were also found. This indicated that the embankment at Reach Lode would be more permeable than the other trial sites.

The landward face of the Reach Lode embankment is coated regularly with aquatic dredgings from the lode, providing a constant source of peat and silt to this bank face. Though it is not known how long this management practice has been in operation, it is possible that Reach Lode has historically received greater quantities of seed from wetland or semi-aquatic plant species (such as *Phragmites australis*) on its landward face than at the other two trial sites where it does not occur.

Phosphorus was recorded at levels that were below the target for agricultural grassland. Potassium and magnesium were not recorded as limiting factors. Available soil nitrogen levels were the highest of the three sites.

3.3.3 Ely Ouse

The soils in the area immediately adjacent to the embankments at Ely Ouse fall into the general classification of Adventurers' 1 (1024a) by the Soil Survey of England and Wales (1983). This soil is described as:

> Fen Peat. Deep peat soils. Flat land. Groundwater levels often controlled by ditches and pumps, some undrained areas. Risk of wind erosion.

The soil of the embankments at Ely Ouse may be described as mostly firm/stiff, dark brown, slightly sandy clay with fine roots and occasional gravel or shell fragments. The pH was generally around 8.0–8.5.

At Ely Ouse, phosphorus was recorded at levels that were below the target for agricultural grassland; potassium and magnesium were not recorded as limiting factors. Ely Ouse embankments generally had high levels of nutrients. Available soil nitrogen levels were intermediate between those at Billingborough and Reach Lode.

3.4 Bank dimensions and aspect

The dimensions of the embankment were recorded for each treatment at each of the three trial sites in Year 5. The dimensions recorded were:

- the gradient of the landward and river faces (10 samples per treatment);
- the length of the land, crest and river faces (one sample per treatment).

The results for the gradients and lengths of embankments are shown in Figures 3.1 and 3.2 respectively. The bank dimensions are influenced by, and in turn influence:

- bank stability (cracking/slumping);
- micro climate (aspect, solar radiation, shading, precipitation interception/run-off);
- bank flora and fauna.

At all the trial sites, the average angle of the bank was steeper on the landward face than the river face, making the landward face more prone to slumping. A typical cross-section of an embankment is shown in Figure 2.2.

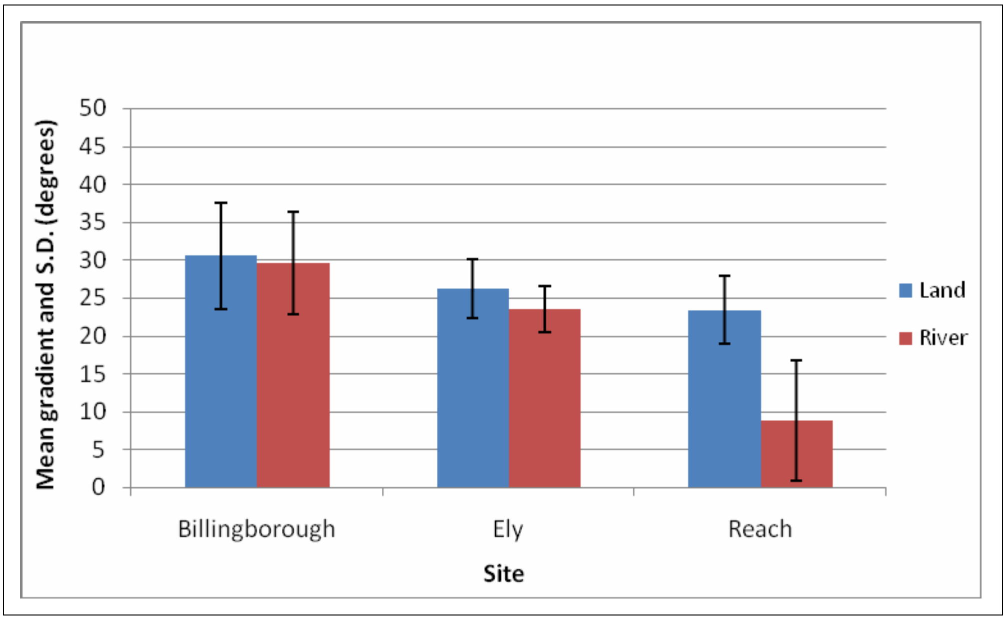

Figure 3.1 Average gradients (with standard deviations) of embankments on the river and landward face at Billingborough, Ely Ouse and Reach Lode, Year 5.

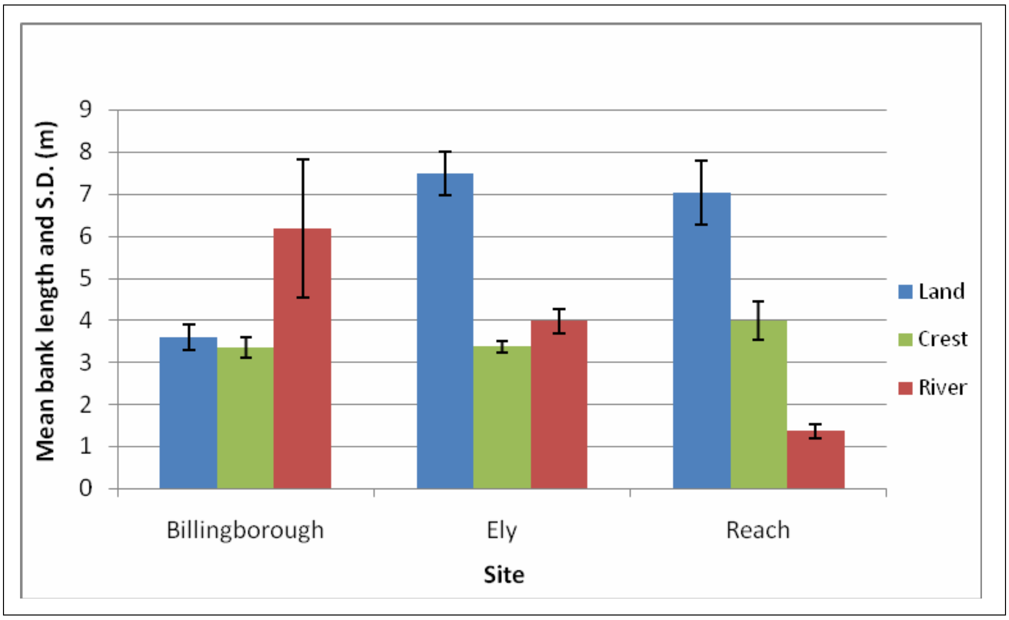

Figure 3.2 Average lengths (with standard deviations) of embankments on the river, crest and landward face at Billingborough, Ely Ouse and Reach Lode, Year 5.

3.4.1 Billingborough

The gradients of the land and river faces at Billingborough were remarkably similar (30.6° and 29.5° respectively) – see Figure 3.3.

These angles are the steepest found at the trial sites and are approaching the natural angle of repose for an unconsolidated material (30–37°). Above this angle, the bank is likely to fail, slump or slide if it were unconsolidated. A slip was observed in 2007 during winter erosion tests which showed signs of reactivation during summer tests in 2008 (L Boorman, personal communication).

At Billingborough it is likely that roots of the vegetation and the clay soil particles are providing some cohesion supporting this bank. However, its strength may be weakened by water during heavy rain or high river levels. The river face was almost double the length of both the land and the crest (6.2, 3.6 and 3.4 m respectively) due to the low level of the river, which is lower than the surrounding land.

The landward face at Billingborough faces north to north-east. Therefore, it is more sheltered from the winds and benefits from morning sunshine. Overall the landward face receives fewer hours of daily sunshine and is cooler. The river face has a south to southwest facing aspect. The river face is more exposed to the prevailing winds and benefits from longer sunshine hours.

3.4.2 Reach Lode

Although the bank angles at Reach Lode were the lowest of all the sites, the difference between the gradients of the two faces was particularly pronounced (land 23.4° and river 8.8°) – see Figure 3.4. This is due to the raised level of the river above the adjacent farmland. As a consequence, it was likely that soil moisture would be higher at Reach Lode than the other trial sites. The length of the river bank was also much shorter (1.4 m) than the landward bank (7.0 m) making it more vulnerable to inundation at times of high water.

At 4 m wide, the crest at Reach Lode was the widest of the three sites.

The landward face at Reach Lode faces south-west. Therefore, it is more exposed to the prevailing winds (although it receives some protection from the hedge) and benefits from long hours of daily sunshine and is warmer. The river face has a north-east facing aspect but the angle of slope is so slight that it receives little protection from prevailing winds and still receives several hours of daily sunshine.

3.4.3 Ely Ouse

The landward face at Ely Ouse was almost double the length of the river and crest faces [7.5, 4.0 and 3.4 m respectively (see Figure 3.5) – the inverse of the trend found at Billingborough]. In this scenario the river lies at a higher level than the agricultural land to the east (see Figure 3.4), but is still well below the crest of the embankment. The bank angle of both the river and land were relatively steep, at 23.5° and 26.2° respectively, but below the natural angle of repose.

The landward face at Ely Ouse has an east to south-easterly aspect. Therefore, it will be more vulnerable to the prevailing winds and benefit from long hours of daily sunshine, particularly in the morning. This is likely to reduce the moisture content of the vegetation at certain times of the year and make it vulnerable to seasonal fires. The river face has a west to north-westerly aspect. Therefore, it benefits from sunshine hours in the later day and is sheltered from prevailing winds.

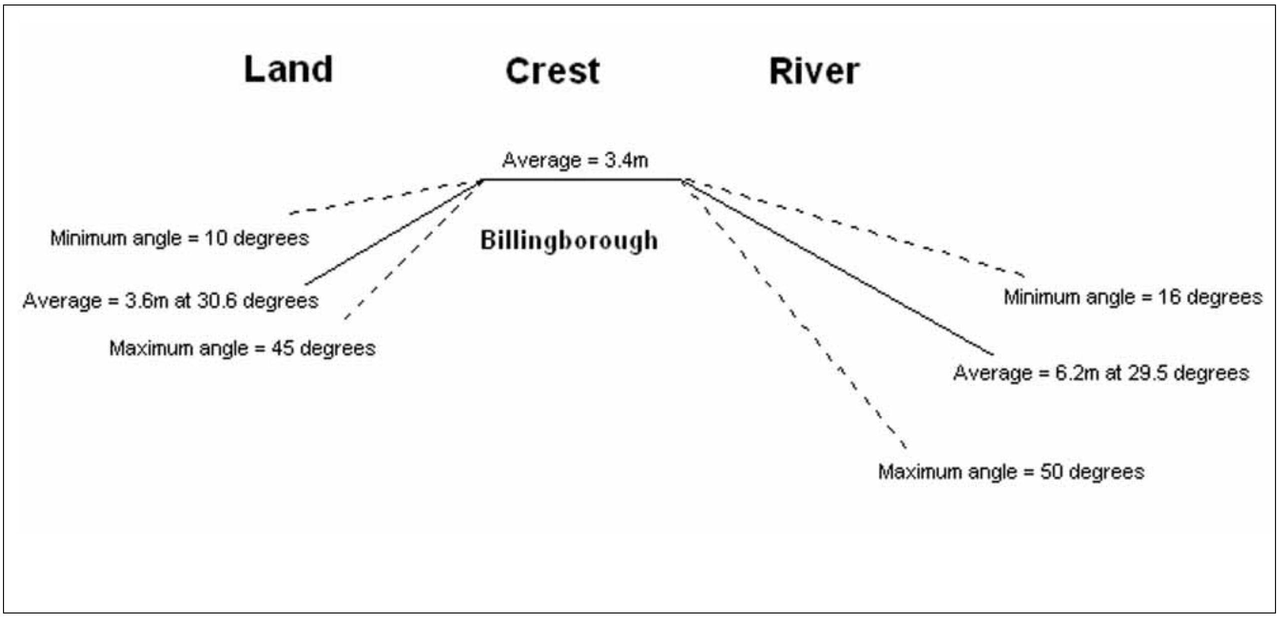

Figure 3.3 Typical bank dimensions recorded at Billingborough, Year 5.

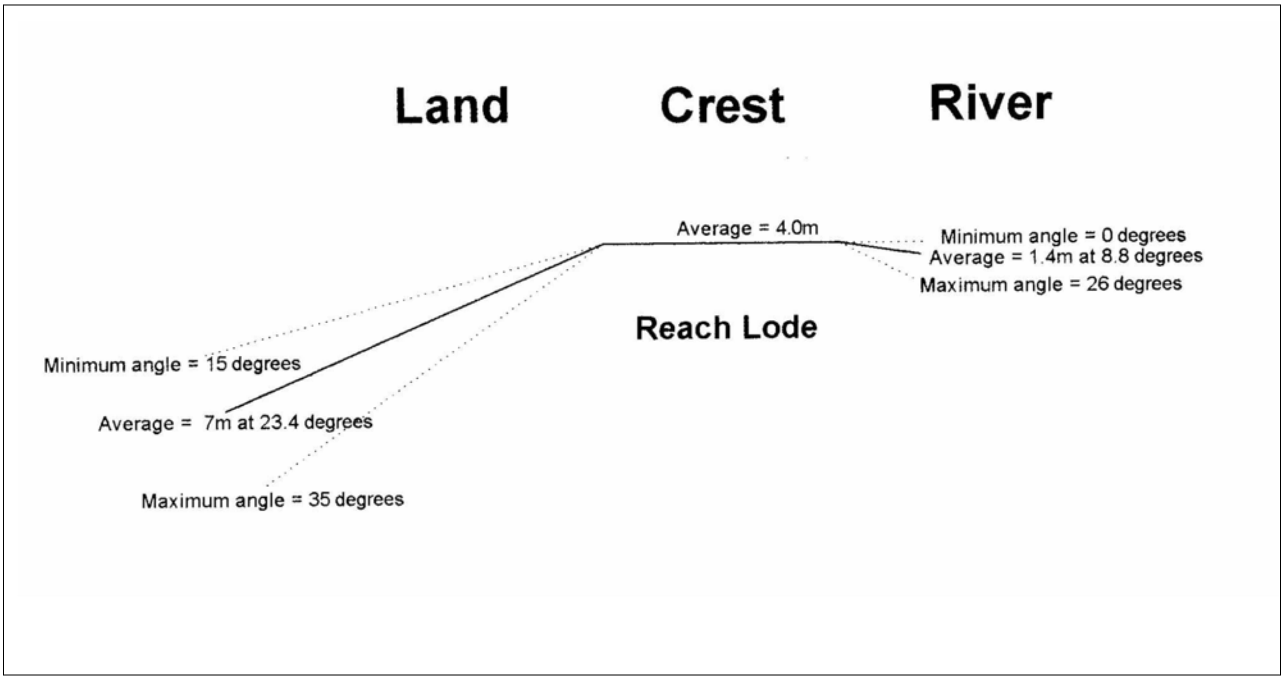

Figure 3.4 Typical bank dimensions recorded at Reach Lode, Year 5.

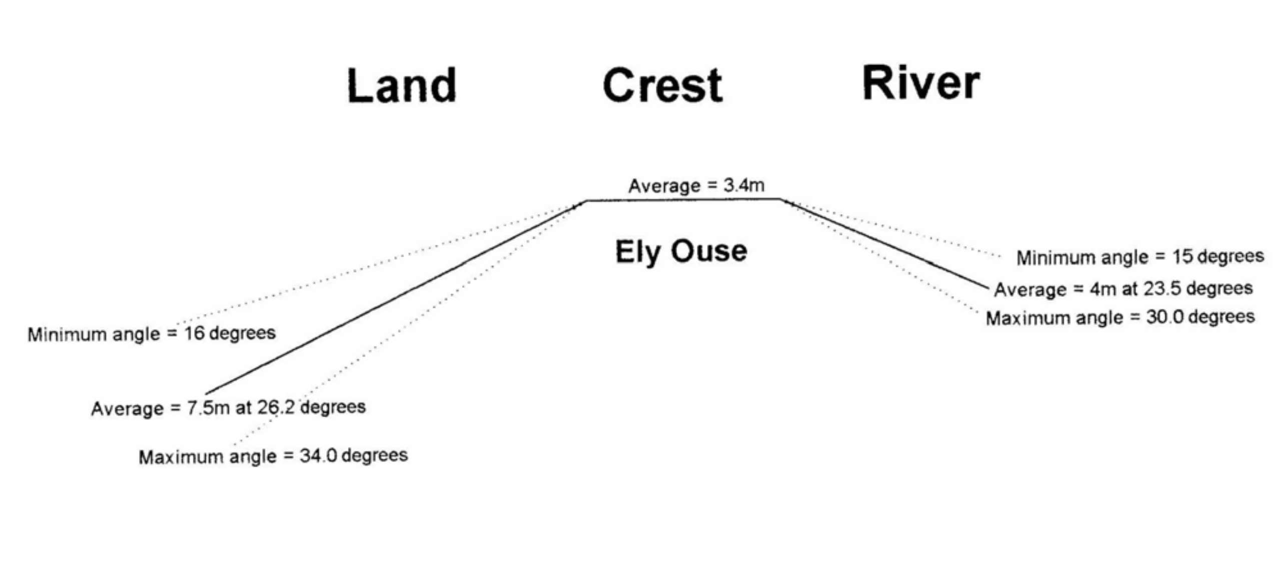

Figure 3.5 Typical bank dimensions recorded at Ely Ouse, Year 5.

3.5 Water levels

Monthly water levels for trial Years 1 to 5 for the rivers associated with each of the three trial sites were provided by the Environment Agency.

3.5.1 Billingborough

The water levels in the Billingborough Lode during the trial period are shown in Figure 3.6. Data were unavailable between January and April in all years, and November and December in Years 2 to 5.

The levels in the Billingborough Lode ranged from an extreme maximum of almost 1.8 m Ordnance Datum Newlyn (ODN) (July, Year 5) to an extreme minimum of -0.6 m ODN (November and December, Year 1, when they were reduced due to annual flood management regimes). On average the water is at its lowest between April and late June (between -0.2 m ODN and 0 m ODN). The average water level peaks between July and September (not exceeding 0.5 m ODN).

Water levels have a range of approximately 0.3–0.4 m during a year (excluding extreme values). The summer months of Year 5 and April to May of Year 2 were atypical due to heavy rainfall and flooding events. April to June of Year 4 had well below average water levels.

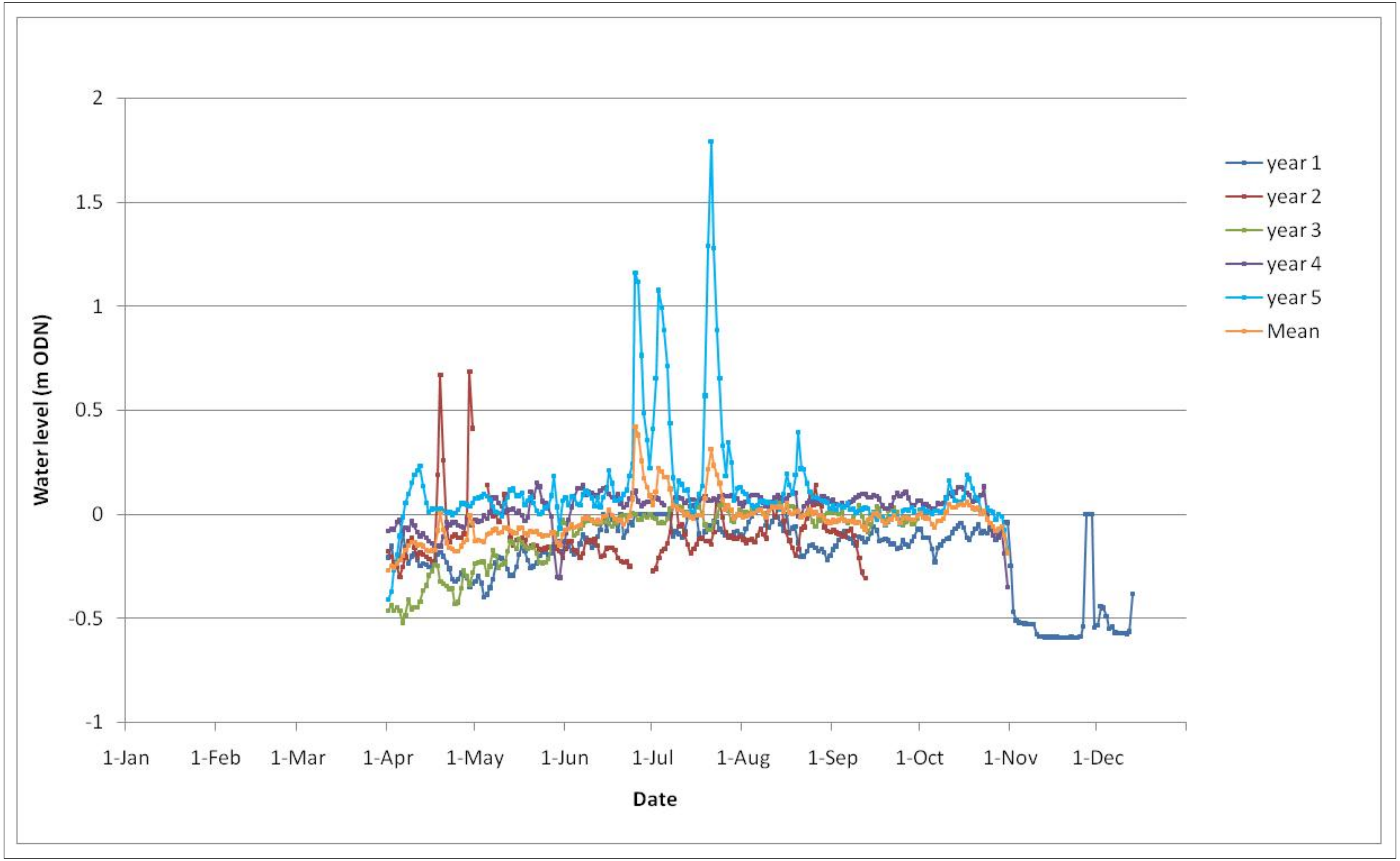

Figure 3.6 Water levels in the Billingborough Lode, Years 1 to 5.

3.5.2 Reach Lode

Water levels in the Reach Lode during the trial period are shown in Figure 3.7. Raw data were not available for this site so it was not possible to calculate mean monthly values.

The extreme maximum water levels (approximately 1.85 m) occurred in December of Year 5. The lowest water level (approximately 1.55 m) was seen in July of Year 3.

Throughout the course of a year, water levels in general remain remarkably stable within a 0.1 m range (1.7–1.8 m), with only slightly lower levels occurring between December and February. The stability of water levels is due to the Reach Lode being controlled by a sluice at Upware.

Although the annual range of water levels is low, there are regular fluctuations within short time intervals at Reach Lode. This variability is likely to be a result of the operation of the Upware sluice gates on the River Cam downstream of the trial location at Reach Lode.

3.5.3 Ely Ouse

Figure 3.8 shows the water levels in the Ely Ouse during the trial period. Raw data were not available for this site so it was not possible to calculate mean monthly values.

The maximum water level occurred in January of Year 1 at almost 2.4 m. More peaks in water level occurred sporadically over the years at levels between 1.7 and 1.8 m. The extreme minimum water level occurred in September of Year 3. The value of this minimum was off the scale, at less than 0.8 m. More frequent extreme low water levels were seen throughout the years at levels between 1.4 and 1.2 m.

In general, the months of low flow occurred between December and March; the river flowed at its highest levels between May and September.

Similarly to Billingborough, water levels had a range of only approximately 0.3 m during a year (excluding extreme values).

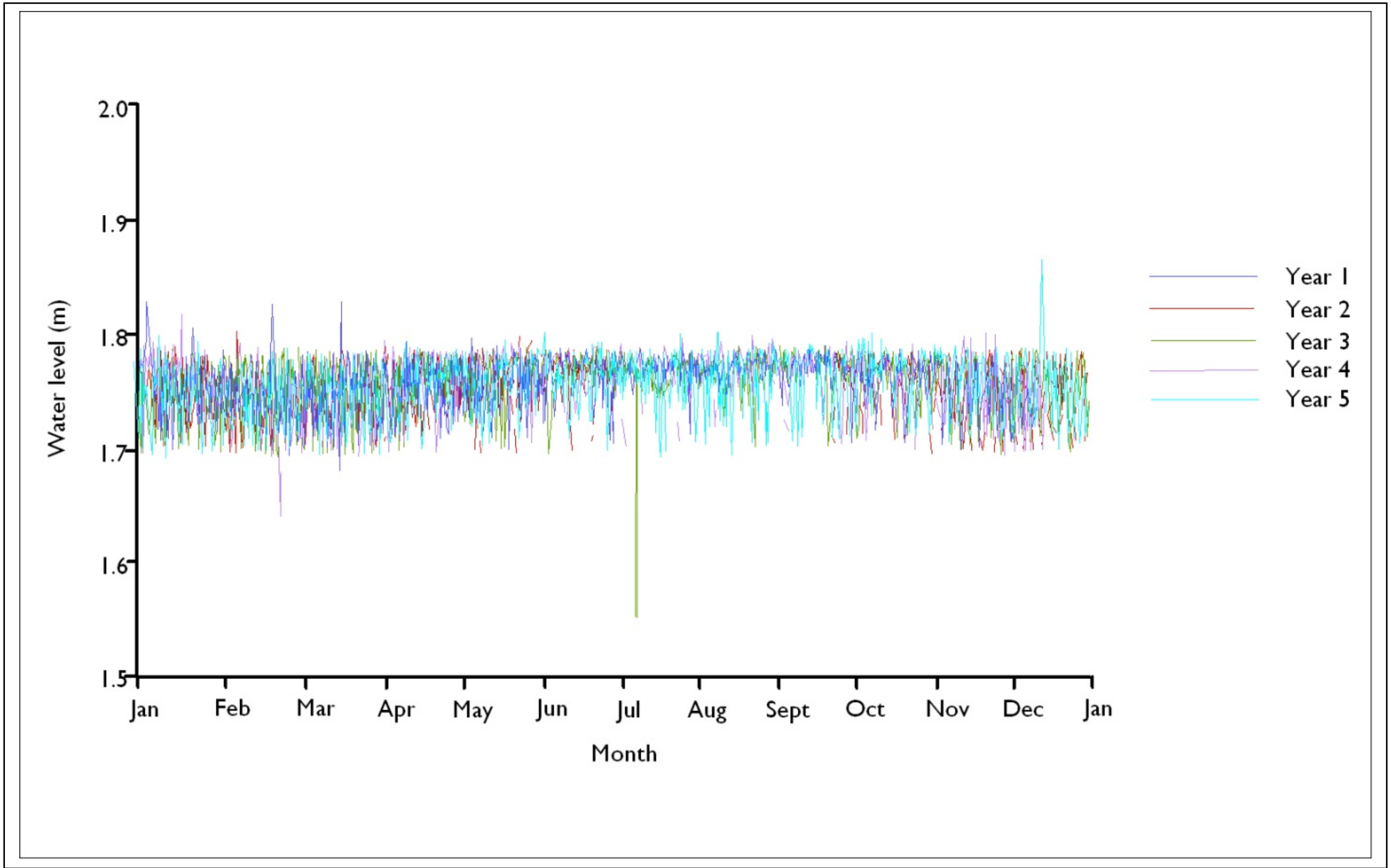

Figure 3.7 Water levels in the Reach Lode, Years 1 to 5.

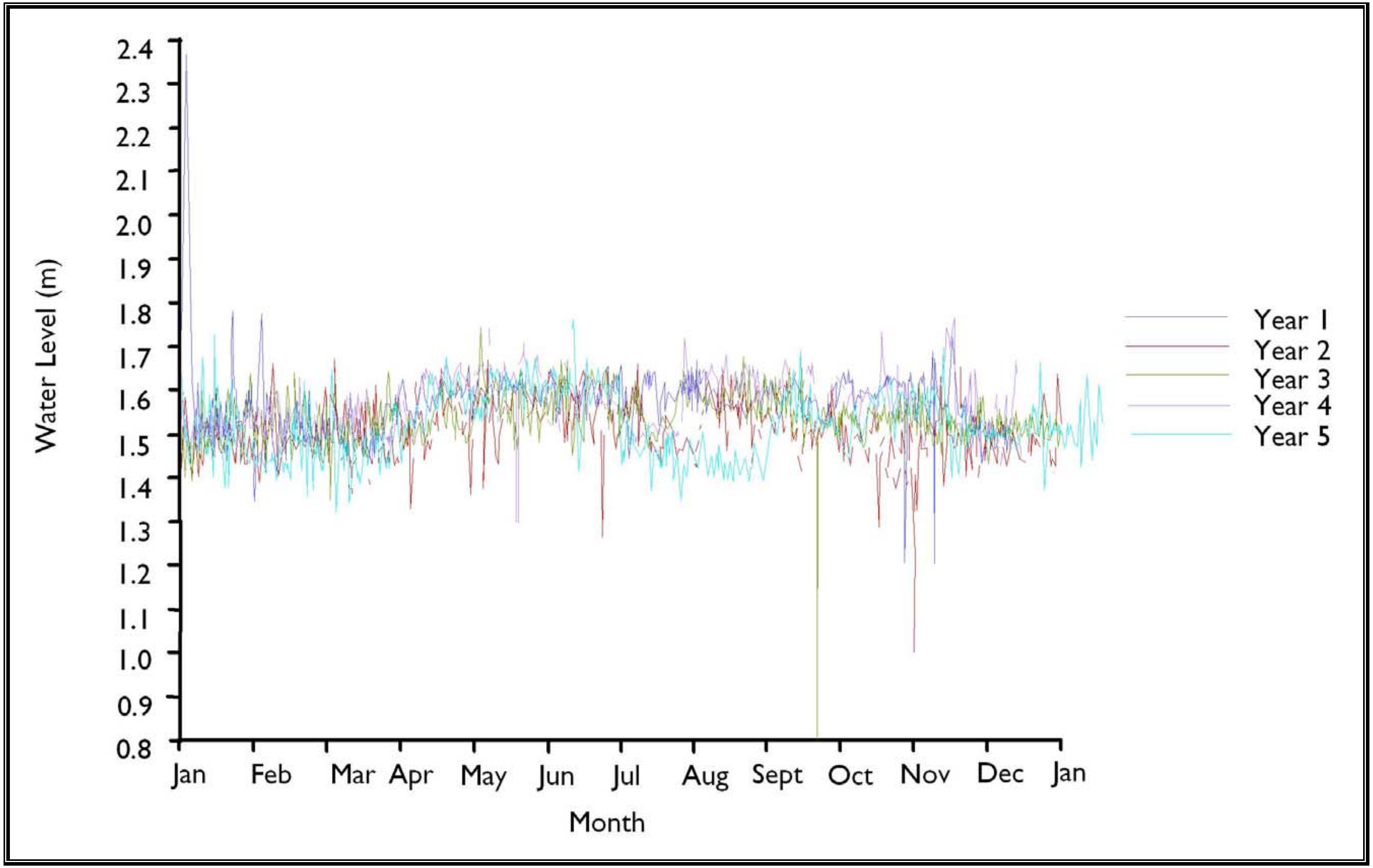

Figure 3.8 Water levels in the Ely Ouse, Years 1 to 5.

3.6 Climate

3.6.1 Billingborough

Climate data for Billingborough were obtained from the Met Office weather monitoring station at Cranwell, Lincolnshire (approximately 20 km north-west of the trial site).

Monthly mean, maximum and minimum temperature values (Figures 3.9, 3.10 and 3.11) show similar annual trends. As expected, peak temperatures occur in June to September (mean values between 15 and 20°C) and lower temperatures in November to February (mean values between 8 and 3°C). July and September of Year 4, and August of Year 1 exhibited warmer than average temperatures, with the highest mean monthly temperature occurring in August of Year 4 (approximately 20°C). March of Year 3 and July of Year 2 had temperatures cooler than average. The highest mean maximum temperature reached was in July of Year 4, at 26.3°C. The lowest mean minimum temperature reached was in February of Year 1, at -1°C.

Not surprisingly, the temperature trends were repeated in the trends shown by the hours of daily sunshine (Figure 3.12), with as many as 10 hours of sunshine per day occurring in the hottest month recorded (July, Year 4).Daily wind speed was at its lowest between June and September (8–10 knots) and at its fastest in the coolest months of November to February (10–13 knots, Figure 3.13).

Rainfall was the most variable of all meteorological parameters at Billingborough (Figure 3.14). On average the wettest months occurred between August and January (receiving 40–70 mm rain per month), although there was variation from this trend in individual years. Year 5 was the wettest year receiving particularly high rainfall in May, June and July (c. 126, 172 and 117 mm respectively).

Clearly this affects any comparison of soil moisture and soil strength data gathered from, for example, Year 1 compared with Year 5. Similarly it may affect comparisons of the abundance of certain plant or invertebrate species found in Year 1 compared with Year 5 – a factor that has been taken into account throughout the analysis. But because all three sites received high levels of rainfall in Year 5 (and all treatments within sites will have received equal quantities of rain), the results are still highly comparable between sites and treatments.

It is of interest that, in Year 1, the months preceding the April survey were particularly dry compared with other trial years.

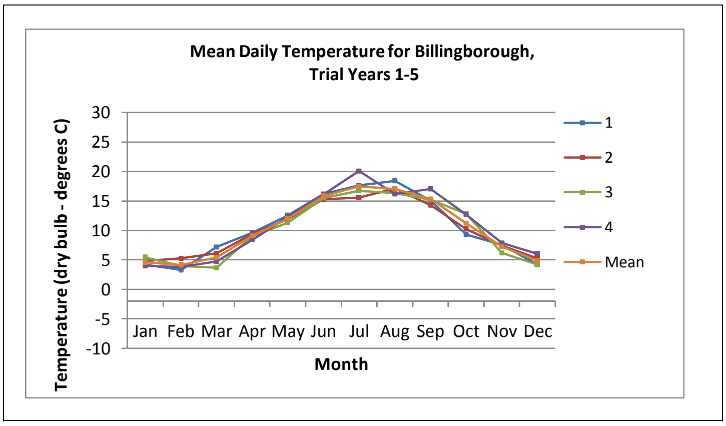

Figure 3.9 Mean daily temperatures at Billingborough, Years 1 to 4 (data not available for Year 5).

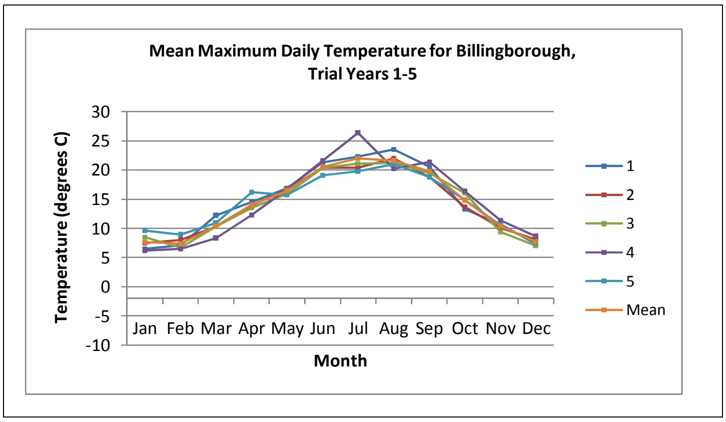

Figure 3.10 Mean maximum daily temperatures at Billingborough, Years 1 to 5.

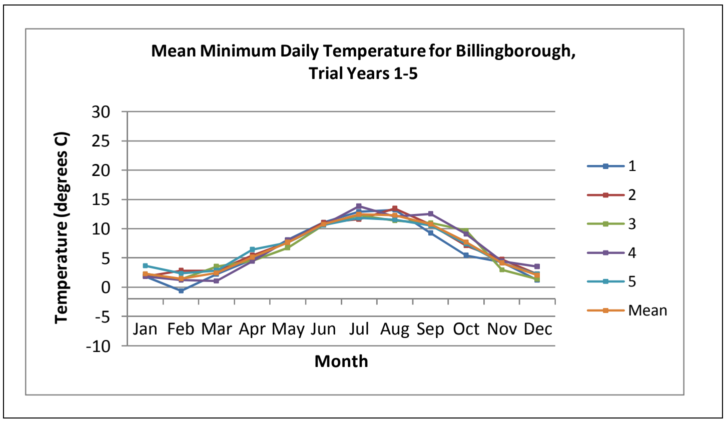

Figure 3.11 Mean minimum daily temperatures at Billingborough, Years 1 to 5.

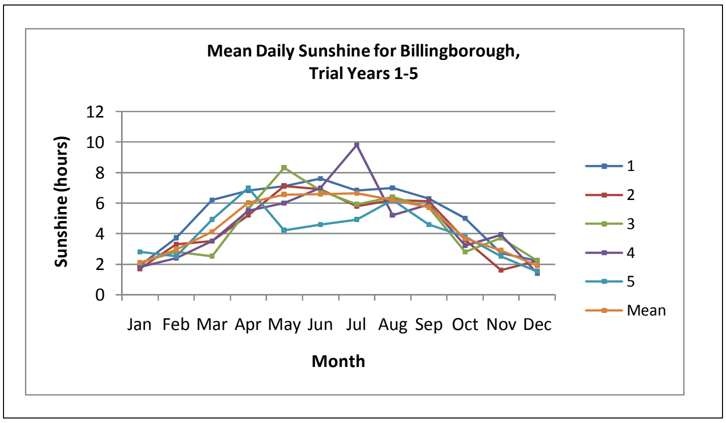

Figure 3.12 Mean daily sunshine at Billingborough, Years 1 to 5.

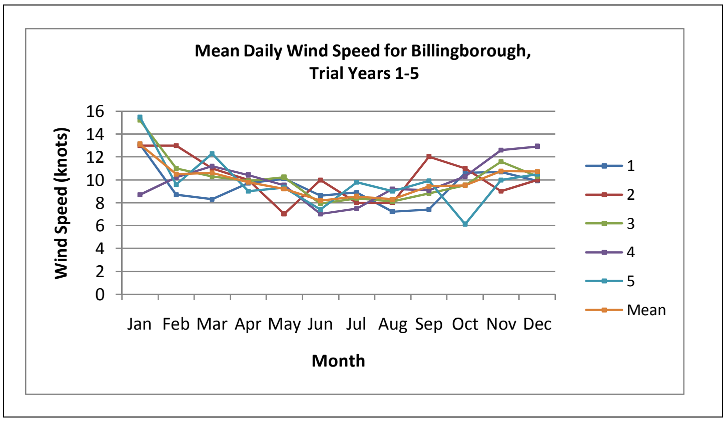

Figure 3.13 Mean daily wind speed at Billingborough, Years 1 to 5.

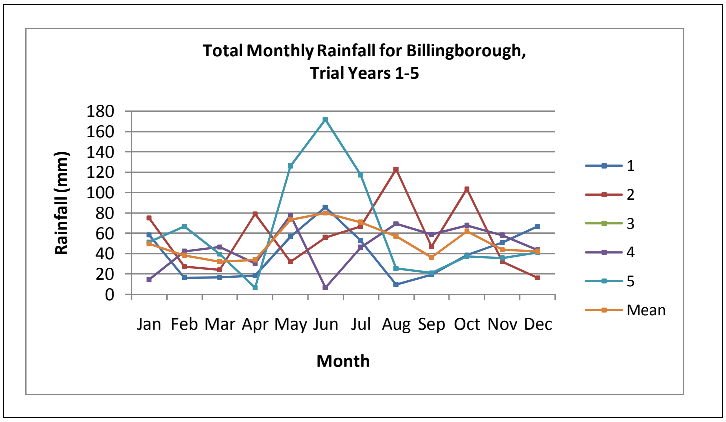

Figure 3.14 Total monthly rainfalls at Billingborough, Years 1 to 5.

3.6.2 Reach Lode and Ely Ouse

Climate data from the Met Office weather monitoring station at Denver, Norfolk (approximately 25 km north-east of Ely Ouse and 35 km north-east of Reach Lode) are representative of both of these sites (due to their close proximity to each other).

The same trends in annual mean, maximum and minimum temperatures (Figures 3.15, 3.16 and 3.17) and in extreme temperatures (months differing from the mean) seen at Billingborough were also exhibited at Reach Lode and Ely Ouse. However, temperatures had a tendency to be slightly higher than those at Billingborough. For example, the mean maximum daily temperature at Reach Lode and Ely Ouse was 1°C higher than that at Billingborough (in July of Year 4) and the mean minimum daily temperature was 2°C higher than that in Billingborough (February of Year 1).

Although the number of daily sunshine hours followed the same annual trends at Reach Lode and Ely Ouse (Figure 3.18) as those at Billingborough, the values were generally lower (despite temperatures being higher). For example, in one of the hottest months, July in Year 4, Billingborough experienced an average of 10 hours of daily sunshine while Reach Lode and Ely Ouse received closer to nine hours of daily sunshine.

The wind speed at Reach Lode and Ely Ouse (Figure 3.19) was considerably lower and less variable than at Billingborough. The mean annual range at Billingborough was 8–13 knots while that at Reach Lode and Ely Ouse was 5–7 knots.

It is possible that the site differences of sunshine and wind speed could be due to the aspect of the individual weather stations rather than the locations of the trial sites.

Rainfall was, again, the most variable of the parameters (Figure 3.20). The same annual trends and extreme conditions were seen, with the wettest months being between August and January. The wet months at Reach Lode and Ely Ouse were, on average, wetter than those at Billingborough (40–90 mm and 40–70 mm respectively). The driest month at Reach Lode and Ely Ouse was, on average, drier than that at Billingborough (c. 20 mm and c.30 mm respectively). Interestingly, the wettest month at Reach Lode and Ely Ouse was in August of Year 4 (160 mm) when only average rainfall was received in Billingborough (c. 70 mm).

This is an example of how localised precipitation can be. Precipitation has the potential to be an influential factor differentiating the three sites. Replicating the anomaly found at Billingborough, the months preceding the April survey in Year 1 were particularly dry compared with other trial years.

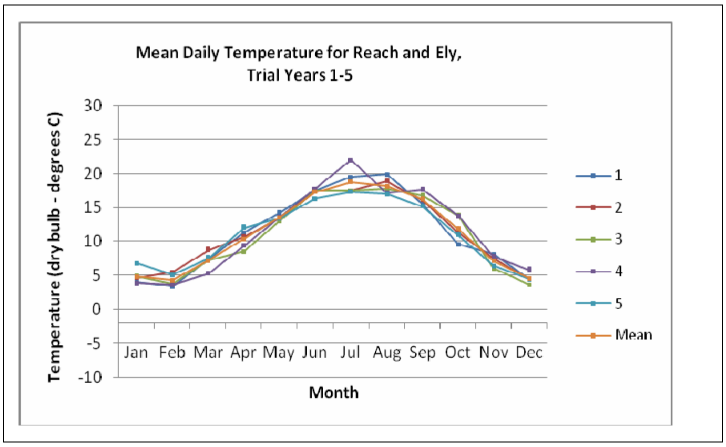

Figure 3.15 Mean daily temperatures at Reach Lode and Ely Ouse, Years 1 to 5.

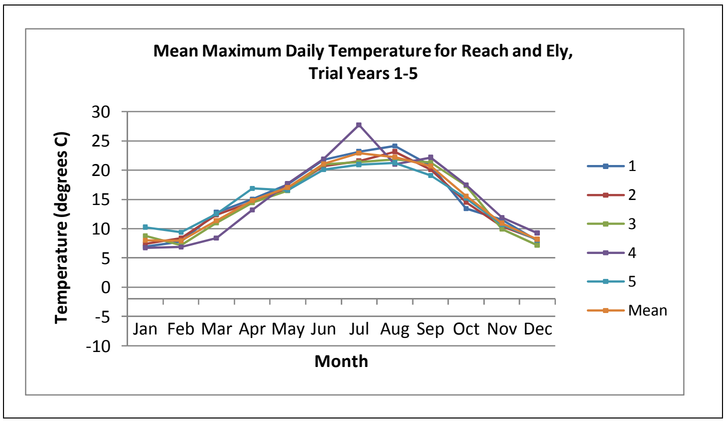

Figure 3.16 Mean maximum daily temperatures at Reach Lode and Ely Ouse, Years 1 to 5.

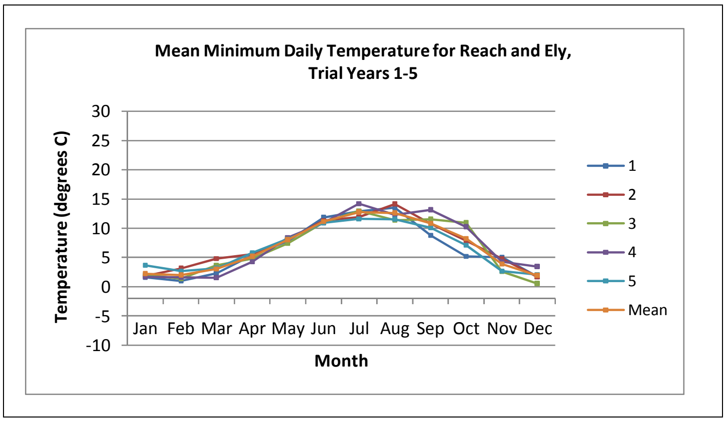

Figure 3.17 Mean minimum daily temperatures at Reach Lode and Ely Ouse, Years 1 to 5.

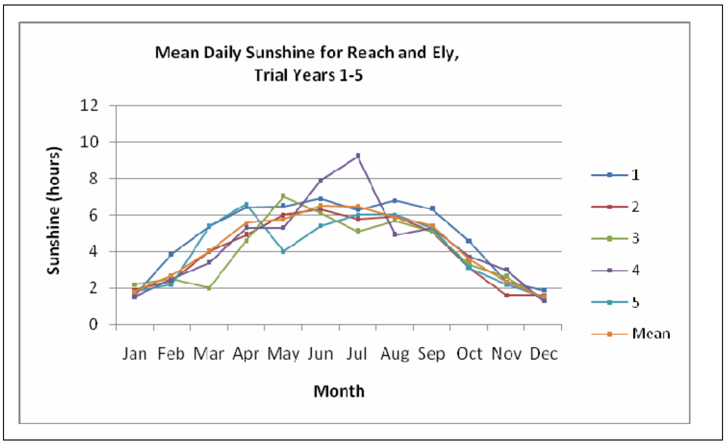

Figure 3.18 Mean daily sunshine at Reach Lode and Ely Ouse, Years 1 to 5.

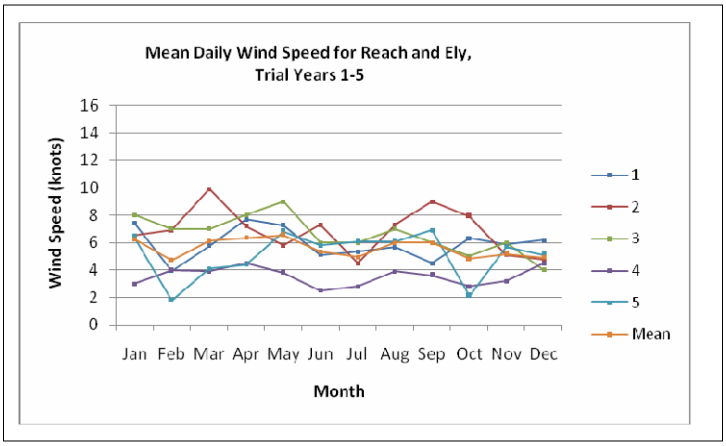

Figure 3.19 Mean daily wind speed at Reach Lode and Ely Ouse, Years 1 to 5.

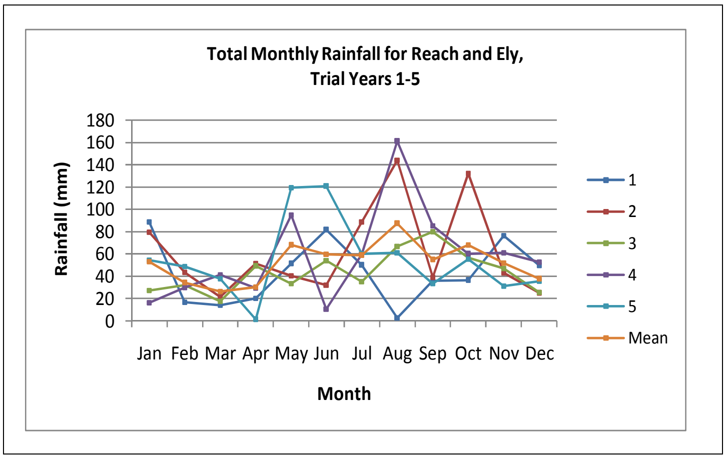

Figure 3.20 Total monthly rainfalls at Reach Lode and Ely Ouse, Years 1 to 5.

4 Results

4.1 Statistical comparison of sites

Qualitative and quantitative analysis revealed that the three trial sites are substantially different in terms of their history, location in the landscape and abiotic characteristics. Detailed site descriptions are given in Section 3. Table 4.1 illustrates the major differences between the sites.

Statistical analysis of quantitative data was made using StatGraphics Centurion version XV (professional edition) software. Means of data from two data sets were analysed using Student's *t*-test, while means of data from three sets were analysed using ANOVA (analysis of variance).

In this scenario it is sufficient to use means of annual data for statistical analysis as the same significant differences are found when using all the raw data (although to a higher level of probability). Those features not listed in Table 4.1 were not sufficiently different between the three sites.

The differences between the sites meant it was not possible to combine the survey data recorded during the five years of trials from all three sites. The statistical analysis of the survey data presented below was therefore undertaken on each site separately. The report also gives a brief overview of comparisons between the sites.

Table 4.1 Major differences between trial sites (and significance levels where appropriate).

Factor	Site			Significance level[2]
	Billingborough	Reach Lode	Ely Ouse	
Soil: type[1]	Wallasea 2 (813 g)	Adventurers' 1 (1024 a) – with peat and silt	Adventurers' 1 (1024 a)	
Soil: mean pH	7.76	8.06	7.98	0.014
Soil: mean potassium	593.58 mg/l	547.28 mg/l	478.48 mg/l	0.036
Soil: mean magnesium	333.96 mg/l	210.74 mg/l	147.84 mg/l	0.002
Soil: mean phosphorus	14.96 mg/l	10.76 mg/l	7.34 mg/l	0.037
Aspect (land face)	North to northeast	East to southeast	Southwest	
Gradient (river face)	29.5^o	8.8^o	23.5^o	0.000
Gradient (land face)	30.6^o	23.4^o	26.2^o	0.001
Average annual monthly wind speed	9.89 knots	5.6 knots		0.000 (d.f.= 1)
Average annual water level range	0.981 m	0.140 m	0.652 m	0.032
Prior management	Six cuts per year	Two cuts per year	Two cuts per year	

Landscape	Arable	Arable, access track and nature reserve	Arable and main road	
Public access	None	Public right of way	Public right of way and used for fishing and walking	

Notes [1] Soil Survey of England and Wales (1983)
[2] A significance level of $p \leq 0.05$ is considered statistically significant, e.g. there is a 95 per cent probability that the difference between the sites is not due to chance alone. Where significance levels are given, the degrees of freedom (d.f.) equals two unless otherwise stated.

4.2 Statistical analysis of soil biological parameters

Year 5 of the trials was considered to be the situation where the effects of the management regimes would have had sufficient time to impact on the banks' characteristics, i.e. Year 5 best represented the condition of the banks with long-term management. Therefore, the Year 5 data were examined to determine interactions and differences between the treatments and soil variables.

All Year 5 data concerning the soil biological parameters were analysed to determine if there were significant differences between:

- Treatments 1–11;
- survey months (April, June and August);
- embankment faces (landward, river and crest).

A multifactor ANOVA was carried out using StatGraphics Centurion version XV (professional edition) software. This enabled analysis of the categorical, non-quantitative data.

Full analysis was carried out to:

- ensure there were no significant differences in soil variables between the treatments at the start of the trial (Year 1) that may have influenced the results;
- see how variables have changed over the five-year survey period.

A full data set for all five years' trials is provided on CD 1 to supplement this report.

4.2.1 Billingborough

Total soil root content

Analysis of the total soil root content (mass) data revealed no significant differences ($p<0.05$) in the amount of roots between treatments, between survey months or between embankment faces.

Treatment 2 was an outlier (although not significantly different from other treatments), with the highest total soil root content; the other treatments had values similar to each other.

The total soil root content tended to be higher during the April survey than it was during the June and August surveys.

Generally, the landward soil recording plots had a greater proportion of roots in the soil than the crest and river recording plots, which had similar root contents to each other.

It appears that the sporadic occurrence of roots in the greatest size category (>1 mm width) was a result of the sampling methodology. Only limited samples were taken per treatment; these in turn were heavily influenced by chance occurrences of deep-rooted species such as *Urtica dioica*. Where these large roots were present, their mass was relatively high. There were insufficient replicates of data for analysis of the root size classes.

Soil pH

Analysis of the soil pH data revealed no significant differences ($p<0.05$) in the soil pH between treatments, between survey months or between embankment faces.

Treatments showed the strongest differences between pH values ($p=0.071$). Treatment 2 and 7 had the highest pH values, while Treatments 9, 4, 6 and 3 had lower values. These slight differences are likely to be the result of subtle variations in the substrate of which the bank is composed. The remaining treatments all had approximately the same soil pH.

Soil pH was greater during the August survey than during the April and June surveys, but the probability of this effect being real is extremely low ($p=0.658$).

The river face soil recording plots had a higher soil pH than the crest and landward facing recording plots. The reason for this is unclear.

Soil phosphorus

Analysis of the soil P data revealed no significant differences ($p<0.05$) in the amount of P in the soil between treatments or between months.

Treatments 2, 3 and 5 had the highest P contents, while Treatments 7, 8 and 9 had lower values. The remaining treatments had very similar soil P contents.

The survey month revealed no discernable differences in the soil P content.

River face recording plots were found to have a significantly greater ($p<0.05$) soil P content than the crest recording plots (14.2 and 8.4 mg/l respectively). The landward recording plots had P values intermediate between the other recording plots (12.0 mg/l), but not significantly different from either (Figure 4.1).

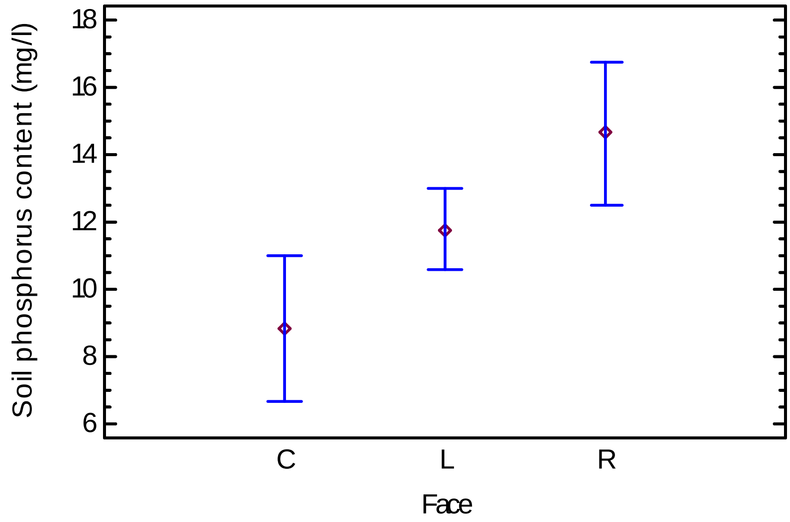

Figure 4.1 Mean phosphorus content of soil in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil potassium

Analysis of the soil K data revealed no significant differences ($p<0.05$) in the amount of K in the soil between embankment faces or between treatments.

Significantly lower soil K levels were found during April than during the months of June and August (490, 610 and 630 mg/l respectively) (Figure 4.2).

As the survey months were found to give significantly different soil K contents, only the April data were chosen (most data were available for this month) for a one-way ANOVA to determine if there was any differences between treatments.

Treatments 2, 10 and 11 had the highest levels of soil K and Treatment 7 had the lowest levels of soil K, although these differences were not significant.

On average, the crest had a lower soil K level than the river and landward faces, but not significantly.

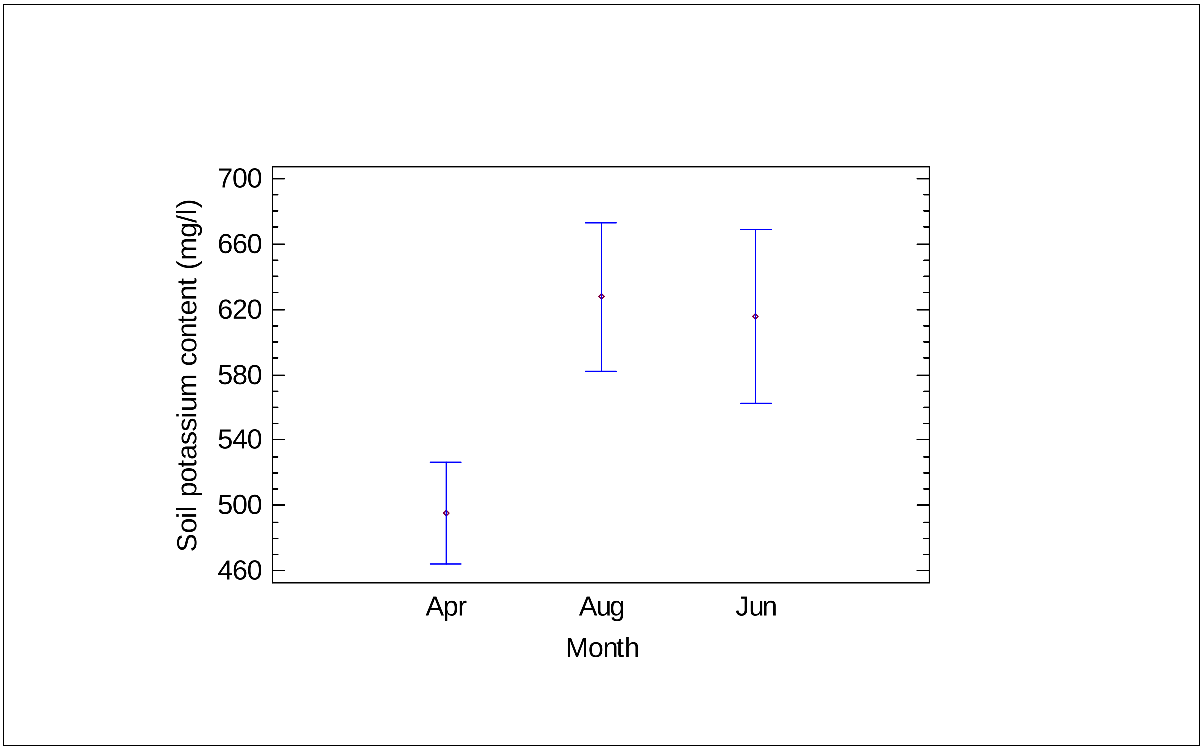

Figure 4.2 Mean potassium content of soil in survey months at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil magnesium)

Analysis of the soil Mg data revealed no significant differences ($p<0.05$) in the amount of Mg in the soil between months.

Treatments were found to have significantly different ($p<0.01$) soil Mg contents (Table 4.2).

Treatments 1 and 10 had above average mean soil Mg contents at c.310 and c.380 mg/l respectively. Treatments 2 and 8 had the lowest mean soil Mg values (c.150 and c.140 mg/l respectively) (Figure 4.3).

Table 4.2 Significantly different treatments for soil magnesium content at Billingborough, Year 5.

Treatment	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1		*			*		*	*			
2	*								*	*	
3											
4										*	
5	*									*	
6											
7	*									*	
8	*									*	
9		*								*	
10		*		*	*		*	*	*		*
11										*	

* Significantly different pairs of treatments ($p<0.01$)

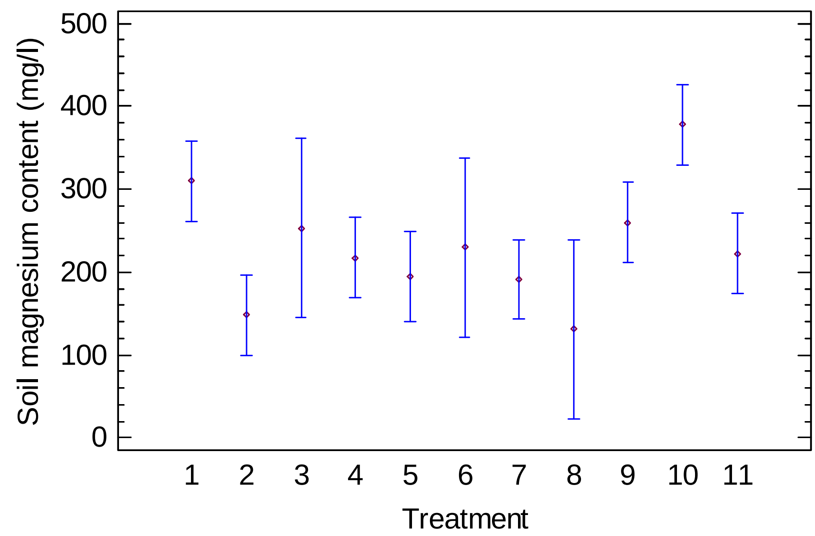

Figure 4.3 Mean magnesium content of soil for treatments at Billingborough, Year 5 ($p<0.01$).

Bars represent least significant differences (LSD).

The river face of embankments was found to have significantly lower soil Mg levels than the landward face (160 and 260 mg l^{-1} respectively) (Figure 4.4).

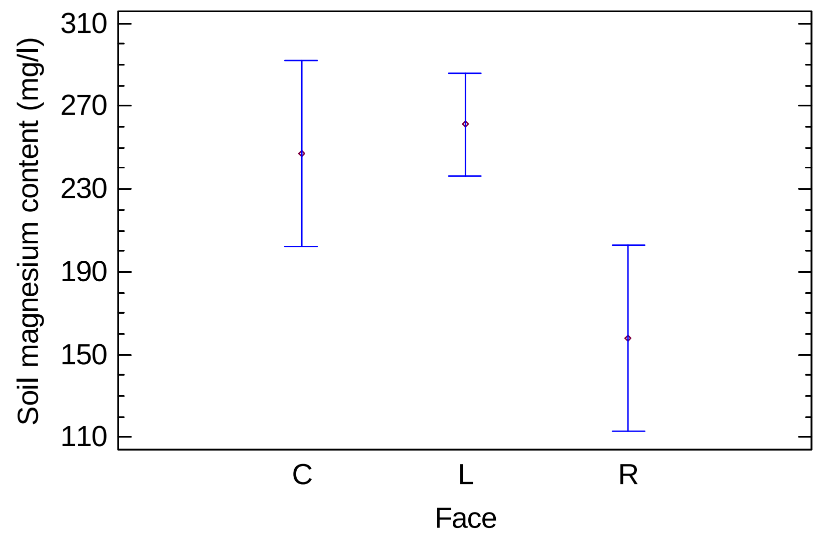

Figure 4.4 Mean magnesium content of soil in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil organic matter

Analysis of the soil organic matter data revealed no significant differences ($p<0.05$) in the organic matter content of the soil between months or between treatments.

The crest of the embankment had a significantly lower ($p<0.05$) content of organic matter in the soil than both the landward and river faces of the embankment (c.5.5, c.7 and c.7.4 per cent respectively) (Figure 4.5).

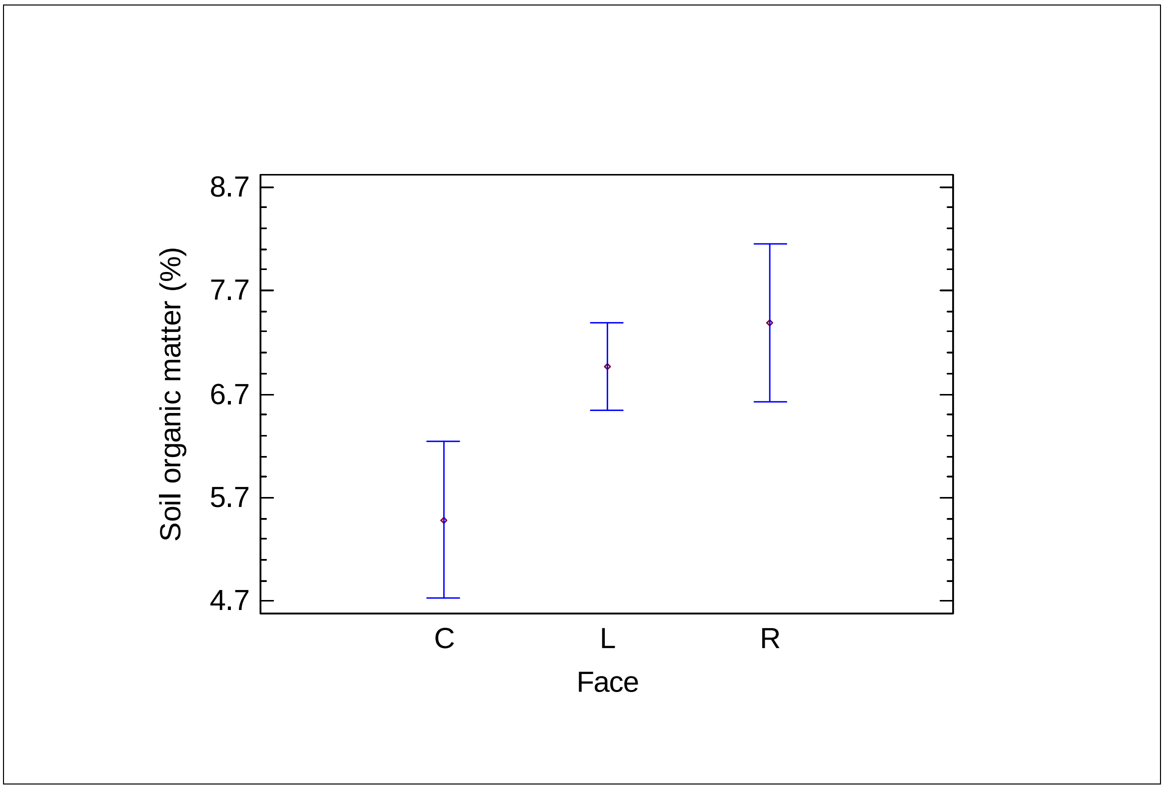

Figure 4.5 Mean organic matter contents of soil in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Although not significant (p=0.058), Treatments 5 and 9 tended to have the highest organic matter contents, while Treatments 2, 7, 8 and 11 had the lowest amounts of organic matter in the soil.

Soil nitrate

Analysis of the soil nitrate data revealed no significant differences (p<0.05) in the nitrate content of the soil between survey months, between treatments or between embankment faces.

The higher nitrate contents were found in August (compared to April and June) and in Treatment 11 (compared to other treatments).

Soil biological parameters summary: Billingborough

Summaries of the main trends (that were significant, p<0.05) found between treatments (Table 4.3), between embankment faces (Table 4.4) and between survey months (Table 4.5) at Billingborough are given below.

Overall, the embankment face had more influence on soil biological parameters than the treatment or survey date. When comparing embankment faces, significant differences were found in three of the seven parameters measured. But when comparing treatments and comparing survey months, only one significant difference in the parameters assessed was found for each.

Considering treatments, the soil magnesium content revealed differences between treatments; Treatments 1 and 10 had the highest levels and Treatments 2 and 8 had the lowest levels.

Of the embankment faces, the river had high values of potassium and organic matter and the landward face had high values of magnesium and organic matter.

For the survey months, April had a low potassium content compared to that in June and August.

Table 4.3 Main differences ($p<0.05$) between treatments in Year 5 at Billingborough for soil biological parameters.

Soil biological parameter	Treatment										
	1	2	3	4	5	6	7	8	9	10	11
Soil magnesium content	H	L						L		H	

H= relatively high value for data, L= relatively low value for data.

Table 4.4 Main differences ($p<0.05$) between embankment faces in Year 5 at Billingborough for soil biological parameters.

Soil biological parameter	Embankment face		
	River	Crest	Land
Soil potassium content	H	L	
Soil magnesium content	L		H
Soil organic matter content	H	L	H

H= relatively high value for data, L= relatively low value for data.

Table 4.5 Main differences ($p<0.05$) between survey months in Year 5 at Billingborough for soil biological parameters.

Soil biological parameter	Survey month		
	April	June	August
Soil potassium content	L	H	H

H= relatively high value for data, L= relatively low value for data.

4.2.2 Reach Lode

Total soil root content

Analysis of the total soil root content revealed no significant differences ($p<0.05$) in the mass of roots between treatments or between embankment faces.

The August survey had a significantly higher content of roots in soil samples (c.16 mg/g) than the April survey (c.3 mg/g, $p<0.05$), while the June survey was intermediate (c.9 mg/g) (Figure 4.6). This was consistent with the growth of vegetation over the course of the year.

There was a slight tendency for Treatments 4 and 9 to have a greater root contents in the soil, while Treatment 11 had lower root content, although this was not significant.

The total soil root content was significantly affected by the survey month. This effect could be masking any significant differences between the effects of treatment. A further one-way ANOVA based on the April data only (most data were available from April) confirmed that treatments did not have significantly different total soil root contents.

Once again, it appears that the sporadic occurrence of roots in the greatest size category (>1 mm) was a result of the sampling methodology being highly vulnerable to chance occurrences of deep-rooted species. Where these large roots were present, their mass was relatively high. There were insufficient replicates of data for analysis of root size class.

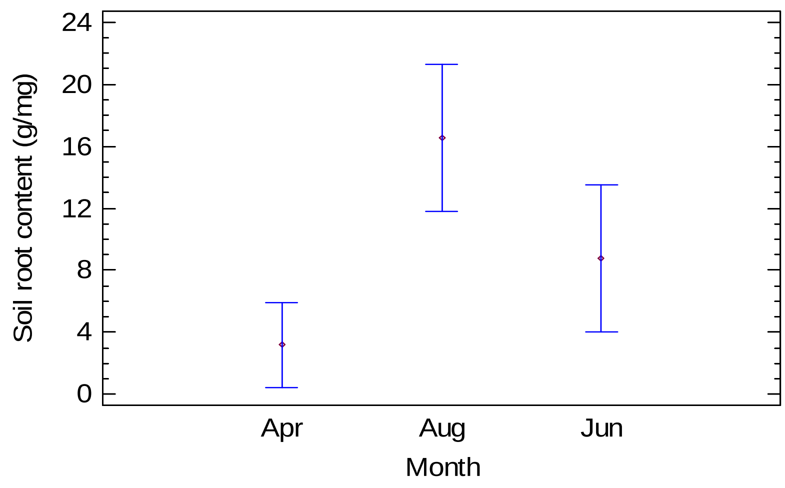

Figure 4.6 Mean total soil root contents in survey months at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil pH

Analysis of the soil pH data revealed no significant differences ($p<0.05$) in the pH between treatments, between survey months or between embankment faces.

Month showed the strongest differences between pH values (although not significant), with April having the lowest values.

Treatments 5 and 10 exhibited the highest average pH values while Treatment 11 had the lowest, although the differences were not significant.

There were no discernable differences in pH values between the aspects of the embankment faces.

Soil phosphorus

Analysis of the soil P content data revealed no significant differences ($p<0.05$) in the amount of P in the soil between embankment faces or between months.

Treatments 1 and 6 had the highest P contents (c.24 and c.30 mg/l respectively) (Figure 4.7) and were significantly greater than all the other treatments ($p<0.001$, Table 4.6). Treatment 10 had the lowest value for soil P content at c.5 mg/l. The remaining treatments had more similar soil P contents (8–12 mg/l).

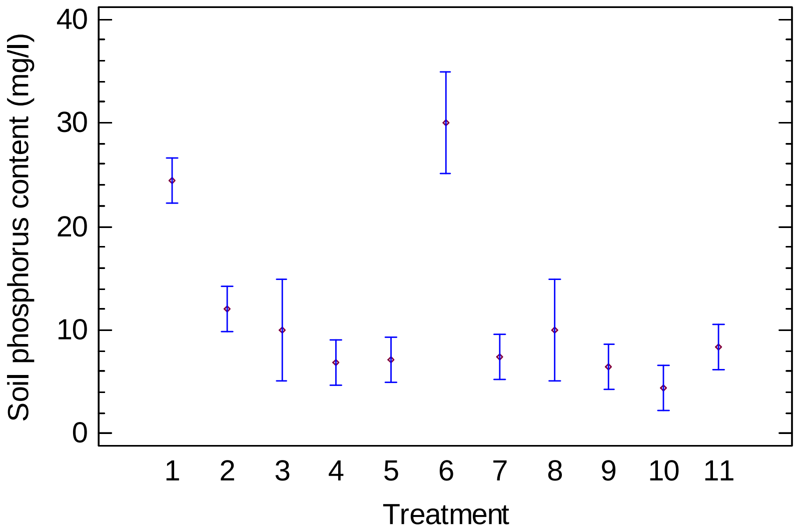

Figure 4.7 Mean phosphorus content of soil for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Table 4.6 Significantly different treatments for soil phosphorus content at Reach Lode, Year 5.

Treatment	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1		*	*	*	*		*	*	*	*	*
2	*			*	*	*	*		*	*	
3	*			*		*					
4	*	*	*			*					
5	*	*				*					
6		*	*	*	*		*	*	*	*	*
7	*	*				*					
8	*					*					
9	*	*				*					
10	*	*				*					
11	*					*					

* Significantly different pairs of treatments ($p<0.01$)

Soil potassium

Analysis of the soil K data revealed no significant differences ($p<0.05$) in the amount of K in the soil between embankment faces or between survey months.

Treatments were found to have significantly different ($p<0.01$) soil K contents (Table 4.7). Unlike Billingborough, Treatments 3 and 6 had above average mean soil K contents at c.1,100 mg/l and c.1,800 mg/l (Figure 4.8) and were significantly higher than all other treatments; Treatment 8 had the lowest mean soil K value (c.450 mg/l).

The landward face of the embankments had a greater K content in the soil than the river face, which had a greater soil K content than the crest, although these differences were not quite significant ($p=0.051$).

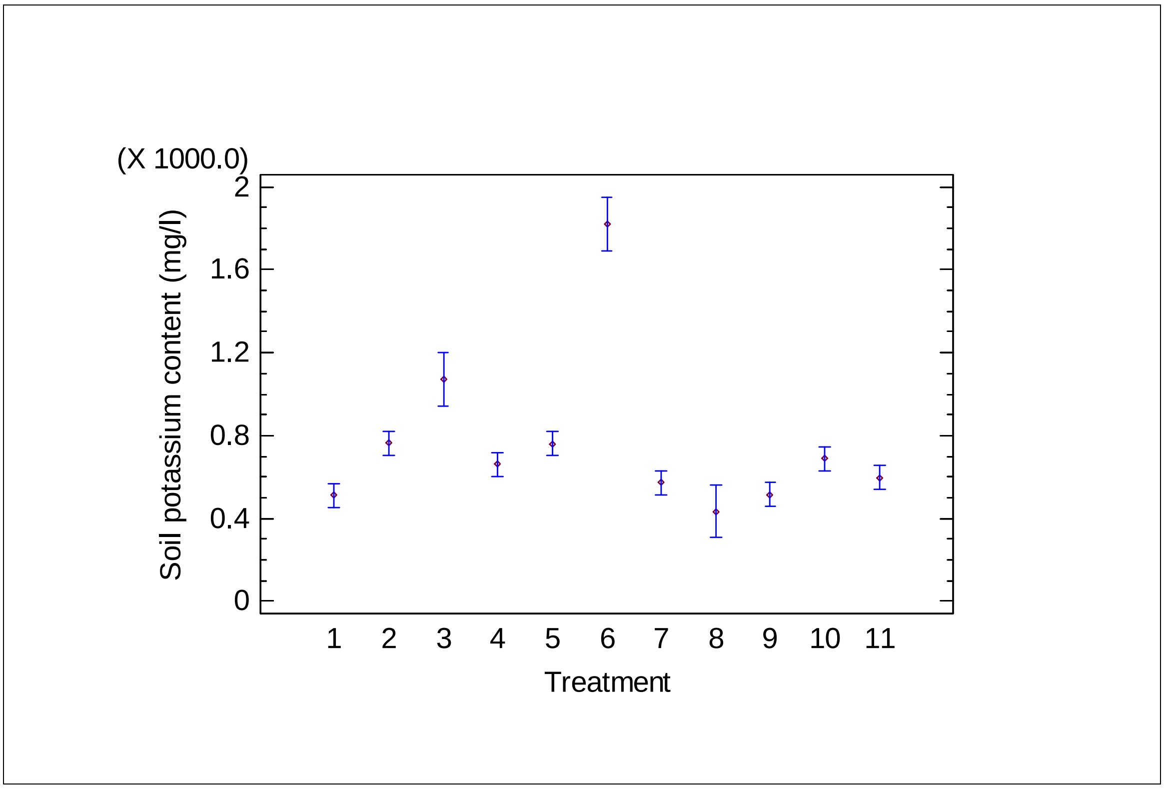

Figure 4.8 Mean potassium content of soil for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Table 4.7 Significantly different treatments for soil potassium content at Reach Lode, Year 5.

Treatment	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1		*	*	*	*	*				*	
2	*		*			*	*	*	*		*
3	*	*		*	*	*	*	*	*	*	*
4	*		*			*		*	*		
5	*		*			*	*	*	*		*
6	*	*	*	*	*		*	*	*	*	*
7		*	*		*	*				*	
8		*	*	*	*	*				*	
9		*	*	*	*	*				*	
10	*		*			*	*	*	*		
11		*	*		*	*					

* Significantly different pairs of treatments (p<0.01)

Soil magnesium

Analysis of the soil Mg data revealed no significant differences ($p<0.05$) in the amount of Mg in the soil between months or between embankment faces.

Treatments were found to have significantly different ($p<0.01$) soil Mg contents (Table 4.8). Unlike Billingborough, Treatments 2, 3, 5 and 6 had above average mean soil Mg contents (at c.215, c.235, c.240 and c.240 mg/l) and Treatments 1, 8 and 11 had the lowest mean soil Mg values (c.125, c.130 and c.120 mg/l) (Figure 4.9).

The April survey found lower Mg levels in the soils than both the June and August surveys, although this difference was not quite significant ($p=0.072$).

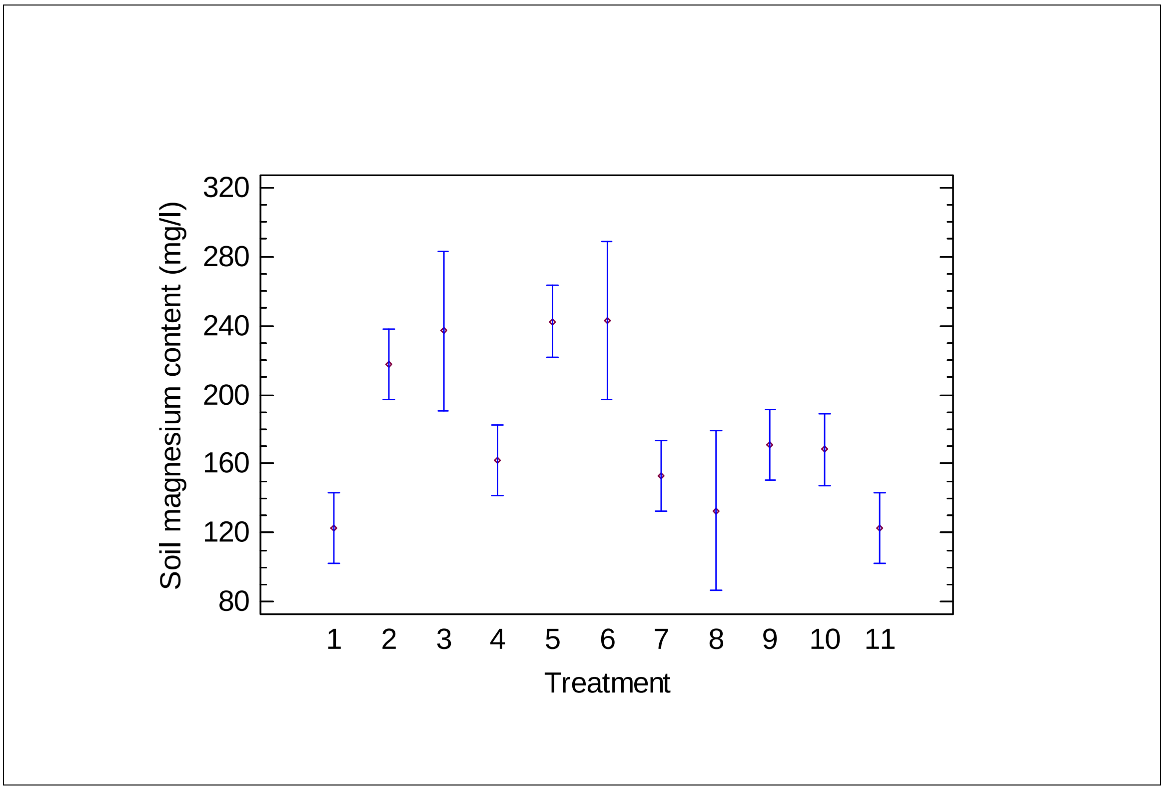

Figure 4.9 Mean magnesium content of soil for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Table 4.8 Significantly different treatments for soil magnesium content at Reach Lode, Year 5.

Treatment	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1		*	*		*	*			*	*	
2	*			*			*	*	*	*	*
3	*			*			*	*	*	*	*
4		*	*		*	*					
5	*			*			*	*	*	*	*
6	*			*			*	*	*	*	*
7		*	*		*	*					
8		*	*		*	*					
9	*	*	*		*	*					*
10	*	*	*		*	*					*
11		*	*		*	*			*	*	

* Significantly different pairs of treatments ($p<0.01$)

Soil organic matter

Analysis of the soil organic matter data revealed no significant differences ($p<0.05$) in the organic matter content of the soil between months, between embankment faces or between treatments. The range in data in Year 5 was 2.7–25.8 per cent organic matter.

Treatments 6, 7 and 9 tended to have the highest organic matter contents while Treatments 5 and 10 had the lowest amounts of organic matter in the soil. These differences were not quite significant ($p=0.057$).

The crest tended to have less soil organic matter than the landward or river faces of the embankment (but not significantly).

Soil nitrate

Analysis of the soil nitrate data revealed no significant differences ($p<0.05$) in the nitrate content of the soil either between survey months or between embankment faces.

When analysing the data from all survey months, Treatment 6 was found to have a significantly higher soil nitrate content than all other treatments ($p<0.01$); no other treatments showed differences between each other (Figure 4.10). The high levels of nitrate recorded in Treatment 6 may indicate contrasting abundances of certain plant species to those found in the other treatments but, as Treatment 6 was removed from the vegetation monitoring in Year 1, this does not affect the overall results.

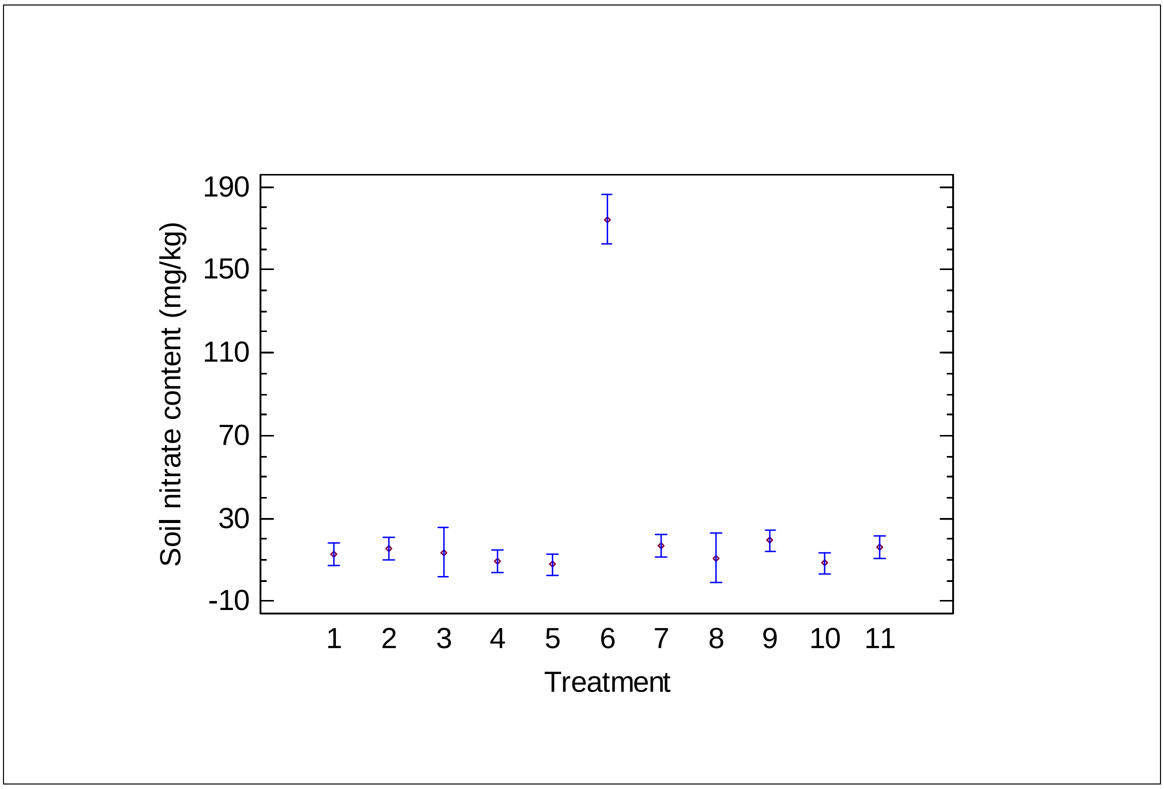

Figure 4.10 Mean nitrate content of soil for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Although the survey months were not significantly different from each other, it is interesting to note that, in this particular scenario, only one treatment was different from the others. Treatment 6 (like Treatments 3 and 8) had a different sampling procedure to the other treatments (i.e. there was no sampling in April and it was only sampled on the landward face in June and August). Therefore, to exclude any influence that the survey month may be having, a one-way ANOVA was performed on only the April data (when most data were available) but excluding Treatments 3, 6 and 8. Soil nitrate levels in April showed no significant differences between treatments. Treatment 2 had the highest soil nitrate levels while Treatment 10 had the lowest.

Soil biological parameters summary: Reach Lode

The trends that were significant at Reach Lode ($p<0.05$) were found mainly between treatments and are summarised in Tables 4.9 and 4.10.

When comparing the treatments, significant differences were found in three of the seven factors measured. However, comparison of the data between the survey months revealed a significant difference for only one of the factors.

Considering treatments, the major differences were found in the nutrient composition of the soil.

- The soil phosphorus content was highest in Treatments 1 and 6 and lowest in Treatment 10.
- The soil potassium content was highest in Treatments 3 and 6 and lowest in Treatment 8.

- The soil magnesium content was highest in Treatments 2, 3, 5 and 6 and lowest in Treatments 1, 8 and 11.

This may influence the abundances of certain plant species that favour nutrient-rich situations and has been taken into account within the vegetation analysis.

For the survey months, August had high total soil root contents compared to the low values of April.

Table 4.9 Main differences ($p<0.05$) between treatments in Year 5 at Reach Lode for soil biological parameters.

Soil biological parameter	Treatment										
	1	2	3	4	5	6	7	8	9	10	11
Soil phosphorus content	H					H				L	
Soil potassium content			H			H		L			
Soil magnesium content	L	H	H		H	H		L			L

H= relatively high value for data, L= relatively low value for data.

Table 4.10 Main differences ($p<0.05$) between survey months in Year 5 at Reach Lode for soil biological parameters.

Soil parameter	Survey month		
	April	June	August
Total soil root content	L		H

H= relatively high value for data, L= relatively low value for data.

4.2.3 Ely Ouse

Total soil root content

Analysis of the total soil root content data revealed no significant differences ($p<0.05$) in the mass of roots between treatments, between months or between embankment faces.

Treatments 7 and 9 had the greatest contents of soil roots, although this was not significantly different from the other treatments.

The river face had, on average, a greater content of roots on the crest than the land (not significant).

There were no discernable differences between months.

As was found at the other two sites, the sporadic occurrence of roots in the greatest size category (>1 mm) was a result of the sampling methodology and the chance occurrence of deep-rooted plant species. There were insufficient replicates of data for analysis of root size class.

Soil pH

Analysis of the soil pH data revealed no significant differences ($p<0.05$) in the pH between treatments or between embankment faces.

Survey month showed significant differences between pH values ($p<0.05$), with August having a significantly higher mean value (c.8.03) than April and June (c.7.90 and 7.89 respectively) (Figure 4.11).

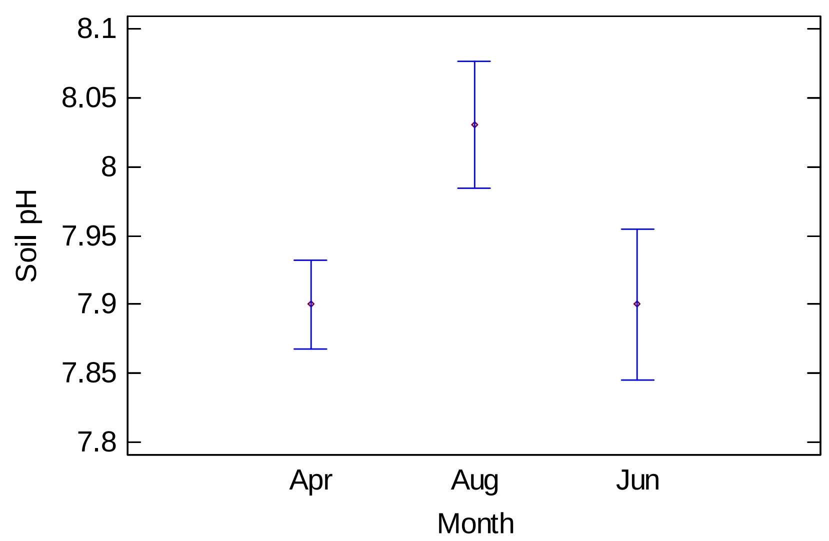

Figure 4.11 Mean soil pH in survey months at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

The landward facing soil recording plots tended to have a lower pH than those on the crest or river face of the embankment (not significant).

As survey months were found to have significantly different soil pH, only the April data were chosen (when most data were available) for a one-way ANOVA to determine whether there were any differences between treatments. These data revealed that Treatment 5 had a particularly low pH from the other treatments, although these differences were not significant.

Soil phosphorus

Analysis of the soil P content data revealed no significant differences ($p<0.05$) in the amount of P in the soil between treatments, between embankment faces or between months.

June had the highest soil P levels; these were almost significantly different from those of April and August.

The crest tended to have a lower soil P level than the river and landward faces of the embankment (not significant).

There were no discernable differences between treatments.

Soil potassium

Analysis of the soil K content data revealed no significant differences ($p<0.05$) in the amount of K in the soil between treatments, between embankment faces or between survey months.

On average, Treatment 4 exhibited a soil K level greater than those of other treatments (although this was not significant).

Of the three survey months, August had the lowest K levels while April and June had similar, lower levels (not significant).

The river face of the embankment had the lowest K values compared with the landward face and the crest, although this was not significant.

Soil magnesium

Analysis of the soil Mg data revealed no significant differences ($p<0.05$) in the amount of Mg in the soil between treatments, between months or between embankment faces.

Treatments 2, 4 and 5 had the greatest soil Mg levels while Treatment 9 had the lowest. The differences between treatments were not significant.

Unlike at Reach Lode, the April survey revealed higher levels of Mg in the soils compared with the June and August surveys, although this difference was not significant.

The landward face of the embankment tended to have soil Mg contents that were lower than the river face, which in turn were lower than at the crest.

Soil organic matter

Analysis of the soil organic matter revealed no significant differences ($p<0.05$) in the organic matter content of the soil between months, between embankment faces or between treatments.

Treatments 7 and 9 tended to have the highest organic matter contents, while Treatments 1 and 11 had the lowest amounts of organic matter in the soil. These differences were not significant.

The landward face of the embankment tended to have a higher soil organic content than the river face or crest, although these differences were not quite significant ($p=0.077$).

The survey month of April had the highest content of organic matter in the soil compared with the other two survey months (not quite significant, $p=0.064$).

Soil nitrate

Analysis of the soil nitrate data revealed no significant differences ($p<0.05$) in the nitrate content of the soil between treatments, between survey months or between embankment faces.

The August survey found a slightly higher level of nitrates in the soil than the April or June surveys, but this was not significant.

The crest had lower levels of soil nitrates than the landward or river facing recording plots (not significant).

Treatments showed the least differences for any of the factors analysed; Treatments 6 and 11 had the highest soil nitrate contents while Treatment 5 had the lowest.

Soil biological parameters summary: Ely Ouse

The only trend (that was significant, $p<0.05$) for soil biological parameters was found between survey months at Ely Ouse (Table 4.11). For the survey months, August had a high soil pH compared with April and June.

Table 4.11 Main differences ($p<0.05$) between survey months in Year 5 at Ely Ouse for soil biological parameters.

Soil parameter	Survey month		
	April	June	August
Soil pH	L	L	H

H= relatively high value for data, L= relatively low value for data.

4.3 Statistical analysis of geotechnical parameters

4.3.1 Billingborough

Soil strength: hand vane at soil surface

Analysis of the hand vane values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength either between survey months or between treatments.

The crest of the embankment was found to have significantly stronger ($p<0.05$) surface soils from hand vane readings than the landward and river face of the embankment (on average c.110 and c.60 kPa) (Figure 4.12). The weakness of the river face coincides with observations made in the field of this face showing larger coverage of bare ground due to the presence of competitive ruderals such as *Sinapis arvensis*.

Treatments 1, 6, 9 and 10 had the stronger soils at the surface (using the hand vane) and Treatments 3 and 11 tended to be weakest, although this was not significant.

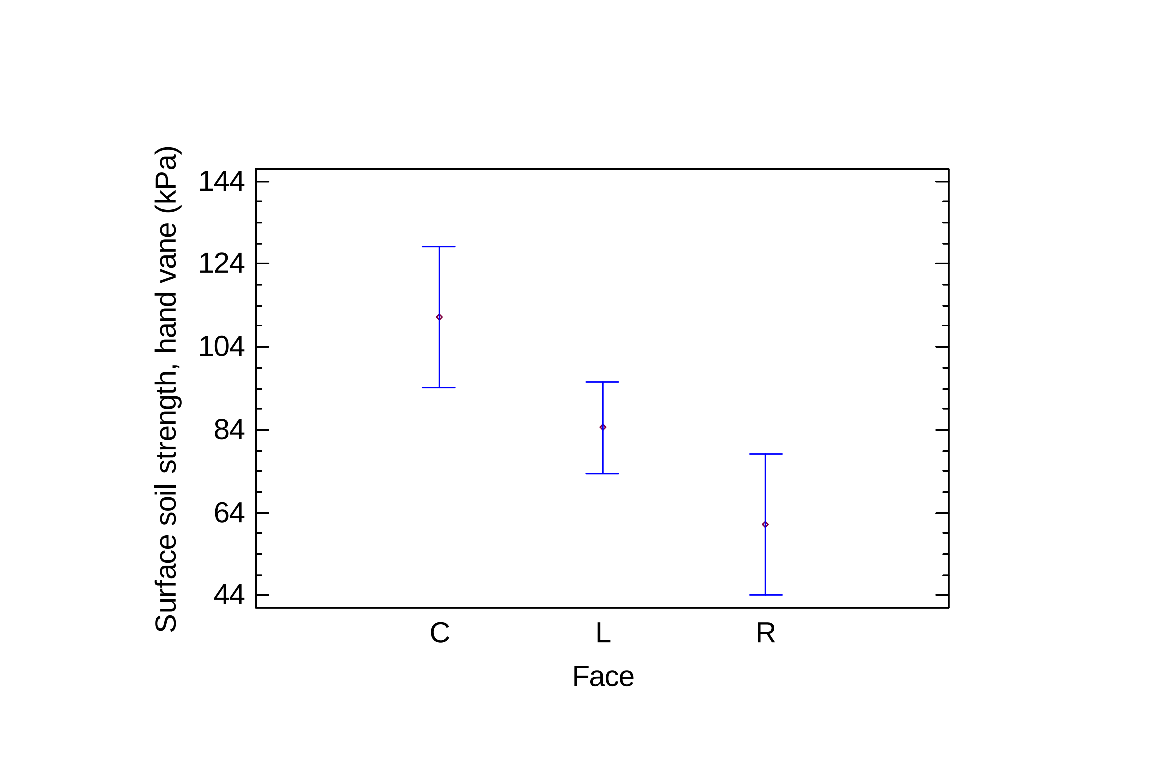

Figure 4.12 Mean soil strengths at the surface using a hand vane inembankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: hand vane at 0.25 m below soil surface

Analysis of the hand vane values taken at 0.25 m (250 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength either between survey months or between treatments.

As with the hand vane readings taken at the surface, the crest of the embankment was found to have the strongest ($p<0.05$) soils at 0.25 m depth (on average, c.109 kPa) compared with the other faces of the embankment (Figure 4.13). However, at a depth of 0.25 m, the crest was significantly stronger than the landward face and not the river face (unlike at the surface).

The lowest soil strength values (<50 kPa) recorded in Year 5 were generally in August from the landward face (the only face surveyed in August). These recording plots showed similar characteristics in that:

- leaf litter cover was typically high (85 per cent);
- organic matter content was somewhat low (<6.1 per cent);
- soil moisture content at depth was low (<20 per cent);
- vole activity was abundant (typically more than five holes per recording plot);
- surface fissures were frequent.

Recording plots where soil strength values at depth were highest (>100 kPa) also occurred in August. These recording plots showed characteristics of:

- low leaf litter cover (<30 per cent);
- slightly more organic matter (>6.2 per cent);
- slightly higher soil moisture at depth (>20 per cent);
- similar levels of vole activity and surface fissures.

Where high soil strength values at depth were recorded in April, they tended to be on the crest where plant litter was low (<40 per cent) and soil moisture was >20 per cent.

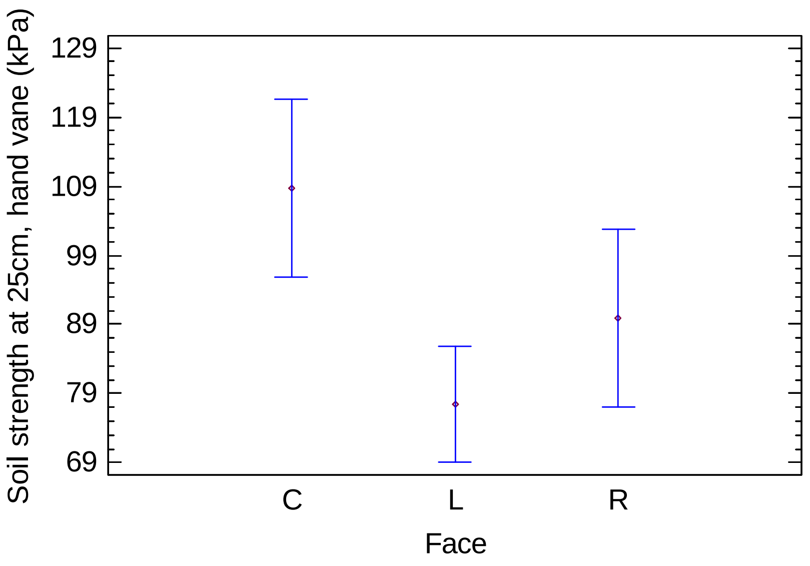

Figure 4.13 Mean soil strengths at 0.25 m below the surface using a hand vane in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: pocket penetrometer at surface

Analysis of the pocket penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the survey months.

As with the hand vane readings, the crest of the embankment was found to have the strongest surface soils (c.7.4 kg/cm^2) for pocket penetrometer readings, while those of both the landward and river faces were significantly weaker ($p<0.05$, on average c.4.3 and 4.1 kg/cm^2) (Figure 4.14).

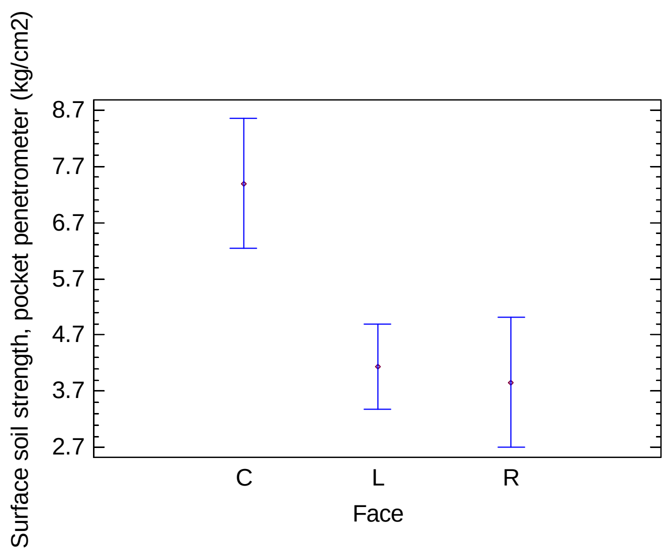

Figure 4.14 Mean soil strength at the surface using a pocket penetrometer in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Unlike when using the hand vane, treatments showed significantly different ($p<0.05$) soil strengths at the surface when using a pocket penetrometer (Table 4.12). The highest surface strengths were found in Treatments 1, 2 and 5 (c.7.0, c.6.0 and c.7.5 kg/cm^2 respectively), while Treatments 3, 8 and 11 were weaker (c.2.0, c.0.5 and c.2.5 kg/cm^2 respectively) (Figure 4.15). All three of the treatments showing the highest surface strengths received three cuts a year or more.

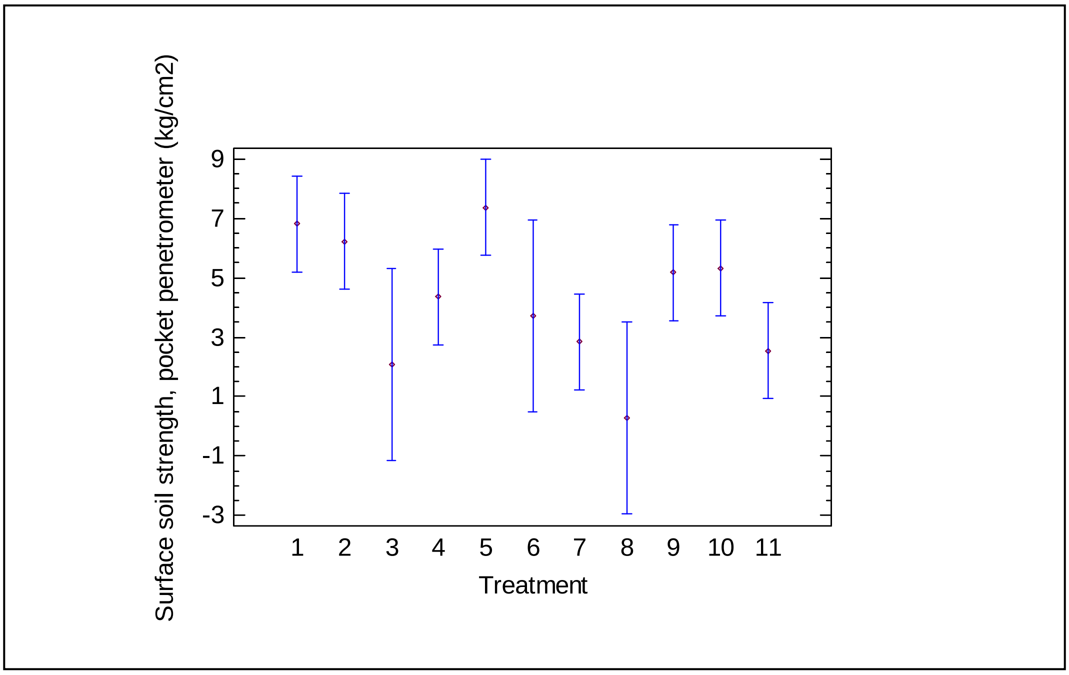

Figure 4.15 Mean soil strengths at surface using a pocket penetrometer for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Table 4.12 Significantly different treatments for soil strength at surface using a pocket penetrometer at Billingborough, Year 5.

Treatment	Treatment										
	1	2	3	4	5	6	7	8	9	10	11
1							*	*			*
2							*	*			*
3					*						
4											
5			*				*	*			*
6											
7	*	*			*						
8	*	*			*				*	*	
9								*			
10								*			
11	*	*			*						

* Significantly different pairs of treatments (p<0.01)

Soil strength: pocket penetrometer at 0.07 m below surface

Unlike the surface readings, analysis of the pocket penetrometer values taken at 0.07 m (70 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments or between the embankment faces.

Interestingly, at 0.07 m depth, the pocket penetrometer readings taken showed that April strengths were significantly higher ($p<0.05$) and more than double those taken in August (c.6.0 and c.2.5 kg/cm^2 respectively) (Figure 4.16)

Treatments 1, 5 and 6 had the stronger soils at 0.07 m (using the pocket penetrometer) while Treatments 3 and 11 tended to be weakest, although this was not significant.

For the pocket penetrometer values taken at 0.07 m, the survey month had a significant effect. This effect may mask any significant differences between the treatments. A further one-way ANOVA using only the April data (most data were available from April) confirmed that pocket penetrometer readings at this depth were not detecting any significantly differences between treatments.

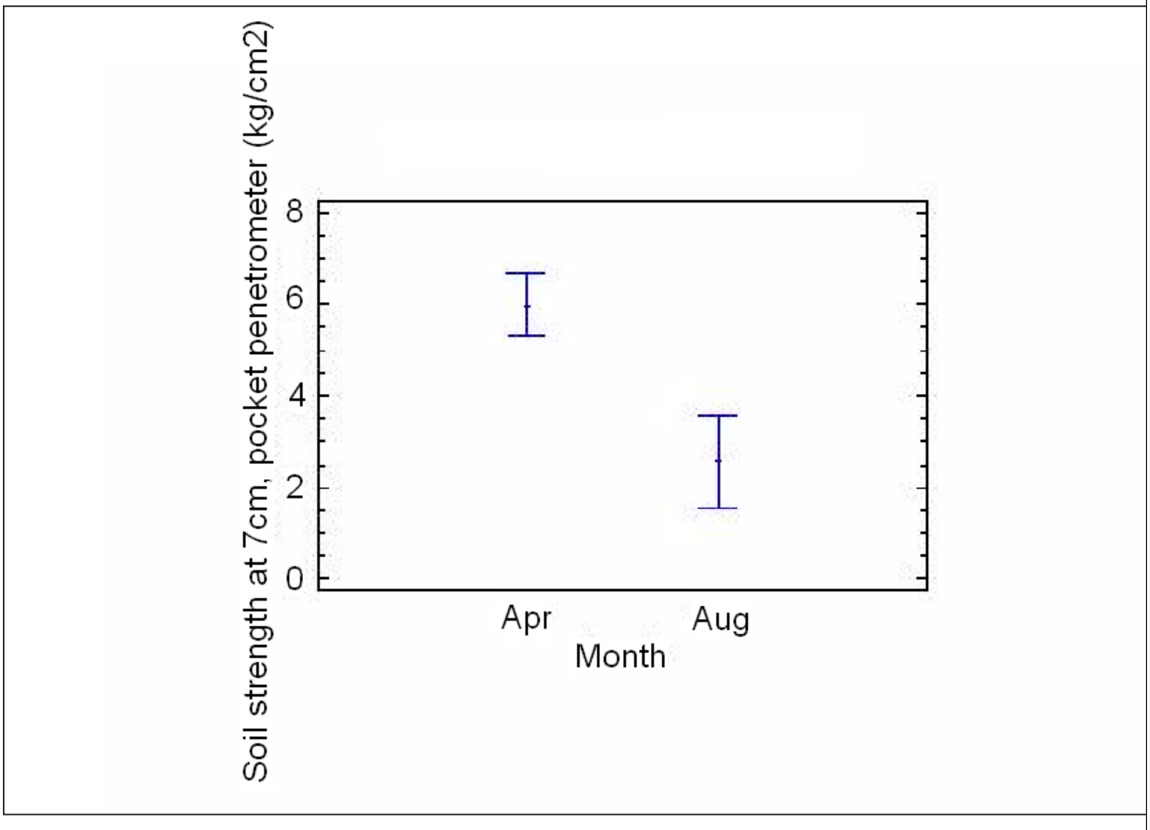

Figure 4.16 Mean soil strengths at 0.07 m below the surface using a pocket penetrometer insurvey months at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Soil strength: pocket penetrometer at 0.3 m below surface

Analysis of the pocket penetrometer values taken at 0.3 m (300 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments (as was the case at the surface) or between the embankment months (as was the case at 0.07 m below the surface).

At this depth, both the crest and the river faces were significantly stronger ($p<0.01$) than the landward face of the embankment (Figure 4.17).

Similarly to the 0.07 m depth tests using the pocket penetrometer, Treatments 1 and 5 had the stronger soils at 0.3 m depth while Treatments 3 and 11 tended to be weakest, although this was not significant.

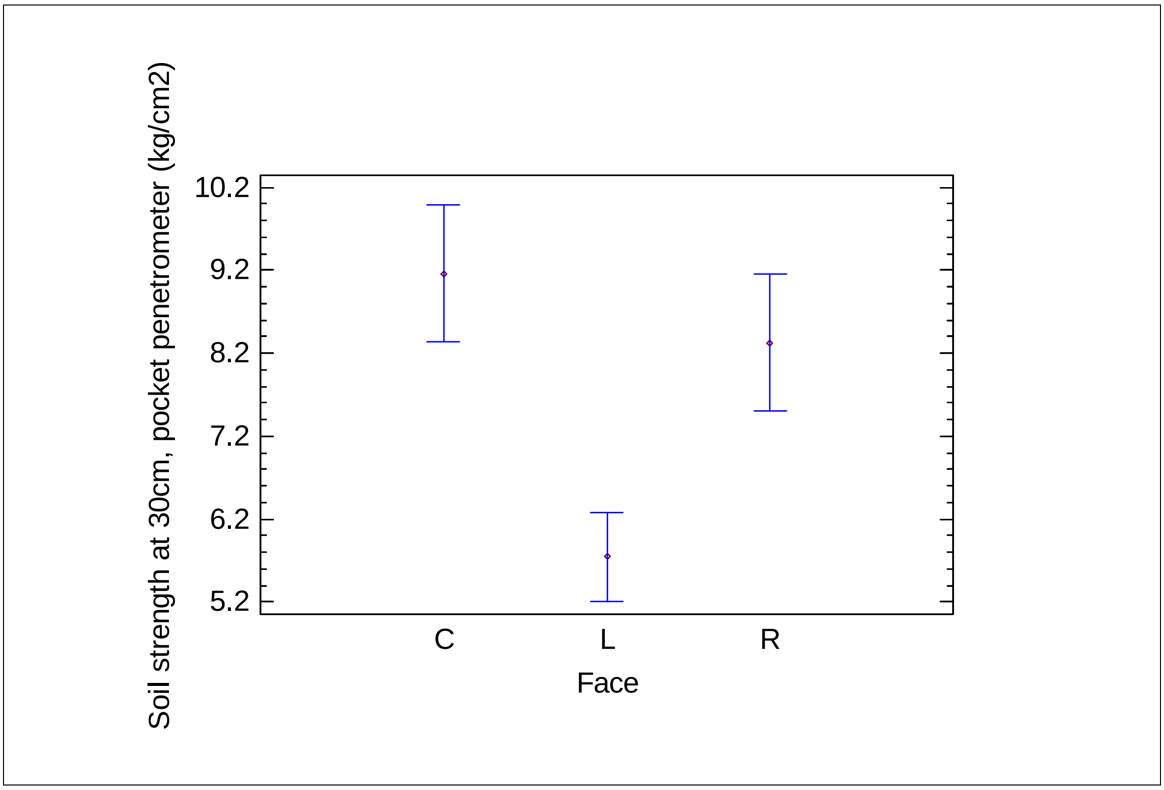

Figure 4.17 Mean soil strengths at 0.3 m below the soil surface using a pocket penetrometer at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: proving ring penetrometer at soil surface

Analysis of the proving ring penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments (as was the case with the hand vane but not the pocket penetrometer at the surface) or between months (as was the case with both the hand vane and the pocket penetrometer at the surface).

The crest, once again, proved to be the strongest of the embankment faces (c.990 gauge units or 0.55 kN). It had a significantly higher ($p<0.05$) value than both the land and river faces (c.390 gauge units or c.0.22 kN and 490 gauge units or 0.3 kN respectively) (Figure 4.18).

As found when using the pocket penetrometer, Treatments 1, 2 and 5 tended to have stronger surface soils compared with the other treatments while Treatments 3, 8 and 11 had the weakest soils, although this was not significant. Once again this suggests that treatments involving cutting three times a year or more may result in stronger surface soil strength.

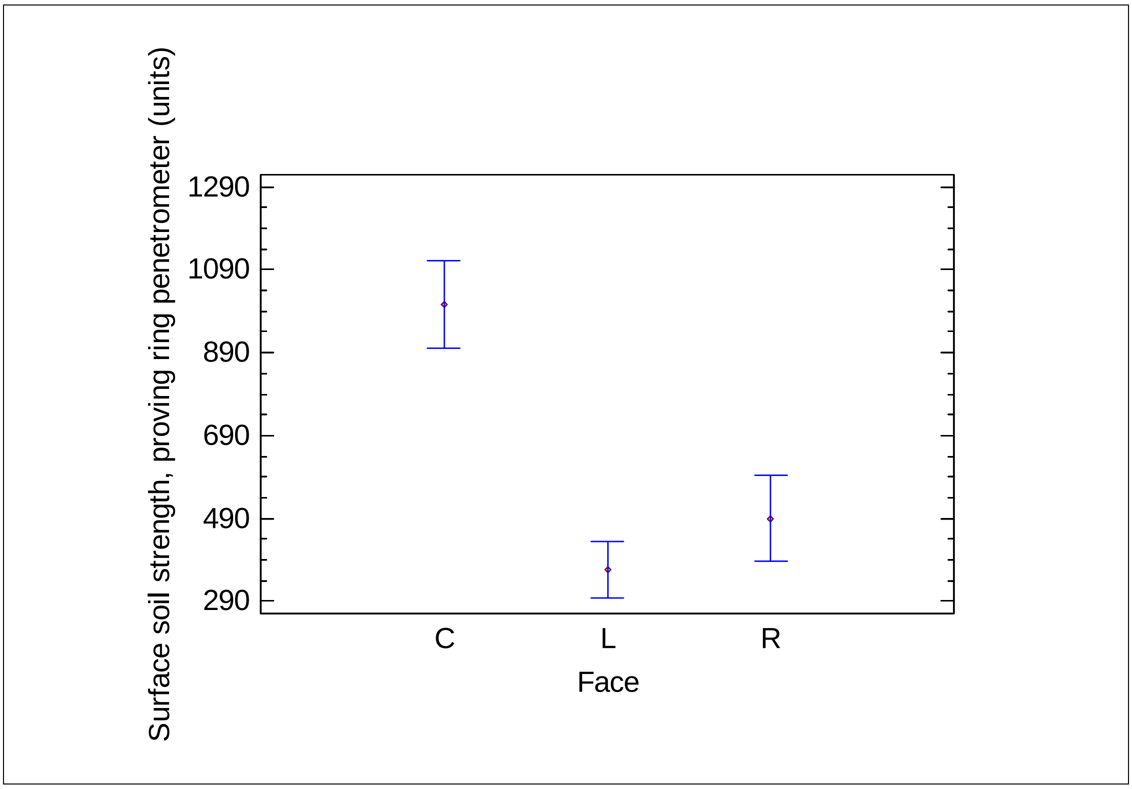

Figure 4.18 Mean soil strengths at the soil surface using a proving ring penetrometer for embankment faces at Billingborough, Year 5.

Values in gauge units (see conversion chart in Appendix 4).
Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil moisture at surface

Analysis of the soil moisture content data taken at the soil surface revealed no significant differences ($p<0.05$) in the soil moisture between the treatments or between the survey months.

The soil on the landward face of the embankments was significantly wetter ($p<0.05$) than both the soil in recording plots on the crest and on the river face (Figure 4.19). This was presumed to be due to the landward face being sheltered from the prevailing winds at Billingborough.

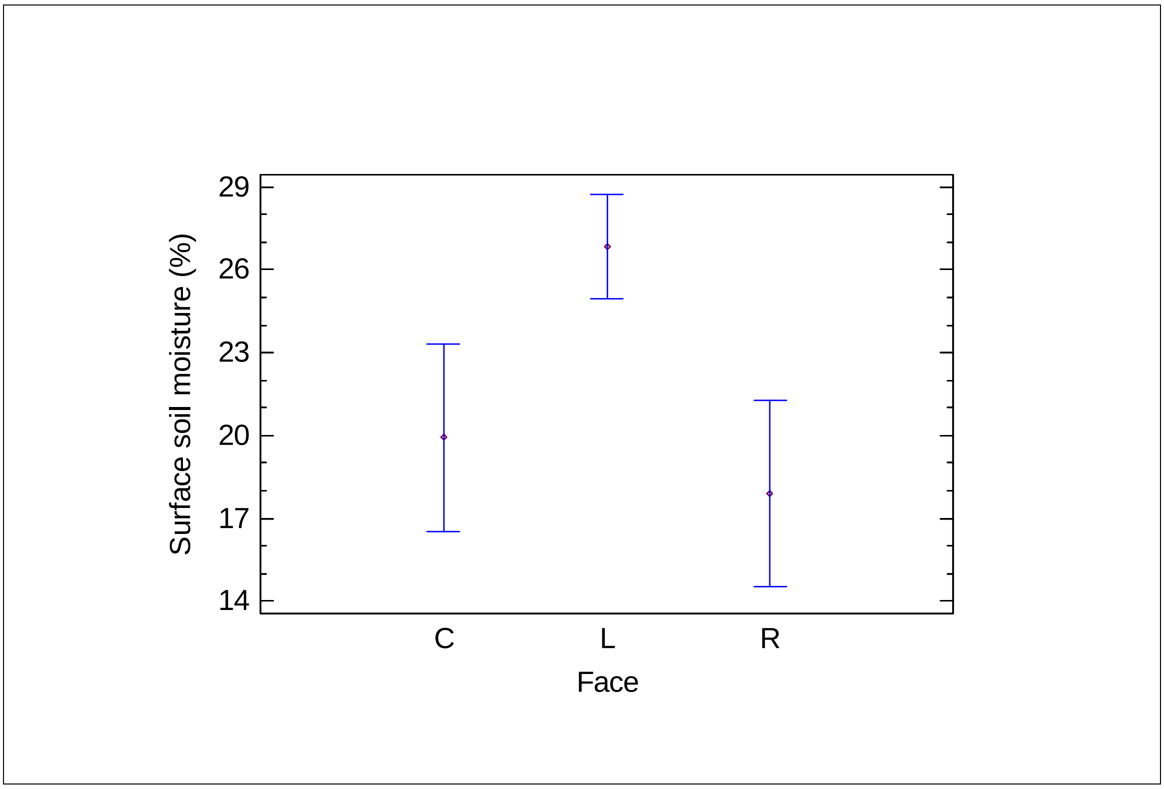

Figure 4.19 Mean soil moisture contents in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil moisture at 0.3 m below surface

Analysis of the soil moisture content data taken at 0.3 m (300 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil moisture between the treatments or between the survey months (as was also found at the surface).

Once again, the soil on the landward face of the embankments was the wettest at depth than on the other embankment faces (c.22.5 per cent). The landward soil recording plots were significantly wetter ($p<0.05$) than the soil in recording plots on the crest, but at this depth, the river recording plots were not the driest (Figure 4.20). The river face was the only face that was wetter at depth than at the surface.

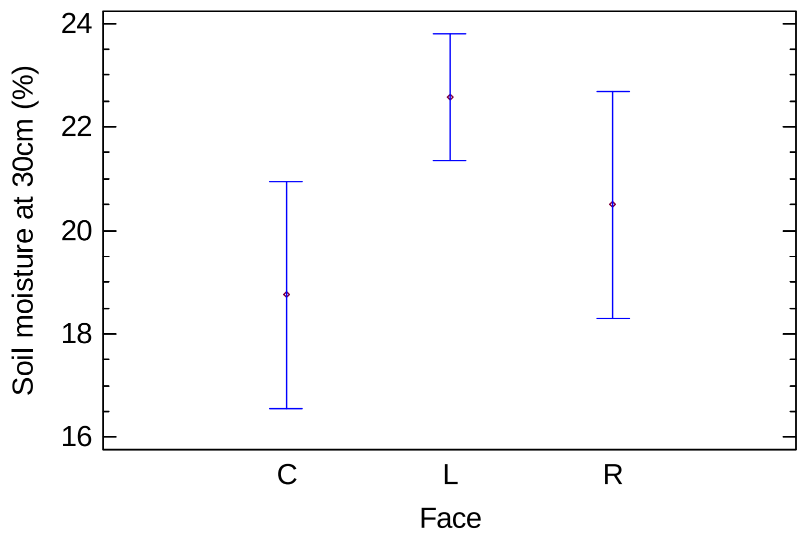

Figure 4.20 Mean soil moisture contents in embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Total number of embankment fissures

Analysis of the total number of fissures on the ground surface revealed no significant differences ($p<0.05$) between the treatments, between the embankment faces or between the survey months.

Treatment 3 had the most fissures, while Treatments 2, 4 and 8 had least fissures on the ground, although these differences are not quite significant ($p=0.088$).

There were no discernable differences between survey months or between embankment faces.

The majority of fissures found (523 of 527) were of size class 1 (depth <50 cm, width <20 cm) and size class 2 (depth 60–100 cm, width 20–50 cm). There were insufficient cracks of size classes 3 (depth 110–150 cm, width 60–90 cm) and size class 4 (depth >160 cm, width >100 cm) for analysis.

Considering size class 1 fissures, there were no significant differences ($p<0.05$) between embankment faces and survey months (although there was a tendency for the crest to have more fissures than the river or landward face, and for August to have more fissures than April).

Class 1 fissures showed significantly different ($p=0.028$) distributions across treatments. Treatment 3 had significantly more fissures than all other treatments and Treatment 1 had significantly more fissures than Treatments 2 and 4. Therefore, as the greatest cracking appeared in treatments with very different mowing regimes (two or six cuts per year), and treatments with the least cracking also had differences in the mowing regime, it can be concluded that vegetation management is not the overriding factor in the frequency of size class 1 fissures.

Analysis of size class 2 fissures did not reveal the same trends. Survey month and management treatment showed no significant differences ($p<0.05$) for the number of these fissures. However, the crest had significantly fewer ($p<0.01$) fissures than the land and river faces of the embankment, presumably due to the compaction of the soil experienced on the crest. Treatments 6 and 7 tended to have more size class 2 fissures, while Treatments 1 and 8 had fewer.

Total number of embankment holes

Analysis of the total number of holes on the ground surface revealed no significant differences ($p<0.05$) between the treatments, between the embankment faces or between the survey months.

Treatments 5 and 6 had the most holes, while Treatments 4 and 11 had least holes on the ground, although these differences are not significant.

The crest had fewer holes than the river face of the embankment. The landward face had the greatest number of holes. These differences were not significant.

There were no discernable differences between survey months.

All except four of the 139 holes found were <0.05 m diameter and <0.1 m deep. However, field observations showed that the true length of the subterranean tunnels tended to be >0.1m due to the tunnels turning 90° to run parallel to the surface beyond this point. Thus the top 0.1m layer of the bank is particularly prone to erosion due to vole activity.

Geotechnical summary: Billingborough

Summaries of the main trends (that were significant, $p<0.05$) found between treatments (Table 4.13), between embankment faces (Table 4.14) and between survey months (Table 4.15) at Billingborough are presented below.

Overall, the embankment face had more influence on geotechnical factors than the treatment or survey date. When comparing embankment faces, significant differences were found in seven of the 10 geotechnical factors measured. However, when comparing treatments and survey months, only one significant difference was found for the factors assessed.

Considering treatments, most differences were found when the soil strengths were tested at the surface using a pocket penetrometer; Treatments 1, 2 and 5 (those cut three or more times a year) were strongest and Treatments 3, 8 and 11 were weakest.

Of the embankment faces, the crest had high surface strengths when using the hand vane, pocket penetrometer and proving ring penetrometer. The crest was also strong at depths of 0.25 m using the hand vane and 0.3 m using the pocket penetrometer. Interestingly, the river face was also strong at 0.3 m using the proving ring penetrometer. Soils were wettest on the landward face at both the surface and at 0.3 m below the surface; the river face had the driest soils – presumably due to this face receiving the full force of the prevailing wind.

For the survey months, August had low soil strengths at 0.07 m below the surface and April had higher strengths, when tested with a pocket penetrometer.

Table 4.13 Main differences (p<0.05) between treatments in Year 5 at Billingborough for geotechnical factors.

Geotechnical parameter	Treatment										
	1	2	3	4	5	6	7	8	9	10	11
Soil strength: pocket penetrometer at 0 m	H	H	L		H			L			L

H= relatively high value for data, L= relatively low value for data.

Table 4.14 Main differences (p<0.05) between embankment faces in Year 5 at Billingborough for geotechnical factors.

Geotechnical parameter	Embankment face		
	River	Crest	Land
Soil strength: hand vane at 0 m	L	H	
Soil strength: hand vane at 0.25 m		H	L
Soil strength: pocket penetrometer at 0 m	L	H	L
Soil strength: pocket penetrometer at 0.3 m	H	H	L
Soil strength: proving ring penetrometer at 0 m	L	H	L
Soil moisture content at 0 m	L	L	H
Soil moisture content at 0.3 m	L		H

H= relatively high value for data, L= relatively low value for data.

Table 4.15 Main differences (p<0.05) between survey months in Year 5 at Billingborough for geotechnical factors.

Geotechnical parameter	Survey month		
	April	June	August
Soil strength: pocket penetrometer at 0.07 m	H		L

H= relatively high value for data, L= relatively low value for data.

4.3.2 Reach Lode

Soil strength: hand vane at soil surface

Analysis of the hand vane values taken at the soil surface revealed no significant differences (p<0.05) in the soil strength between survey months.

The crest of the embankment was found to have significantly stronger (c.120 kPa, p<0.05) surface soils (for hand vane readings) than the landward and river face of the embankment (on average c.70 and c.50 kPa respectively) (Figure 4.21).

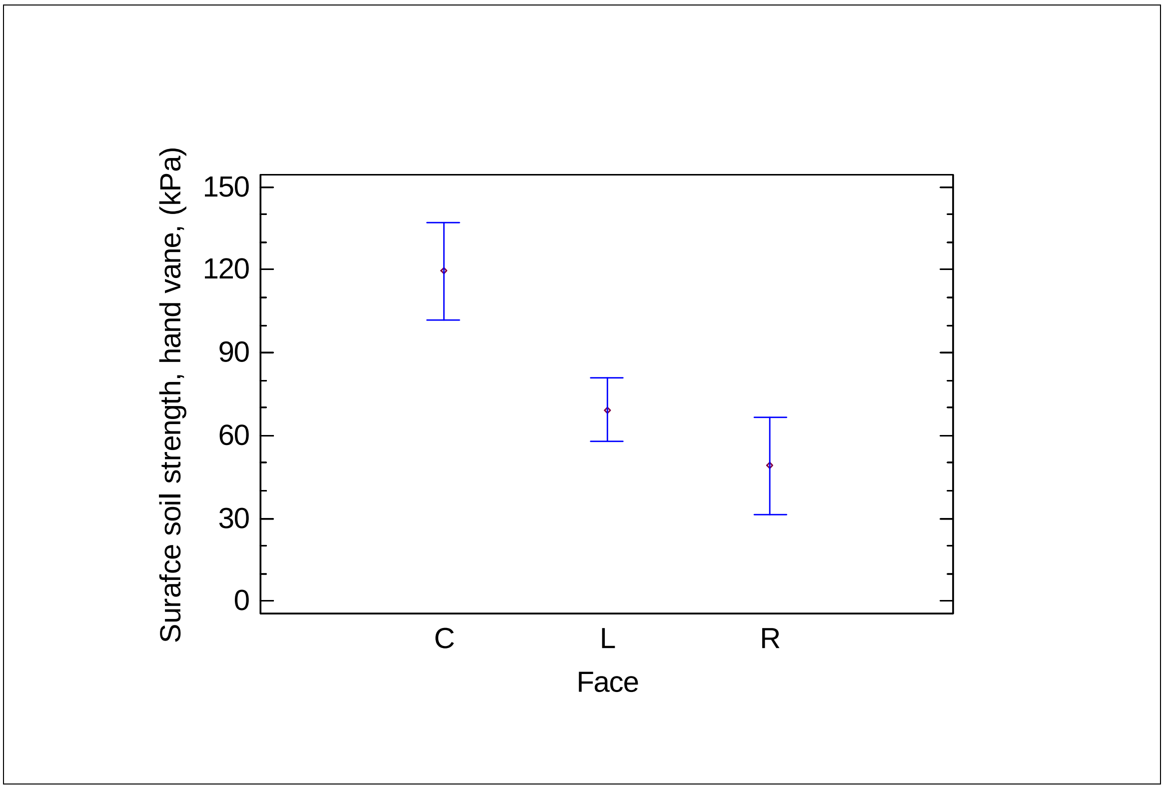

Figure 4.21 Mean soil strengths in embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Treatment 6 had significantly weaker surface soils (using the hand vane) than Treatments 4 and 5 ($p<0.05$) (Figure 4.22).

Although the survey months were not significantly different from each other, it is interesting to note that, once again, only one treatment was different from another two. Treatment 6 (like Treatments 3 and 8) had a different sampling frequency to the other treatments (because these three were taken out of regular monitoring after the baseline survey). Therefore, a one-way ANOVA was carried out on only the April data in order to exclude any influence that the survey month may be having. It was confirmed that surface soil strengths, determined using a hand vane, in April showed no significant differences between treatments. Treatments 2, 4 and 5 had the highest strength, while Treatments 1 and 7 had the lowest.

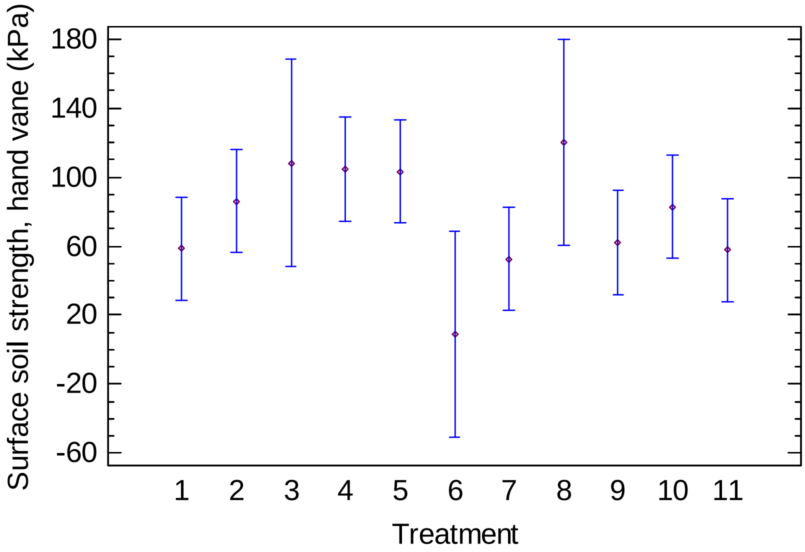

Figure 4.22 Mean soil strengths at the surface using a hand vane for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: hand vane at 0.25 m below soil surface

Analysis of the hand vane values taken at 0.25 m (250 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between treatments.

As with the hand vane readings taken at the surface (and as found at Billingborough), the crest of the embankment was found to have the strongest ($p<0.01$) soils at 0.25 m depth (on average c.100 kPa) compared with the river face of the embankment (c.25 kPa). The landward face (c.95kPa) was also significantly stronger than the river face (Figure 4.23).

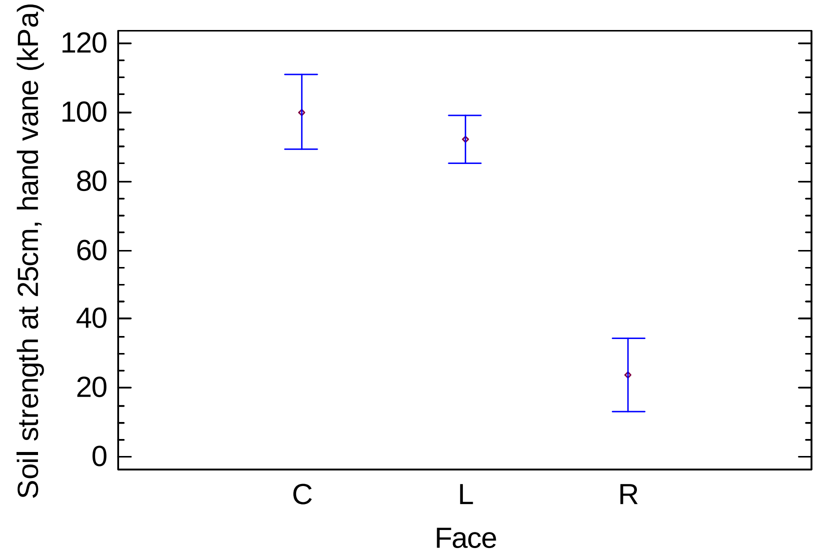

Figure 4.23 Mean soil strengths at 0.25 m below the surface using a hand vane for embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soils were found to be significantly stronger ($p<0.01$) at a depth of 0.25 m, using a hand vane, during August surveys than during April surveys. The average strength in August was c.110 kPa and the average strength in April was c.65 kPa.

The soil strength at 0.25 m (using a hand vane) was significantly affected by the survey month. It is possible that this effect may mask any significant differences between the effects of treatment. However, a further one-way ANOVA completed on the April data only (most data were available from the April survey) confirmed that treatments were not significantly different from each other.

Those samples that showed the lowest soil strength values at depth in Year 5 (<40 kPa) all occurred on the river face in April (nearly all treatments). These recording plots shared similar characteristics of:

- high leaf litter cover (typically >80 per cent);
- high soil moisture content at depth (>25 per cent);
- moderate organic matter content (10–20 per cent);
- several vole holes per recording plot.

In contrast, those recording plots that had the highest soil strength at depth (>100 kPa) occurred in August (in almost all treatments) and in April (on the crest only). These recording plots had very variable levels of leaf litter cover and organic matter, with several vole holes and surface fissures.

Soil strength: pocket penetrometer at surface

Analysis of the pocket penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the survey months or between the treatments.

As with the hand vane readings, the crest of the embankment was found to have the strongest surface soils (c.7.75 kg/cm^2), for pocket penetrometer readings, while both those of the landward and river faces were significantly weaker ($p<0.01$, on average c.1.5 and 2.75 kg/cm^2 respectively) (Figure 4.24).

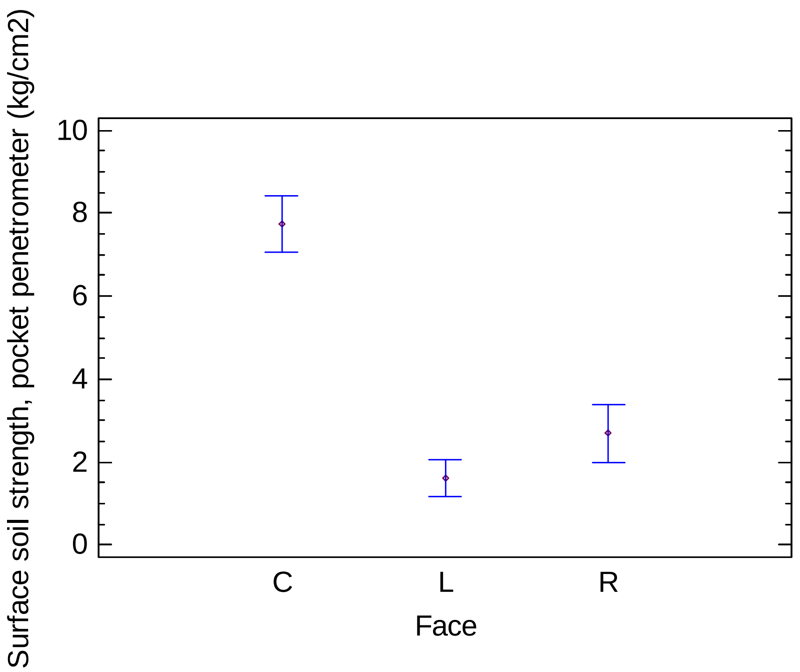

Figure 4.24 Mean soil strengths at the surface using a pocket penetrometer for embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Average August soil strengths were slightly, although not significantly, higher than average April soil strengths taken at the surface using a pocket penetrometer.

There were no discernable differences between treatments.

Soil strength: pocket penetrometer at 0.07 m below surface

Like the surface readings, analysis of the pocket penetrometer values taken at 0.07 m (70 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments or between the survey months.

Once again, at 0.07 m depth, the pocket penetrometer readings taken on the crest were the greatest (c.4.9 kg/cm^2) and significantly higher ($p<0.05$) than those on the landward face of the embankment (c.2.3 kg/cm^2) (Figure 4.25).

Treatments 1 and 10 tended to have stronger soils at 0.07 m depth (using a pocket penetrometer) and Treatments 2, 3 and 8 had, on average, weaker soils (not significant).

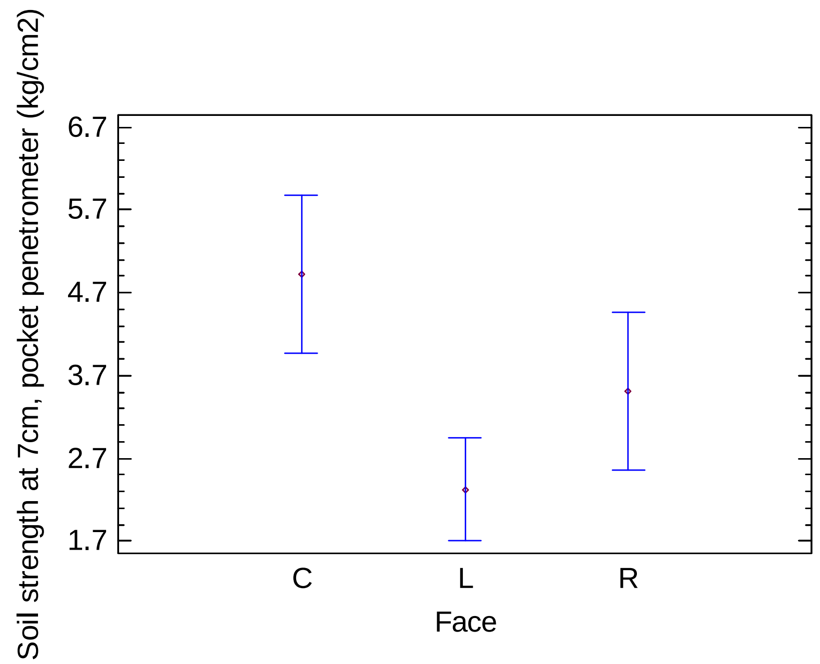

Figure 4.25 Mean soil strengths at 0.07 m below the soil surface using a pocket penetrometer for embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: pocket penetrometer at 0.3 m below surface

Once again, the pocket penetrometer values for soil strength, this time taken at 0.3 m (300 cm) below the soil surface, revealed no significant differences ($p<0.05$) between the treatments or between the survey months.

Interestingly, at this depth, the landward face was strongest (c.7 kg/cm^2) and both the landward face and crest were significantly stronger than the river face (c. 3 kg/cm^2) (Figure 4.26).

On average, soils from April surveys were stronger, at 0.30 m (using a pocket penetrometer) than those from August surveys (not significant, $p=0.062$). This was the opposite of the trend found at the surface using the same instrument and at 0.25 m using the hand vane.

There were no discernable differences between treatments.

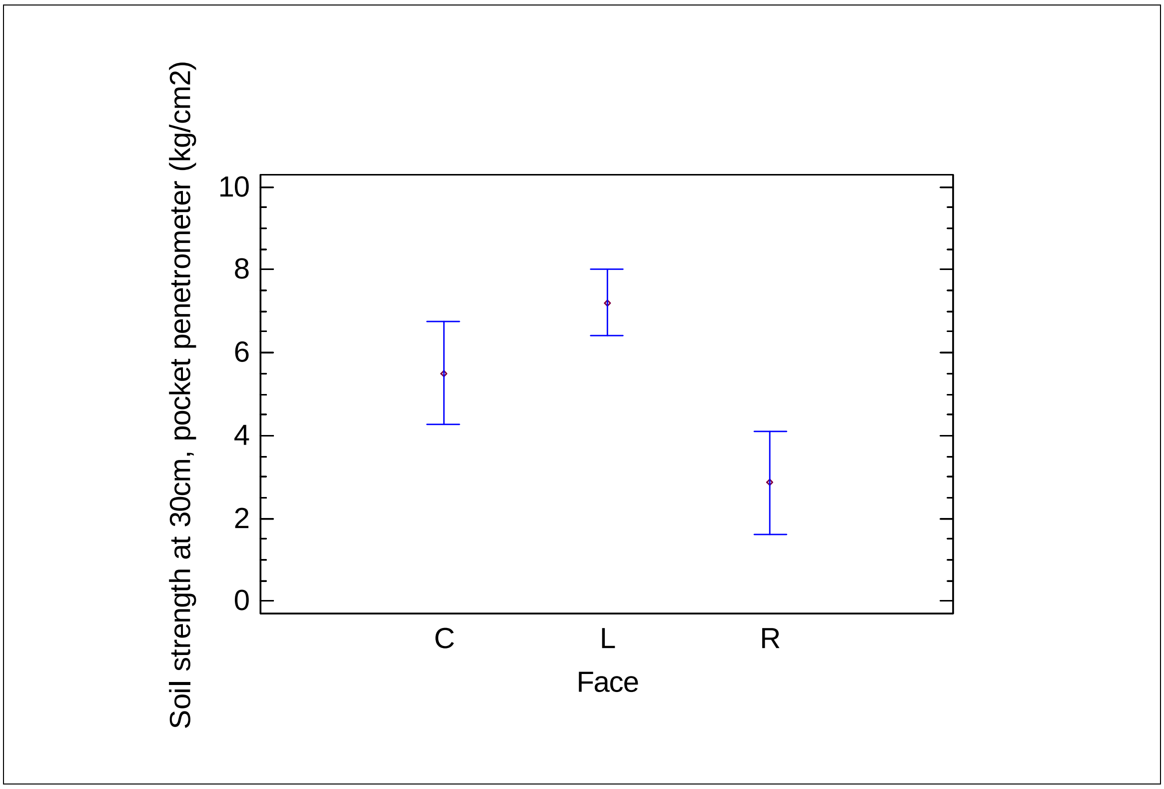

Figure 4.26 Mean soil strengths at 0.3 m below the soil surface using a pocket penetrometer for embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil strength: proving ring penetrometer at soil surface

Analysis of the proving ring penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments (as was the case with the pocket penetrometer at the surface) or between the survey months (as was the case with both the hand vane and the pocket penetrometer at the surface).

The crest, once again, proved to be the strongest of the embankment faces (c.1,200 units or 0.7 kN). It had a significantly higher ($p<0.01$) value than both the land and river faces (c.300 units or 0.18 kN and c.400 units or 0.23 kN respectively) (Figure 4.27).

Treatments 4, 10 and 5 had slightly greater average strengths than other treatments at the surface when using a proving ring penetrometer, although these differences were not significant.

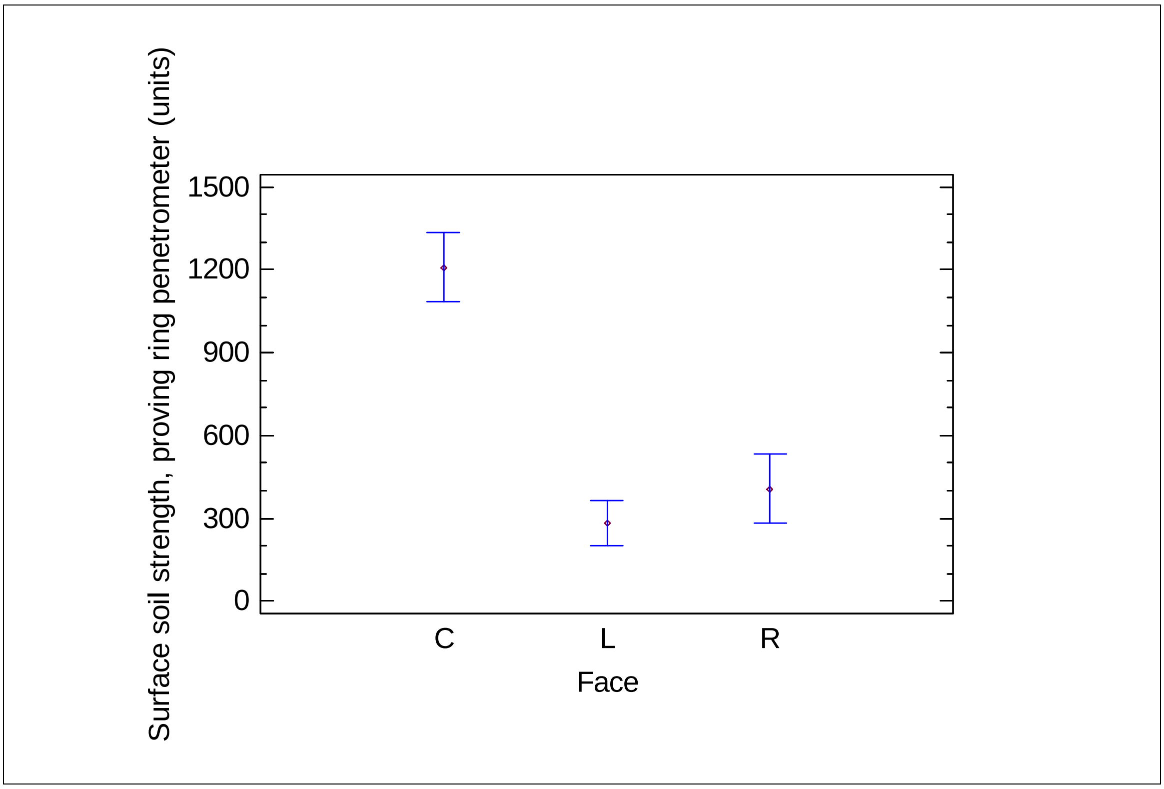

Figure 4.27 Mean soil strengths at the soil surface using a proving ring penetrometer for embankment faces at Reach Lode, Year 5.

Values in gauge units (see conversion chart in Appendix 4).
Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil moisture at surface

Analysis of the soil moisture content data taken at the soil surface revealed no significant differences (p<0.05) in the soil moisture between embankment faces.

The April and June surface soils were found to have significantly higher moisture content (c.31.5 and c.39.5 per cent respectively, p< 0.01) than those in August (c. 24 per cent) (Figure 4.28).

As months were found to have significantly different soil water contents at the surface, only the April data were chosen (most data were available from this month) for a one-way ANOVA to determine whether there were any differences between treatments. The April data revealed that Treatments 4 and 2 had the wettest surface soils while Treatments 10 and 11 had the driest soils, although these differences were not significant.

On average, the crest was drier than the river and landward faces, but not significantly.

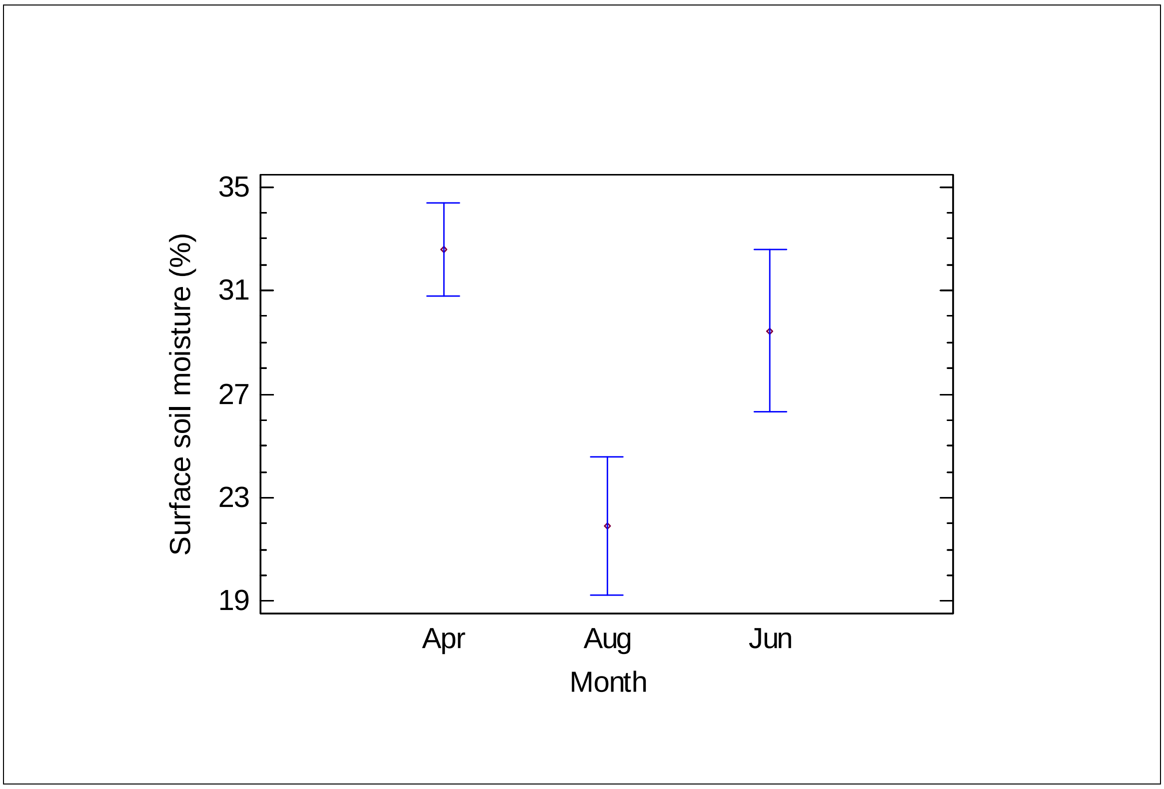

Figure 4.28 Mean soil moisture contents at the soil surface in the survey months at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Soil moisture at 0.3 m below surface

Analysis of the soil moisture content data taken at 0.3 m (300 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil moisture between the treatments or between the embankment faces (as was also found at the surface). This was surprising because the river face recording plots could be expected to show high soil moisture given their proximity to the lode.

Once again, soils sampled in August were significantly drier at depth (c.18 per cent moisture content, $p<0.01$) than those sampled in April and June (c.25 and c.25.5 per cent moisture content) (Figure 4.29).

As months were found to have significantly different soil water contents at 0.3 m below the surface, only the April data were chosen (most data were available for this month) for a one-way ANOVA to determine whether there were any difference between the treatments.

The April data revealed that Treatments 1, 2 and 4 had the wettest soils at depth and Treatments 7, 10 and 11 had the driest soils, although these differences were not significant.

On average, the crest was drier at depth than the river face which in turn was drier than the landward face, but not significantly.

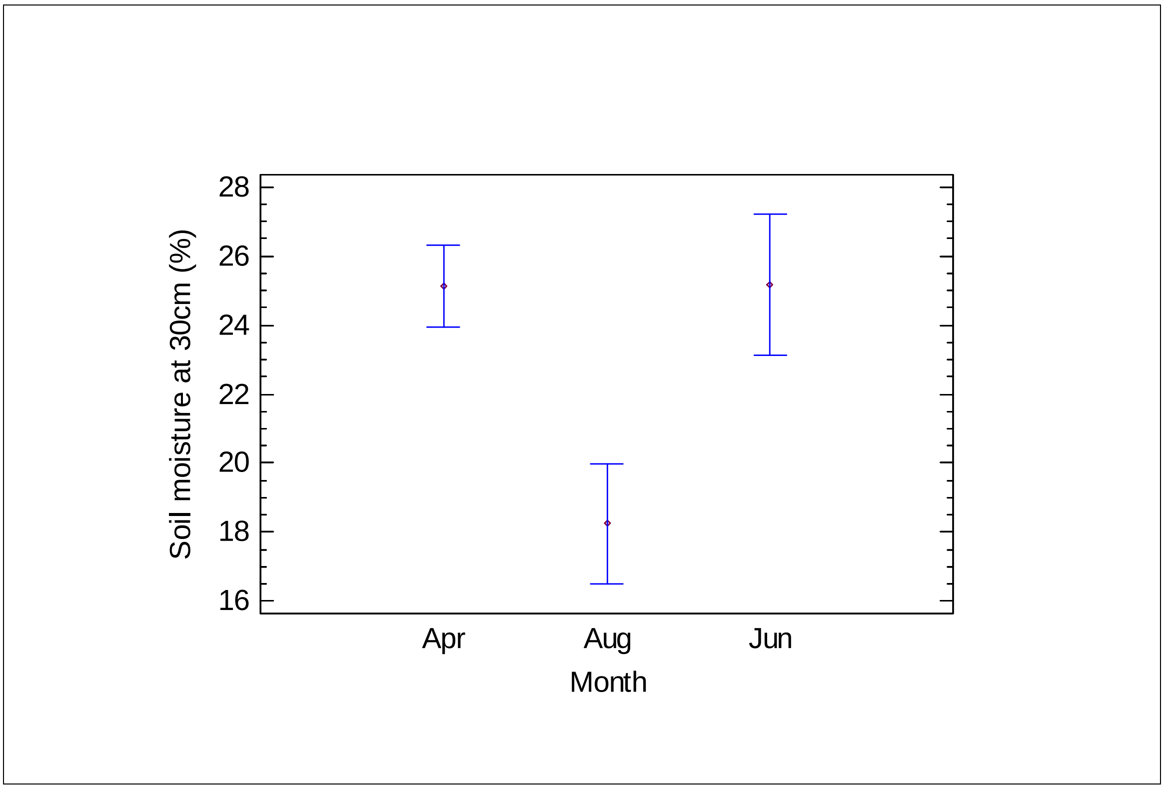

Figure 4.29 Mean soil moisture contents at 0.3 m below the soil surface in the survey months at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Total number of embankment fissures

Analysis of the total number of fissures on the ground surface revealed no significant differences ($p<0.05$) between the embankment faces.

Considering the survey months, April had significantly ($p<0.05$) more ground fissures than August.

As months were found to have a significantly different number of ground fissures, only the April data were chosen (when most data available) for a one-way ANOVA to determine whether there were any difference between treatments.

Treatments 7 and 9 had significantly more fissures than the other treatments ($p<0.05$), while the remaining treatments had a more variable number of fissures (Figure 4.30).

The river face tended to have less fissures than the landward face or crest, although this was not significant.

The majority of all fissures found (259 of 261) were of size class 1 (depth <50 cm, width <20 cm) and size class 2 (depth 60–100 cm, width 20–50 cm). There were insufficient cracks of size class 3 (depth 110–150 cm, width 60–90 cm) and size class 4 (depth >160 cm, width >100 cm) for analysis.

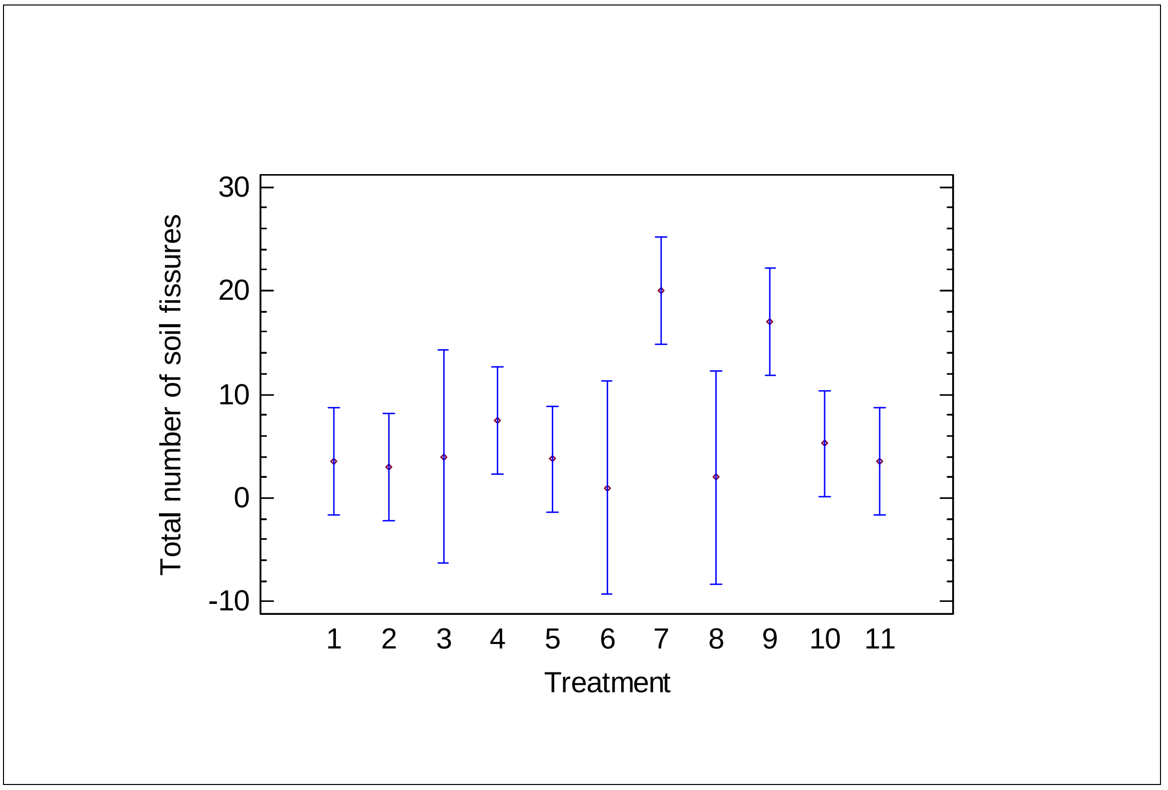

Figure 4.30 Mean total number of ground fissures for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Analysis of size class 1 fissures revealed no significant differences ($p<0.05$) between treatments or survey months for the number of these fissures. However, the crest had significantly ($p=0.037$) more of these fissures than the river or landward face of the embankment, presumably as a result of the presence of an informal footpath here. Treatments 7 and 9 (both cut once a year) tended to have the most fissures, while Treatments 1, 2, 5 (cut 3–6 times a year) and 11 (control) tended to have fewer fissures.

No significant differences ($p<0.05$) were found for the size class 2 fissures. Treatment 7 tended to have the most of these fissures while Treatments 1, 2, 5 and 10 had fewer.

Thus there is some evidence to suggest that treatments receiving three or more cuts a year consistently have fewer fissures.

Total number of embankment holes

Analysis of the total number of holes on the ground surface revealed no significant differences ($p<0.05$) between the survey months. The crest had significantly fewer holes (c. 0 holes, $p<0.01$) than the landward and river face of the embankment (c.3.3 and c. 3.3 holes) (Figure 4.31).

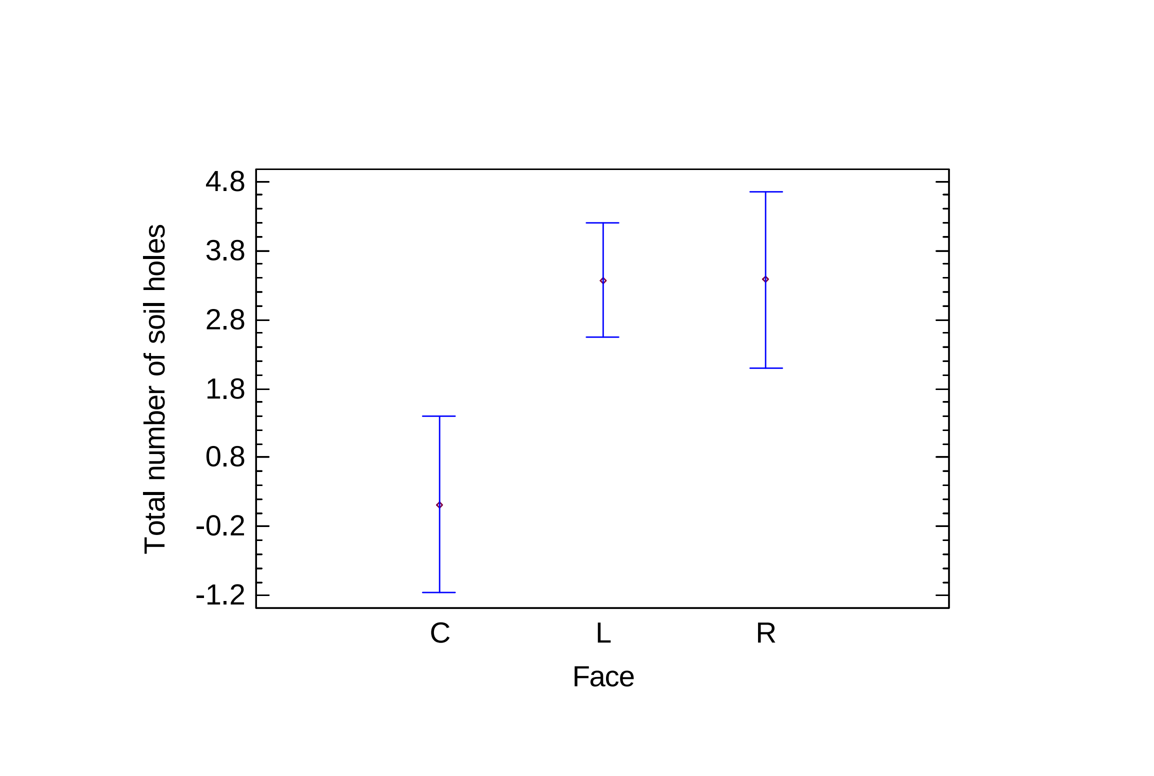

Figure 4.31 Mean total number of ground holes in embankment faces at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Treatment 3 had the most holes and significantly more than all other treatments (c.12 holes, p<0.01). Treatments 6 and 7 tended to have the least holes on the ground (c.0 and c.1 hole respectively) (Figure 4.32).

There were no discernable differences between survey months.

All but two of the 90 holes found were <0.05 m diameter and <0.1 m deep (the remaining two were larger than this).

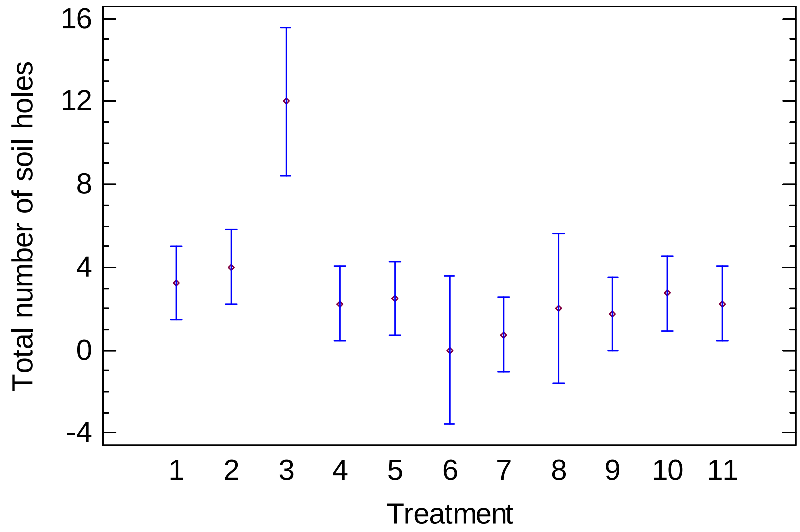

Figure 4.32 Mean total number of ground holes for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Geotechnical summary: Reach Lode

Summaries of the main trends (that were significant, $p<0.05$) found between treatments (Table 4.16), between embankment faces (Table 4.17) and between survey months Table 4.18) at Reach Lode are presented below.

Overall, geotechnical factors were more influenced by the embankment face than by the treatment or survey date.

- When comparing embankment faces, significant differences were found in six of the 10 geotechnical factors measured.
- When comparing treatments and survey months, significant differences were found in only two of the geotechnical factors.
- When comparing survey months, significant differences were found in only four of the geotechnical factors.

Treatments 7 and 9 had a high number of ground fissures and Treatment 3 had a high number of ground holes.

Of the embankment faces, the soil strength was the most influenced of the factors. The crest had high surface strengths (the river face and landward face were weak) when using the hand vane, pocket penetrometer and proving ring penetrometer. The crest, and additionally the landward face, was also strong at a depth of 0.25 m using the hand vane and a depth of 0.3 m using the pocket penetrometer. Interestingly, at 0.07 m (using the proving ring penetrometer) the crest remained strong and the landward face remained weak. The river and landward faces had a high number of ground holes compared with to the crest.

For the survey months, August had high soil strengths at 0.25 m (using a hand vane) compared to the low values of April. The soil moisture content (at both the surface and 0.3 m below the surface) was less in August compared with April and June. April had a higher number of fissures on the ground surface than August.

Table 4.16 Main differences (p<0.05) between treatments in Year 5 at Reach Lode for geotechnical parameters.

Geotechnical parameter	Treatment										
	1	2	3	4	5	6	7	8	9	10	11
Total number of ground fissures							H		H		
Total number of ground holes			H								

H= relatively high value for data.

Table 4.17 Main differences (p<0.05) between embankment faces in Year 5 at Reach Lode for geotechnical parameters.

Geotechnical parameter	Embankment face		
	River	Crest	Land
Soil strength: hand vane at 0 m	L	H	L
Soil strength: hand vane at 0.25 m	L	H	H
Soil strength: pocket penetrometer at 0 m	L	H	L
Soil strength: pocket penetrometer at 0.07 m		H	L
Soil strength: pocket penetrometer at 0.30 m	L	H	H
Soil strength: proving ring penetrometer at 0 m	L	H	L
Total number of ground holes	H	L	H

H= relatively high value for data, L= relatively low value for data

Table 4.18 Main differences (p<0.05) between survey months in Year 5 at Reach Lode for geotechnical parameters.

Geotechnical parameter	Survey month		
	April	June	August
Soil strength: hand vane at 0.25 m	L		H
Soil moisture content at 0 m	H	H	L
Soil moisture content at 0.30 m	H	H	L
Total number of ground fissures	H		L

H= relatively high value for data, L= relatively low value for data

4.3.3 Ely Ouse

Soil strength: hand vane at soil surface

Analysis of the hand vane values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between treatments, between embankment faces or between survey months.

Treatments 1, 6 and 8 had the strongest surface soils (using the hand vane) and Treatment 11 had particularly weak soils. These differences between treatments are not significant.

The crest had a greater, almost significant ($p=0.054$), soil strength at the surface when using a hand vane than the river or landward faces of the embankment.

There were no discernable differences between survey months.

Soil strength: hand vane at 0.25 m below soil surface

Analysis of the hand vane values taken at 0.25 m (250 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between treatments, between embankment faces or between survey months.

Treatments 3, 6 and 8 had the strongest soils at 0.25 m below ground and Treatments 2, 5 and 11 had the weakest soils. However, these differences are highly non-significant.

Soils were stronger at 0.25 m depth when surveyed in August compared to April (not significant, $p=0.072$).

Although not significant, the landward face of the embankment tended to have weaker soils than the river face or crest.

The lowest soil strength values (<50 kPa) recorded at depth in Year 5 were all in April and mainly on the landward face. These recording plots showed very variable characteristics with:

- leaf litter cover ranging from 50–85 per cent;
- variable levels of organic matter (5–15 per cent);
- variable soil moisture at depth (17–26 per cent).

Those recording plots with the highest soil strength values at depth (>100 kPa) included almost all treatments in August (with the exception of Treatments 1 and 4), and several crest recording plots in April. Once again characteristics such as organic matter content and soil moisture at depths for these recording plots were very variable, with no discernable pattern.

Soil strength: pocket penetrometer at surface

Analysis of the pocket penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the survey months or between the treatments.

The crest of the embankment was found to have the strongest surface soils (c.6.6 kg/cm^2) for pocket penetrometer readings (Figure 4.33). Additionally, the surface soil strength of the landward face was significantly weaker than the crest ($p<0.01$, on average 3.0 kg/cm^2).

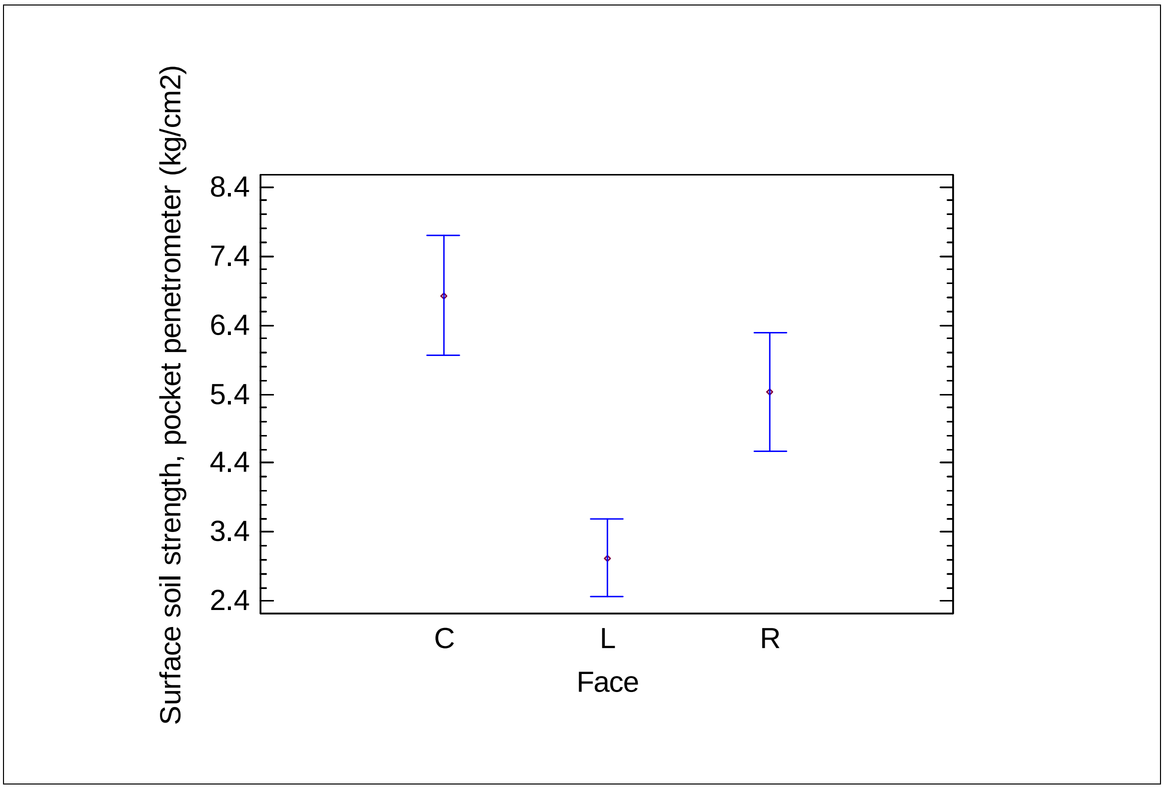

Figure 4.33 Mean soil strengths at the surface using a pocket penetrometer for embankment faces at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Treatment 7 had the highest soil strengths at the surface when using the pocket penetrometer and Treatment 11 was weakest, although these differences were not significant.

There were no discernable differences between survey months.

Soil strength: pocket penetrometer at 0.07 m below surface

Unlike the surface readings, analysis of the pocket penetrometer values taken at 0.07 m (70 cm) below the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments, between the embankment faces or between the survey months.

Treatments 9 and 8 tended to have the strongest soils at 0.07 m depth, while Treatment 11 had the weakest soils (not significant).

The crest tended to have stronger soils at 0.07 m than the other faces, and the soils tended to be stronger in the survey month of August, but these differences had poor significance values.

Soil strength: pocket penetrometer at 0.3 m below surface

Once again, the pocket penetrometer values for soil strength, this time taken at 0.3 m (300 cm) below the soil surface, revealed no significant differences ($p<0.05$) between the treatments, between survey months or between the embankment faces.

Treatment 11 had the weakest soils of all treatments at a depth of 0.3 m, though the difference between treatments was weak.

The strongest of the differences was found between embankment faces, where the soils of the crest at 0.30 m depth were stronger than those of the land and river faces (not quite significant, p=0.064).

As with the hand vane at 0.25 m depth, there was a tendency for stronger soils in August than in April (not significant).

Soil strength: proving ring penetrometer at soil surface

Analysis of the proving ring penetrometer values taken at the soil surface revealed no significant differences ($p<0.05$) in the soil strength between the treatments or between months (as was the case with both the hand vane and the pocket penetrometer at the surface).

The crest, once again, proved to be the strongest of the embankment faces (c.930 gauge units or 0.53 kN). It had a significantly higher ($p<0.01$) value than landward faces (c.480 gauge units or 0.27 kN) (Figure 4.34).

Treatments 1 and 6 tended to have the greatest strengths at the surface when using a proving ring penetrometer; Treatments 3 and 8 had the weakest average strengths, although these differences were not significant.

There were no discernable differences between survey months.

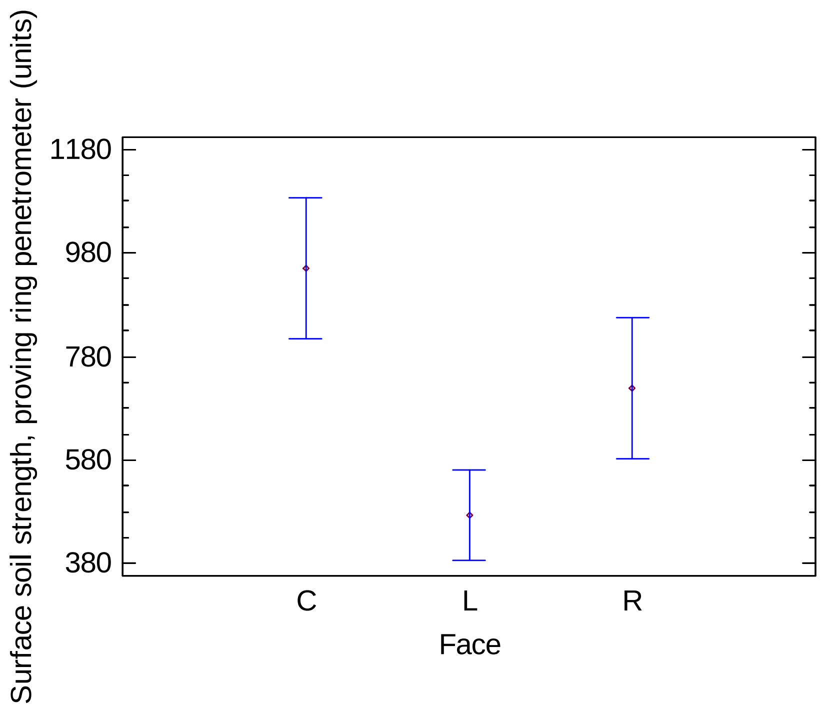

Figure 4.34 Mean soil strengths at the soil surface using a proving ring penetrometer for embankment faces at Ely Ouse, Year 5.

Values in gauge units (see conversion chart in Appendix 4).
Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Soil moisture at surface

Analysis of the soil moisture content data taken at the soil surface revealed no significant differences ($p<0.05$) between treatments.

The river face had the wettest surface soils of the embankment faces (c.30 per cent moisture content). The landward face had the driest surface soils (c.17 per cent moisture content), which were significantly drier ($p<0.01$) than the soils at both the crest and river face (Figure 4.35). This is likely to be the result of several factors including the landward face:

- receiving a greater proportion of sunlight;
- receiving the full force of the prevailing winds;
- being at a greater distance from the watercourse.

Surface soils in April and June were found to be significantly wetter (c.25 and c.22 per cent moisture content respectively, $p<0.01$) than those surveyed in August (c. 11 per cent moisture content) (Figure 4.36).

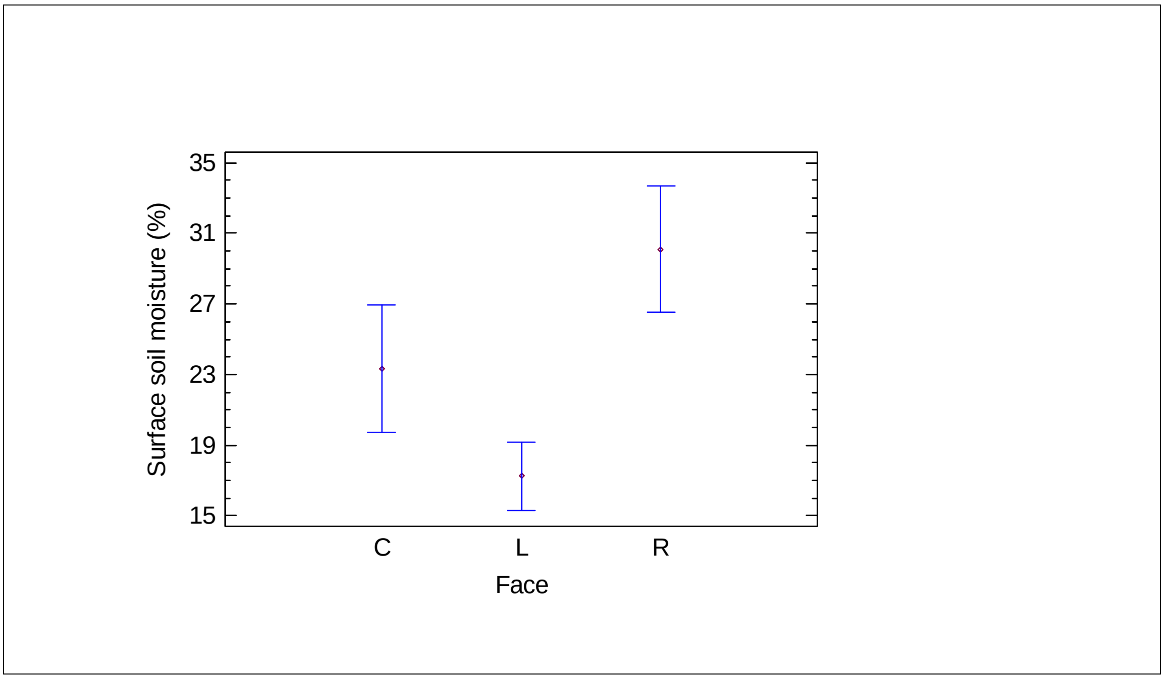

Figure 4.35 Mean soil moisture contents at the soil surface for embankment faces at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

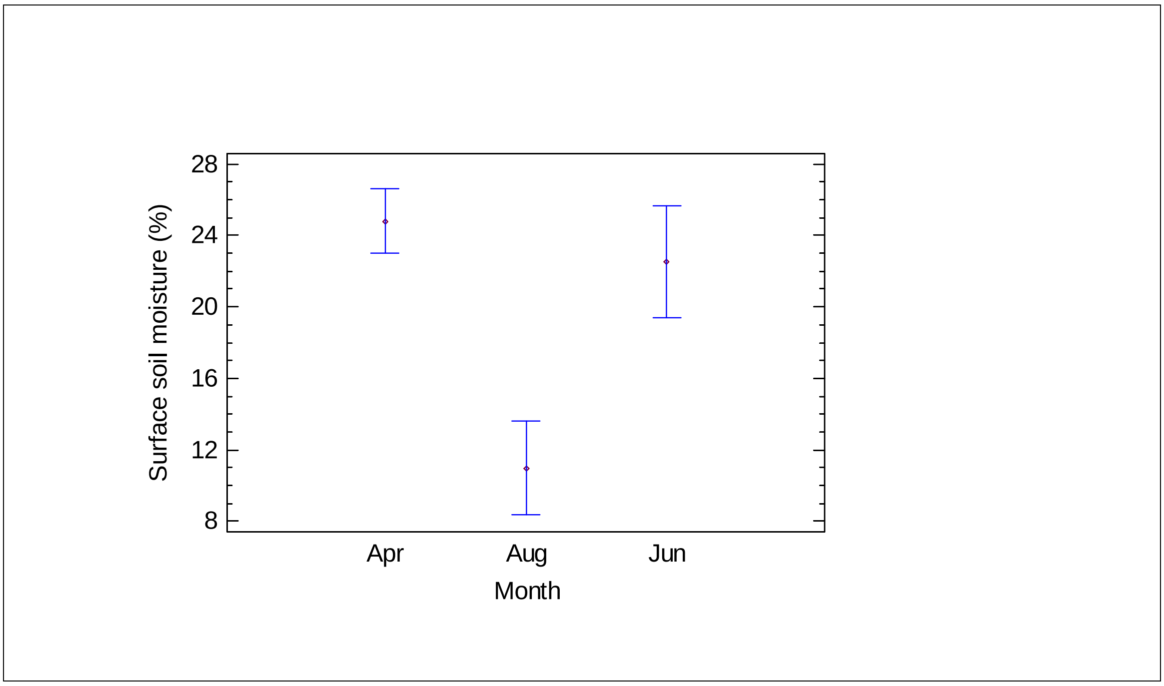

Figure 4.36 Mean soil moisture contents at the soil surface in the survey months at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

As months were found to have significantly different soil water contents at the surface, only the April data were chosen (when most data were available from this month) for a one-way ANOVA to determine whether there were any differences between treatments. The April data revealed that Treatment 5 had the wettest surface soils and Treatment 1 had the driest soils, although these differences were highly unsignificant.

Soil moisture at 0.3 m below surface

Analysis of the soil moisture content data taken at 0.3 m (300 cm) below the soil surface revealed significant differences ($p<0.05$) in the soil moisture between the embankment faces and survey months (as was also found at the surface).

The river face had the wettest soils (at 0.3 m depth) of the embankment faces (c.22.5 per cent moisture content) but, unlike at the surface, the landward face and crest had similar soil moisture contents (c.16.5 per cent moisture content). Both values were significantly less ($p<0.01$) than that of the river face (Figure 4.37).

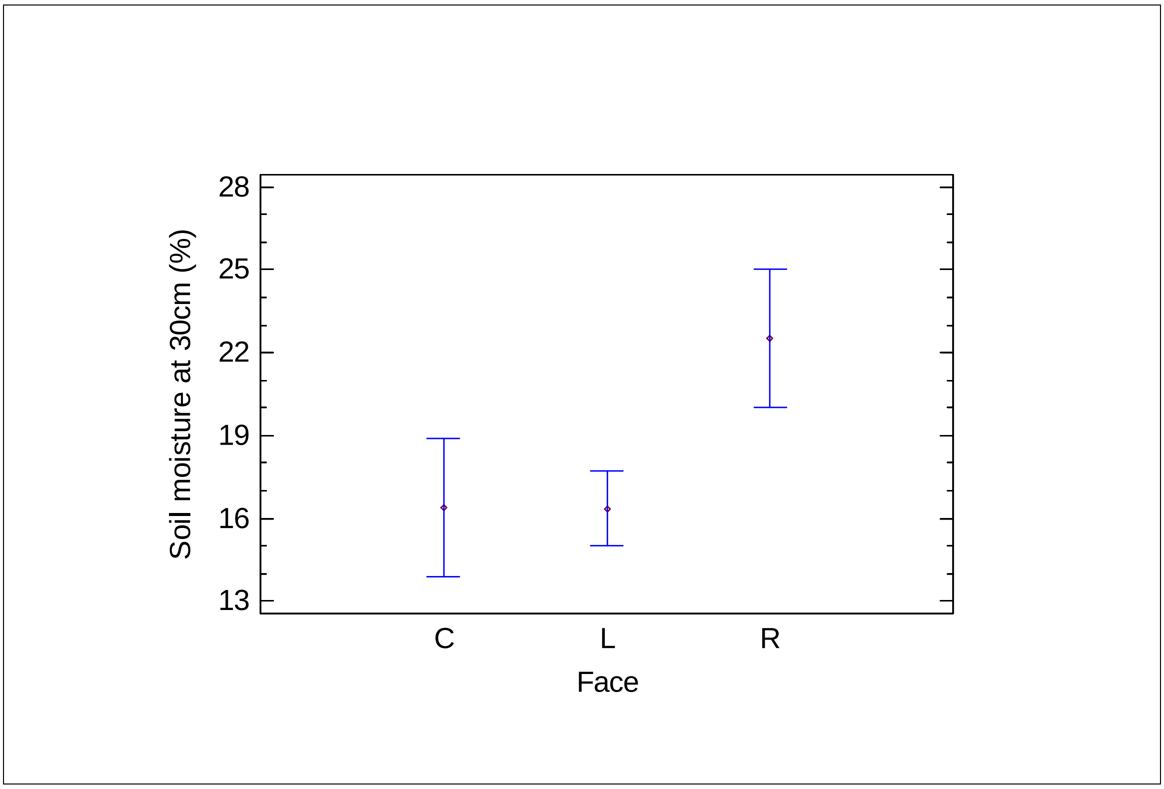

Figure 4.37 Mean soil moisture contents at 0.3 m below the soil surface for embankment faces at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= land and R= river

Once again, soils sampled in August were significantly drier (c.12.5 per cent moisture content, $p<0.01$) than those sampled in April and June (c.20 and c.17 per cent moisture content respectively) (Figure 4.38).

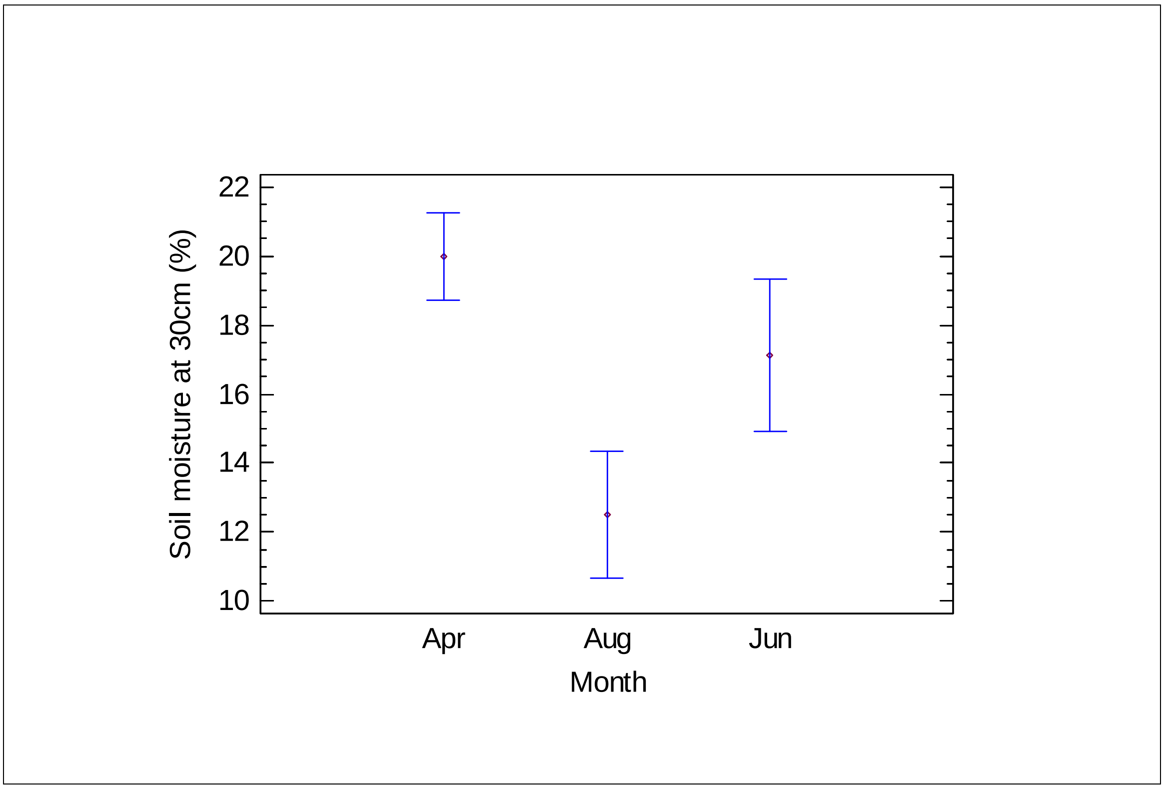

Figure 4.38 Mean soil moisture contents at 0.3 m below the soil surface in the survey months at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

As months were found to have significantly different soil water contents at 0.3 m below the surface, only the April data were chosen (when most data available) for a one-way ANOVA to determine whether there was any differences between treatments. The April data revealed that Treatments 5 and 7 had the wettest soils at 30cm depth and Treatment 4 had the driest soils, although these differences were not significant.

Total number of embankment fissures

Analysis of the total number of fissures on the ground surface revealed no significant differences ($p<0.05$) between the treatments, between the survey months or between the embankment faces.

Treatment 5 tended to have the highest number of fissures, while Treatments 1, 2 and 11 had less fissures (although this was not quite significant, $p=0.098$).

April appeared to have more ground fissures than August and the river face had fewer fissures than the other faces, though neither of these trends is significant.

At Ely Ouse, fissures were recorded at much lower numbers than was found at either of the other trial sites. All 79 of the fissures found were of size class 1 (depth <50 cm, width <20 cm) and size class 2 (depth 60–100 cm, width 20–50 cm).

No significant differences ($p<0.05$) were identified between treatments, between faces or between survey months for size class 1 fissures. Of this size class, Treatment 5 tended to have most fissures and Treatments 1 and 2 tended to have fewer.

The same trend was found for size class 2 fissures, with no significant differences ($p<0.05$) between survey months, embankment faces or treatments.

There was a tendency for Treatment 5 to have a greater number of size class 2 fissures. There was therefore some evidence (although not statistically significant) to suggest that the removal of arisings in Treatment 5 (cut three times a year) may cause a greater frequency of small surface fissures than Treatments 1 or 2 where arisings were left *in situ*.

Total number of embankment holes

Analysis of the total number of holes on the ground surface revealed no significant differences ($p<0.05$) between the treatments, between the survey months or between the embankment faces.

Treatments 4 and 7 (both receiving only one cut annually) tended to have most holes and Treatments 1, 2 and 9 had the least holes, although these differences were not significant.

The crest had fewer holes than the landward and river face of the embankment (not significant), presumably due to the increased compaction of the topsoil on the crest.

There were no differences between survey months.

All except five of the 104 holes found were <0.05 m diameter and <0.1 m deep (the remaining five were larger than this).

Geotechnical summary: Ely Ouse

The main trends (that were significant, $p<0.05$) found between embankment faces and between survey months at Ely Ouse are summarised in Tables 4.19 and 4.20.

Overall, the embankment face was more influential than the treatment or survey date.

- When comparing embankment faces, significant differences were found in four of the 10 geotechnical factors measured.
- When comparing treatments, differences were found in none of the factors.
- When comparing survey months, only two significant differences were found in the factors.

Of all the sites, least differences were found in the geotechnical factors assessed at Ely Ouse.

Considering the embankment faces, the crest had high surface strengths (and the landward face was weak) when using the pocket penetrometer and proving ring penetrometer. The river face was wetter than the landward at the surface and wetter than the landward and crest faces at 0.3 m below ground.

For the survey months, like Reach Lode, the soil moisture content (at both the surface and 0.3 m below the surface) was dry in August compared with April and June.

Table 4.19 Main differences (p<0.05) between embankment faces in Year 5 at Ely Ouse for geotechnical parameters.

Geotechnical parameter	Embankment face		
	River	Crest	Land
Soil strength: pocket penetrometer at 0 m		H	L
Soil strength: proving ring penetrometer at 0 m		H	L
Soil moisture content at 0 m	H		L
Soil moisture content at 0.3 m	H	L	L

H= relatively high value for data, L= relatively low value for data

Table 4.20 Main differences (p<0.05) between survey months in Year 5 at Ely Ouse for geotechnical parameters.

Geotechnical parameter	Survey month		
	April	June	August
Soil moisture content at 0 m	H	H	L
Soil moisture content at 0.3 m	H	H	L

H= relatively high value for data, L= relatively low value for data

4.4 Statistical analysis of changes over time in soil biological and geotechnical parameters

It is particularly important to consider how soil biological and geotechnical parameters changed over time during the five years of trials.

4.4.1 Key factors: all sites

It was known from previous research that some key factors such as soil nutrient content will change over time as a direct result of the management treatment of the site. For example removing a hay crop annually depletes soil nutrients, while allowing the accumulation of organic material increases/stabilises soil nutrients (Croft and Jefferson 1999). One would predict that these effects should be seen at all sites regardless of the differences between the sites or annual meteorological influences.

Therefore, the percentage change (from Year 1 to 5) for the key biological parameters of soil phosphorus, potassium, magnesium, organic matter, nitrate and root content was calculated for all sites. A one-way ANOVA (using StatGraphics Centurion version XV professional edition) of these data was used to determine if there were significant changes between the treatments over time for each of the key soil biological parameters. Standard deviations (SD) for the mean percentage changes of the key factors were also calculated using the StatGraphics Centurion software.

Changes in phosphorus

The change in soil P content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments.

Soil P content fell for all the treatments from Year 1 to Year 5.

Treatments 2, 5 and 10 tended to have the least change in soil P content (<35 per cent decrease). Treatments 4, 7 and 9 had the greatest change in soil P content, with around a 50 per cent decrease (Figure 4.39a).

Changes in potassium

The change in soil K content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments.

All the treatments had an average increase in soil K levels.

Treatment 11 had the greatest change (29 per cent) while Treatments 4 and 7 had the lowest change in soil K content (8 and 1 per cent respectively) (Figure 4.39a). These differences were only trends and not significant.

Changes in magnesium

The change in soil Mg content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments.

The soil Mg content fell from Year 1 to Year 5 for all the treatments, though the percentage changes were the smallest of all the nutrients analysed.

Treatment 11 tended to have the least change in soil Mg content (-2 per cent) and Treatment 5 had the greatest change in soil Mg content (-16 per cent), although the differences are highly non-significant (Figure 4.39a).

Changes in organic matter

For the analysis of organic matter content change over time in both the years available for comparison, data were only available for the landward face of treatments (taken during August surveys).

The change in soil organic matter content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments.

Treatments 5, 10 and 11 tended to have the least change in soil organic content and were close to or greater than 0 per cent (-3, 13 and 2 per cent respectively). Treatment 7 had the greatest change in soil organic matter content at -34 per cent (Figure 4.39a).

Changes in nitrate

The change in soil nitrate content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments.

Soil nitrate content increased with all the treatments from Year 1 to Year 5. The percentage changes observed were the greatest of all the nutrients analysed.

Treatments 4 and 5 tended to have the greatest change in soil nitrate content (1012 and 952 per cent respectively). Treatments 1 and 10 had the least change in soil nitrate content at 75 and 69 per cent respectively, although the differences are not significant (Figure 4.39b).

This result was particularly surprising as:

- nitrate is generally expected to increase where management includes leaving arisings *in situ* after mowing;
- Year 2 data (which were only gathered from the landward face and only in June) showed results in the same order of magnitude as those of Year 5.

It was therefore possible that there was a difference in method of nitrate analysis between the Posford Haskoning laboratory analysis during the baseline year and the Lancrop laboratory used for the remaining four years. For this reason, additional analysis of the change in nitrate content over time was performed between Years 3 and 5 (the only other years in the trials where all three embankment faces were surveyed). The results showed that, between Years 3 and 5, nitrate content declined in the majority of treatments surveyed (with the exception of Treatment 10).

Interestingly, there was little difference in the percentage change in nitrate levels between those treatments where arisings were left on and those where they were removed. This may either be because the greatest degree of change occurred in the first few years (for which the data are not comparable) or possibly because such an affect would take more than five years to become significant.

Changes in root content

The change in total soil root content (as a percentage) between Years 1 and 5 revealed no significant differences ($p<0.05$) between treatments. On average, all of the treatments increased in total soil root content from Year 1 to Year 5 by particularly high values.

Once again this was likely to be the result of using a different analyst in the baseline year and the remaining four years of the trials. Consequently analysis was performed on Year 3 and 5 data, which showed that all except Treatment 11 saw an increase in root content by Year 5. The greatest increase was recorded in Treatments 1, 2 and 9, with slightly higher root content seen in those plots where arisings were left *in situ* when compared to those where arisings were removed – though this was not significant (Figure 4.39c).

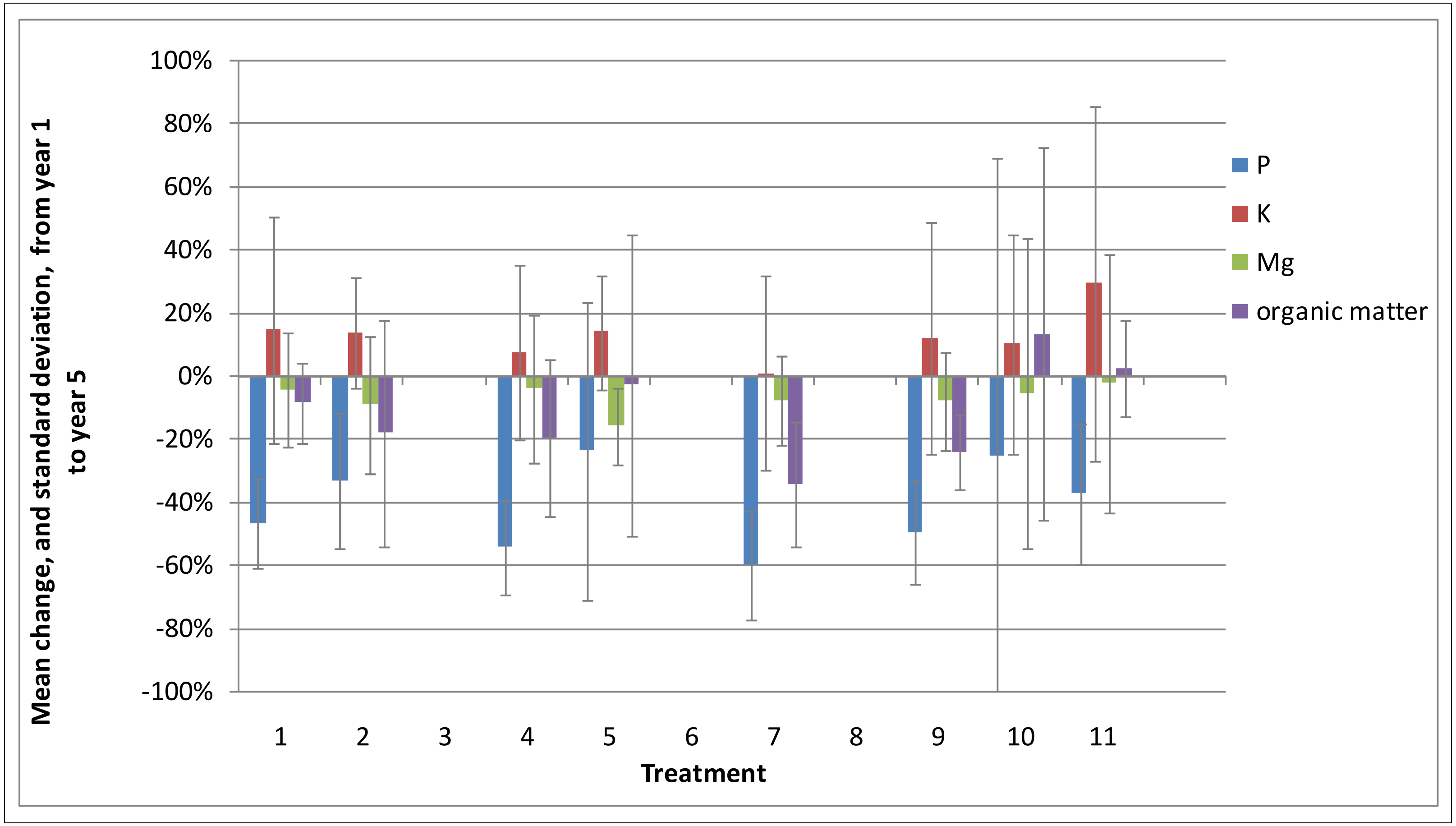

Figure 4.39a Mean percentage change (and standard deviation) of key soil biological factors (soil phosphorus, potassium, magnesium and organic matter content) between survey Years 1 and 5 for all three trial sites, all embankment faces and all survey months .

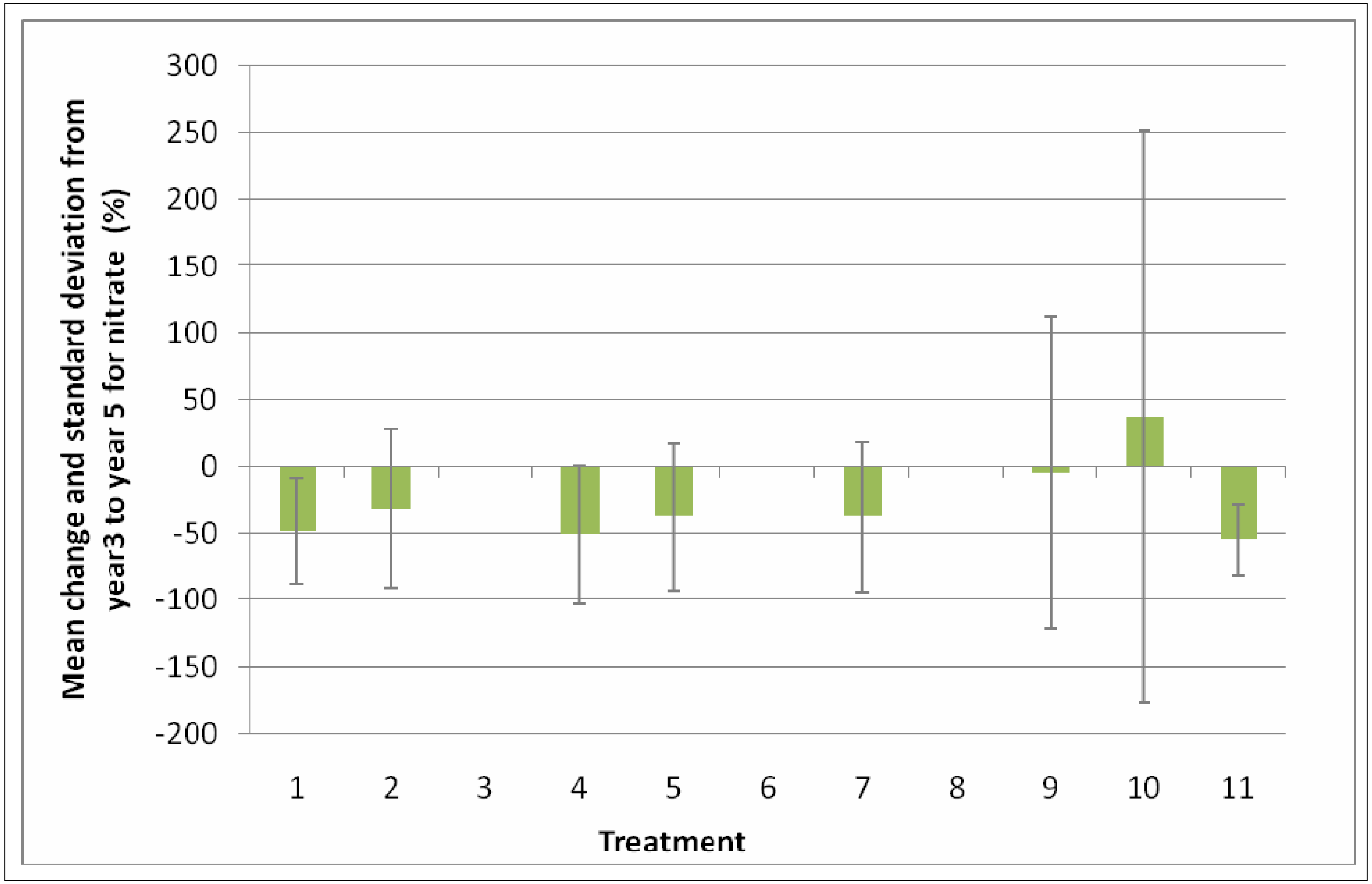

Figure 4.39b Mean percentage change (and standard deviation) of key soil biological factors (soil nitrate) between survey Years 3 and 5 for all three trial sites, all embankment faces and all survey months.

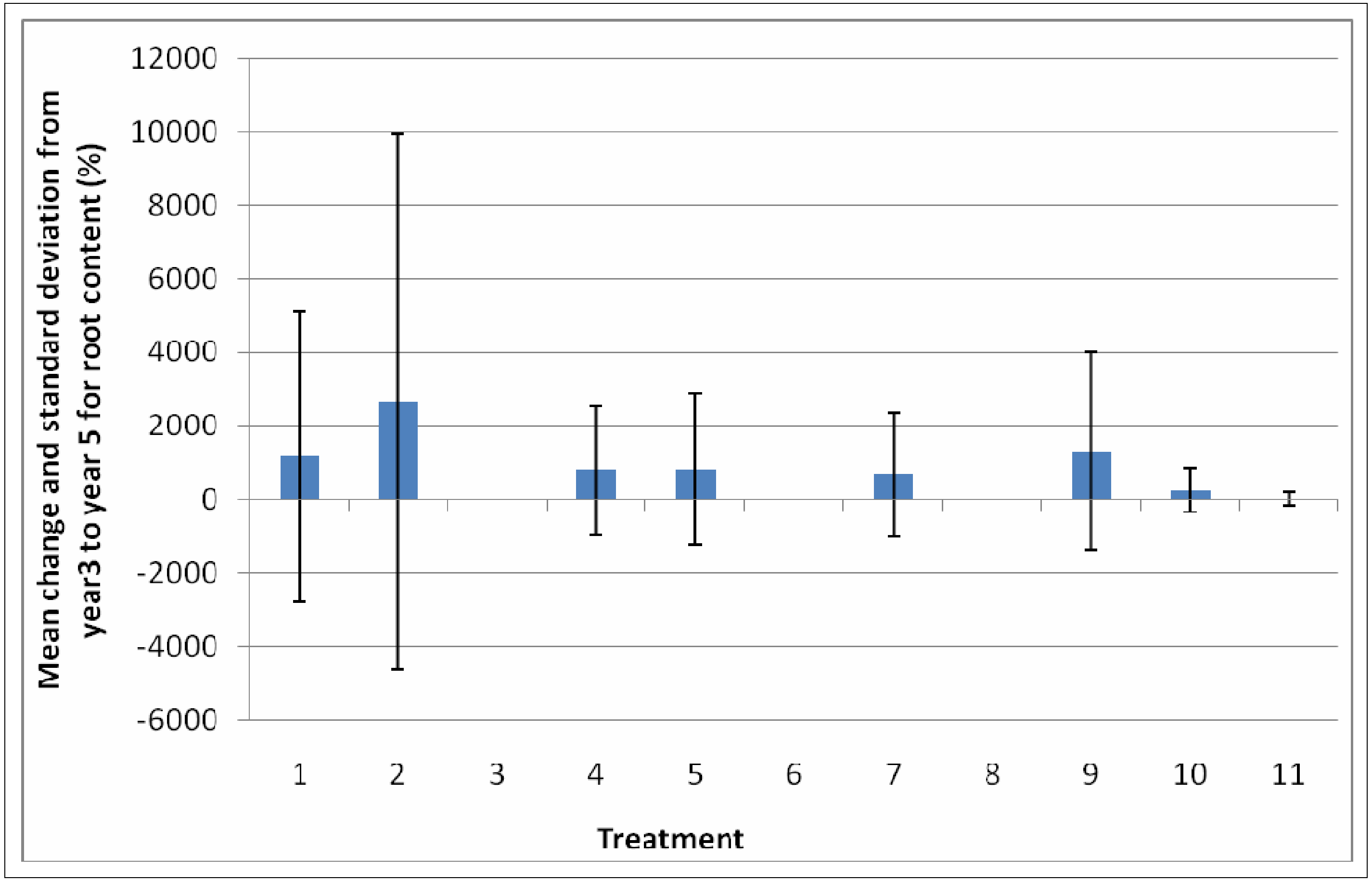

Figure 4.39c Mean percentage change (and their standard deviation) of key soil biological factors (root content) between survey Years 3 and 5 for all three trial sites, all embankment faces and all survey months.

4.4.2 Soil strength: site sensitive

Analysis of Year 5 data revealed some significant differences for the strength of soils (using a range of testing procedures at various depths) between the treatments, between the embankment faces and between the survey months for each site.

It was therefore relevant and of interest to see how the soils' strengths changed over the five year duration of the survey at each site (soil strength was assessed in Years 1, 3 and 5) according to the treatments applied.

Surface soil strength

A simple regression (Table 4.21) for the three methods of testing surface soil strength revealed that all tests were significantly and positively correlated ($p<0.05$) with each other at each site (as would be expected). Therefore, it was only necessary to analyse the change in one of these surface soil strength tests over time.

The data obtained using the proving ring penetrometer were chosen for analysis of change in surface soil strength over time because:

- this data set was particularly highly and positively correlated with the hand vane;
- the readings never exceeded the instrument's scale during tests (unlike the pocket penetrometer and the hand vane).

To determine if treatments had different changes of surface strength over time (Years 1, 3 and 5, i.e. when data were available), a one-way ANOVA was carried out on the percentage change in surface strength between all combinations of years at each site.

Table 4.21 Simple regression results of all combinations of surface soil strength tests used in Year 5 for each trial site.

Simple regression factors	Billingborough			Reach Lode			Ely Ouse		
	Correlation coefficient	R^2 (% adjusted for d.f.)	P	Correlation coefficient	R^2 (% adjusted for d.f.)	P	Correlation coefficient	R^2 (% adjusted for d.f.)	P
Hand vane versus pocket penetrometer	0.473	20.0	0.0041	0.612	35.6	0.0001	0.407	13.7	0.0230
Pocket penetrometer versus proving ring penetrometer	0.401	13.6	0.0169	0.667	42.8	0.0000	0.510	23.4	0.0034
Hand vane versus proving ring penetrometer	0.730	51.9	0.0000	0.889	78.4	0.0000	0.669	42.9	0.0000

d.f. = degrees of freedom

Billingborough

Despite treatment areas having significantly ($p<0.01$) different surface soil strengths in two of the three years tested (Years 3 and 5), the change in surface soil strengths between the treatments was not significantly different over time (either from Year 1 to Year 3, from Year 3 to Year 5, or from Year 1 to Year 5).

From Year 1 to Year 3, soil strength decreased with all treatments with Treatment 10 having the greatest decrease and Treatment 1 having the smallest decrease in surface soil strength. This was undoubtedly due to the dry conditions experienced in Year 1 of the trials. From Year 3 to Year 5, soil strength increased slightly with all treatments (except Treatment 1); Treatment 2 showed the greatest increase (Figure 4.40).

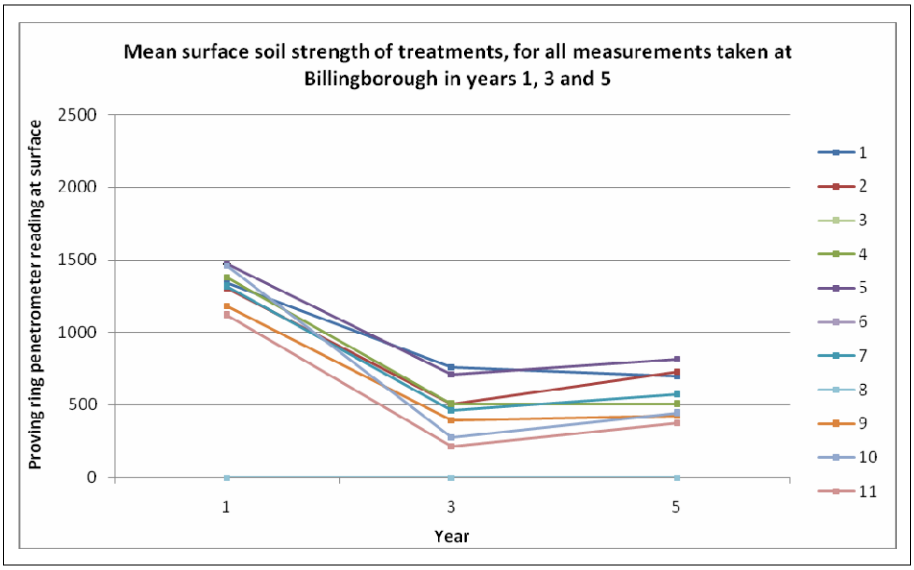

Figure 4.40 Mean surface soil strengths using a proving ring penetrometer for Billingborough in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

Examination of each embankment face (from April surveys) revealed some further trends for the surface soil strengths of the treatments. However, the limited data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.41), surface soil strength decreased with all treatments between Years 1 and 3. Treatments 4, 7, 10 and 11 showed the greatest drop in soil strength (all these treatments received one or less cuts per year). Between Years 3 and 5, surface soil strength increased with all the treatments apart from Treatments 9 and 10. Treatments 5 and 7 produced the greatest increase in soil strength; both these treatments included the removal of arisings after mowing.

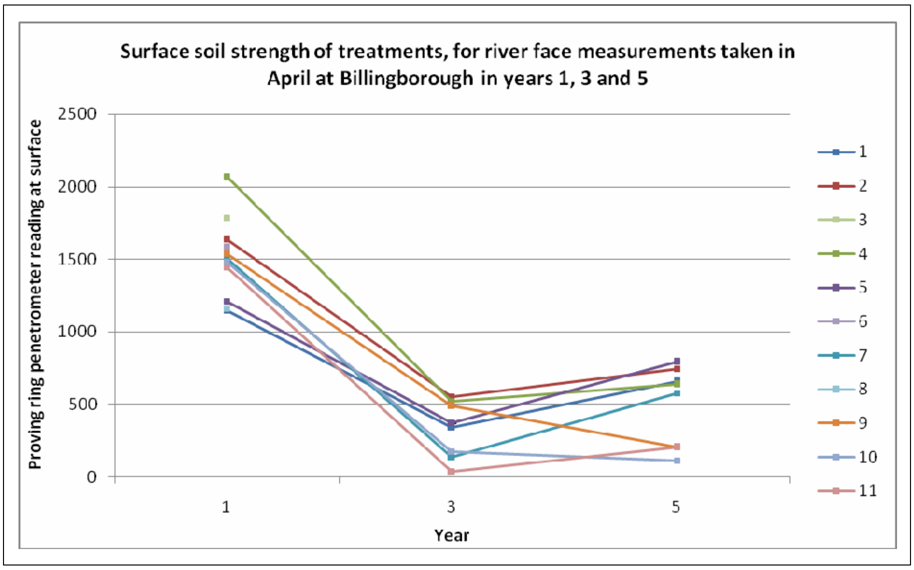

Figure 4.41 Surface soil strengths using a proving ring penetrometer for the river face of the embankment at Billingborough in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

On the embankment crest (Figure 4.42), surface soil decreased with all treatments between Years 1 and 3. Treatments 1 and 5 showed the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments apart from Treatment 1. Treatment 5 showed a very slight increase in soil strength.

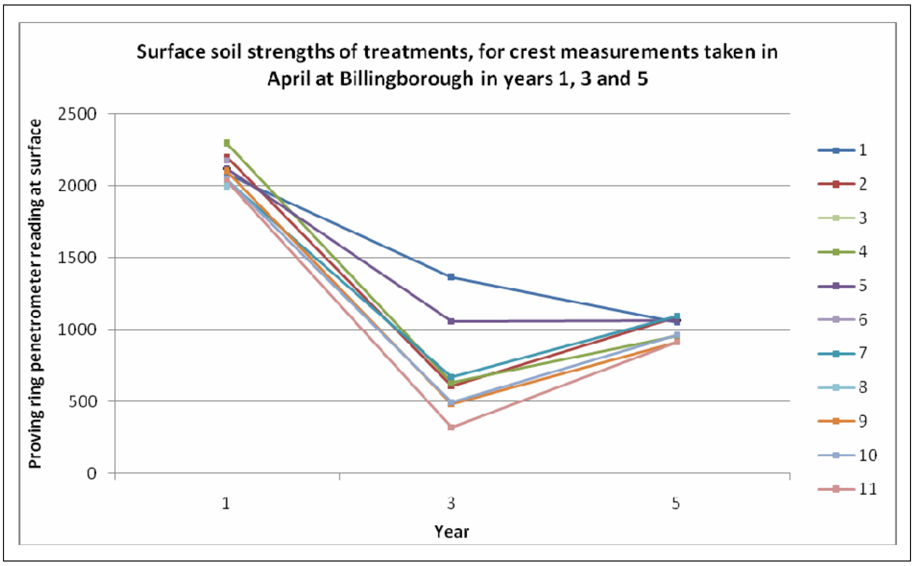

Figure 4.42 Surface soil strengths using a proving ring penetrometer for the crest of the embankment at Billingborough in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

On the landward face of the embankment (Figure 4.43), surface soil strength decreased with all the treatments between Years 1 and 3. Treatments 1, 9 and 11 showed the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments apart from Treatments 7 and 10, where it decreased. Treatment 2 showed the greatest increase in soil strength.

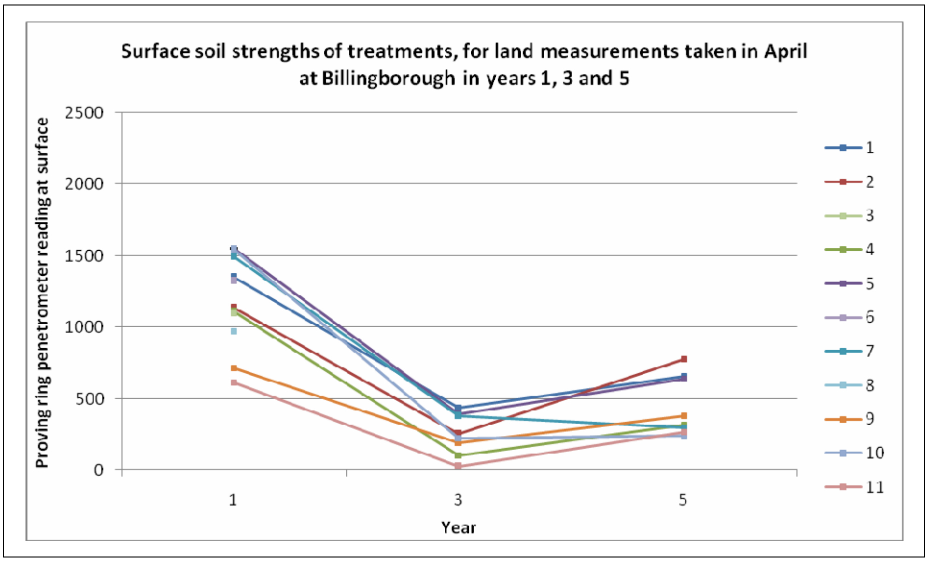

Figure 4.43 Surface soil strengths using a proving ring penetrometer for the landward face of the embankment at Billingborough in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

<u>Reach Lode</u>

Treatment areas did not have significantly ($p<0.05$) different surface soil strengths in any of the three years tested. In addition, the percentage change in surface soil strength between the treatments was not significantly different over time (either from Year 1 to Year 3, from Year 3 to Year 5 or from Year 1 to Year 5).

Once again from Year 1 to Year 3, surface soil strength decreased with all treatments (for climatic reasons), with Treatments 1 and 5 having the smallest decrease and Treatment 10 having the greatest decrease in surface soil strength (although not quite significant). From Year 3 to Year 5, surface soil strength increased with all treatments except Treatments 1, 2 and 5 where it remained high; Treatment 10 showed the greatest increase (Figure 4.44).

Examination of each embankment face (from April surveys) revealed some further trends for the surface soil strengths of the treatments. However, the small amount of data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.45), surface soil strength decreased with all treatments, except Treatment 5, between Years 1 and 3. Treatments 1, 9 and 10 showed the greatest drop in soil strength. Between Years 3 and 5, surface soil strength fell further with all treatments, except Treatments 2 and 11. Treatments 1 and 5 showed the greatest decrease in soil strength.

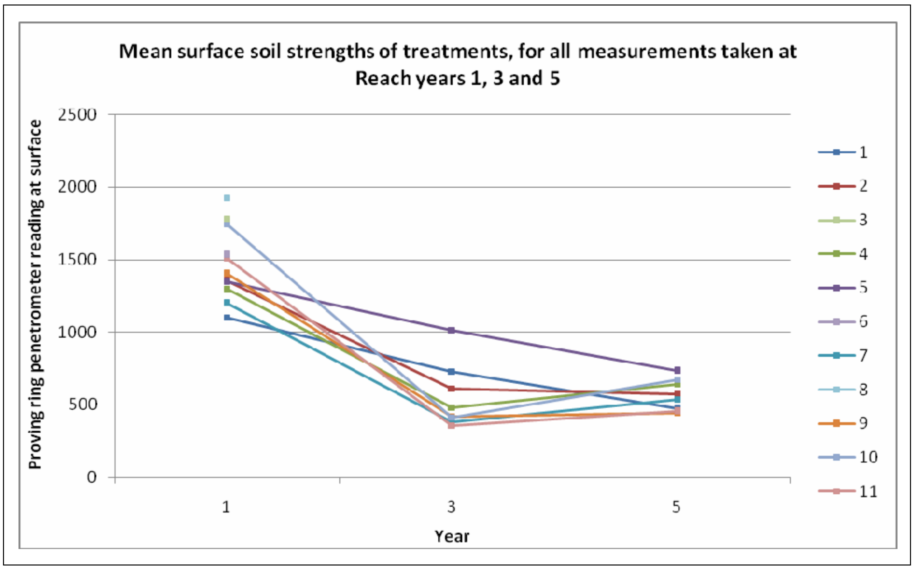

Figure 4.44 Mean surface soil strengths using a proving ring penetrometer for Reach Lode in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

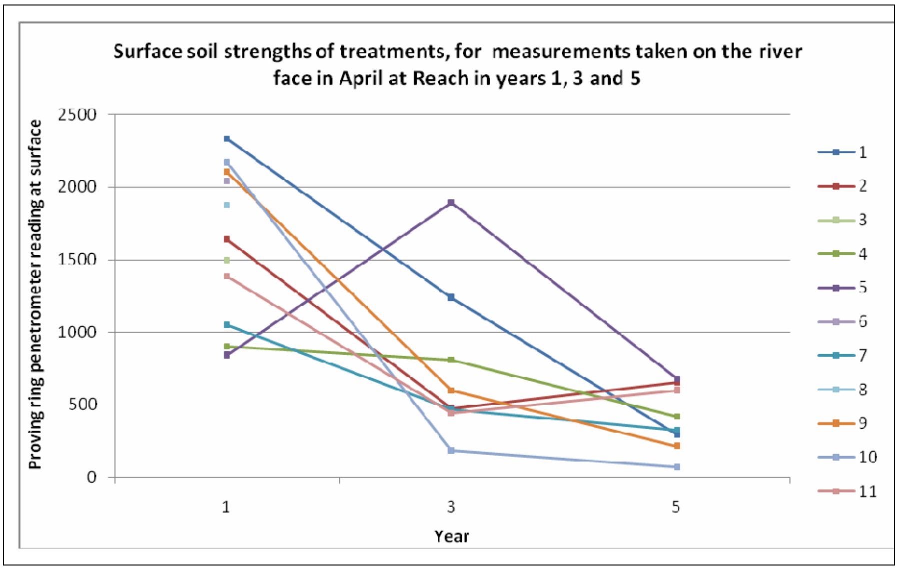

Figure 4.45 Surface soil strengths using a proving ring penetrometer for the river face of the embankment at Reach Lode in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

On the embankment crest (Figure 4.46), surface soil strength decreased with all treatments between Years 1 and 3. Treatments 1 and 2 showed the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments apart from Treatment 2. Treatments 4, 9 and 11 showed the greatest increase in soil strength.

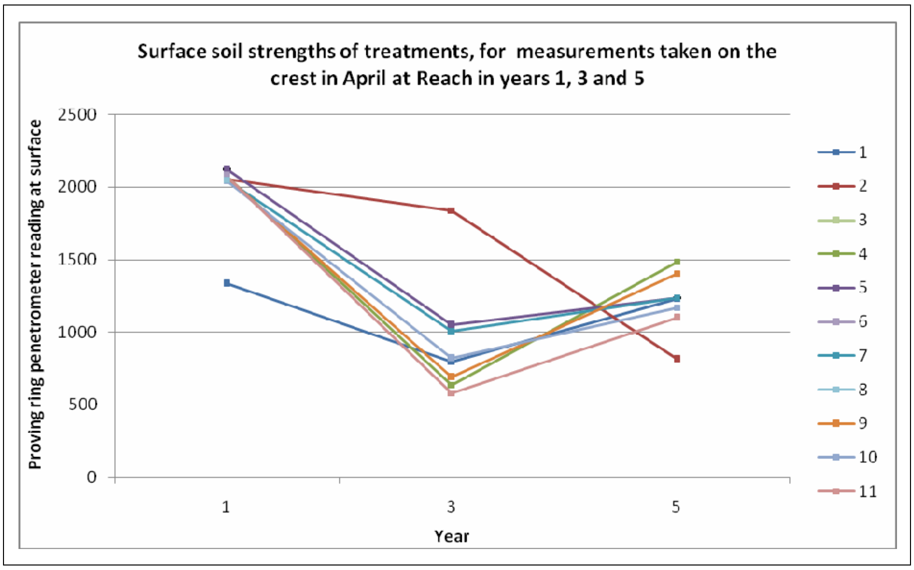

Figure 4.46 Surface soil strengths using a proving ring penetrometer for the crest of the embankment at Reach Lode in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

On the landward face of the embankment (Figure 4.47), surface soil strength decreased with all treatments between Years 1 and 3, with the exception of Treatment 5 which increased. Treatment 10 showed the greatest decrease and Treatment 4 the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength decreased with all treatments apart from Treatments 2 and 11 where it increased. Treatments 1 and 5 showed the greatest decrease in soil strength.

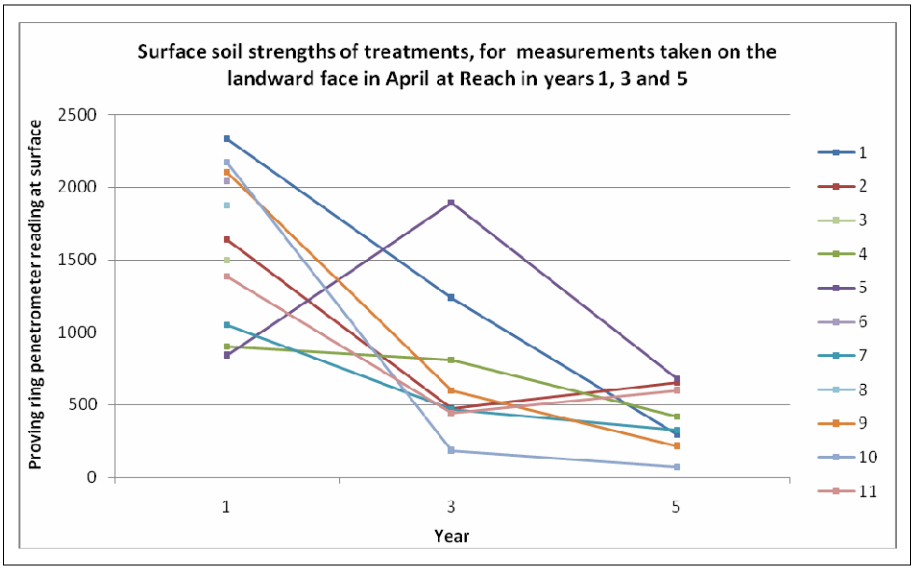

Figure 4.47 Surface soil strengths using a proving ring penetrometer for the landward face of the embankment at Reach Lode in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

The general decrease in the soil strength of the landward face at Reach Lode is presumed to be the result of the large quantities of aquatic dredgings placed here as part of the trials. Even though Treatment 10 involves removal of the aquatic litter after one week, the silt will still have been left *in situ* and may therefore explain why even this plot shows a continued decline in surface soil strength.

Ely Ouse

Treatment areas did not have significantly ($p<0.05$) different surface soil strengths in any of the three years tested. In addition, the percentage change in surface soils strengths between the treatments was not significantly different over time (either from Year 1 to Year 3, from Year 3 to Year 5 or from Year 1 to Year 5).

From Year 1 to Year 3, surface soil strength decreased with all treatments (for climatic reasons), with Treatment 11 showing a slightly smaller decrease than other treatments. From Year 3 to Year 5, surface soil strength increased with all treatments. Treatments 4 and 11 showed a slightly smaller increase than the other treatments (Figure 4.48).

Once again, embankment faces (from April surveys) revealed further trends for the surface soil strengths of the treatments. However, the small amount of data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.49), surface soil strength decreased with all treatments between Years 1 and 3. Treatment 1 showed the smallest drop in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments. Treatments 5 and 7 showed the greatest increase in soil strength.

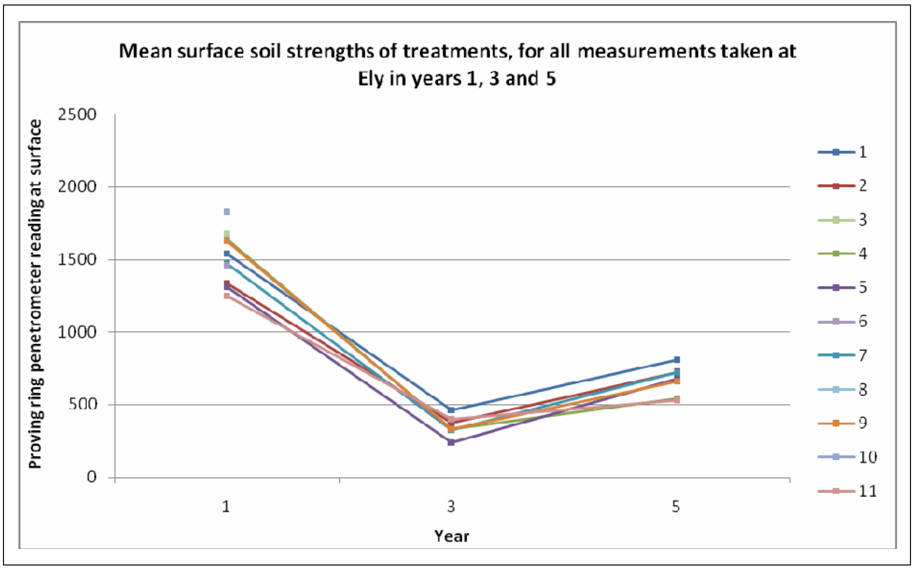

Figure 4.48 Mean surface soil strengths using a proving ring penetrometer for Ely Ouse in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

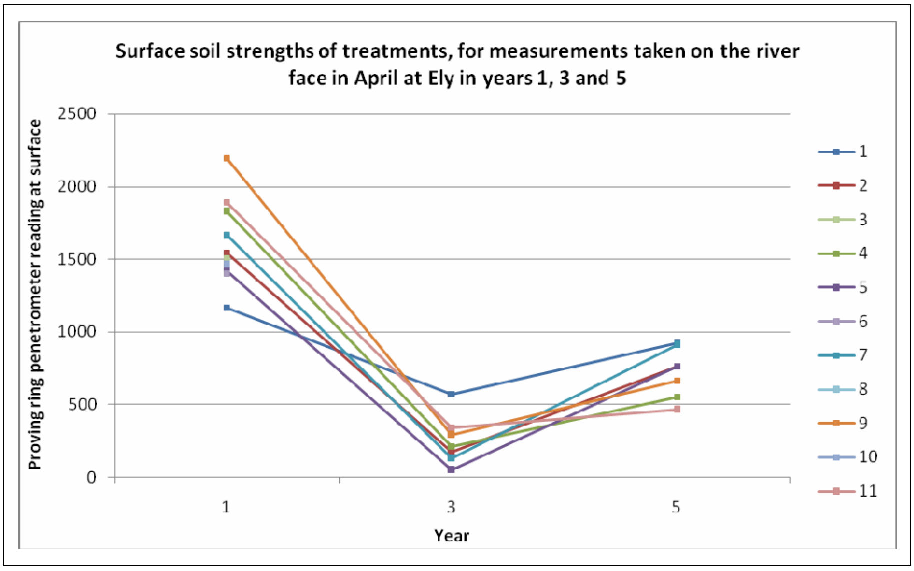

Figure 4.49 Surface soil strengths using a proving ring penetrometer for the river face of the embankment at Ely Ouse in survey Years 1, 3 and 5.

Values in gauge units (see conversion chart in Appendix 4).

On the embankment's crest (Figure 4.50), surface soil strength decreased with all treatments between Years 1 and 3. Treatment 11 showed the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments apart from Treatments 4 and 9, where it decreased (both these treatments involved one cut per year with the arisings left *in situ*). Treatment 5 (arisings removed) and Treatment 11 (no cuts) showed the greatest increase in soil strength.

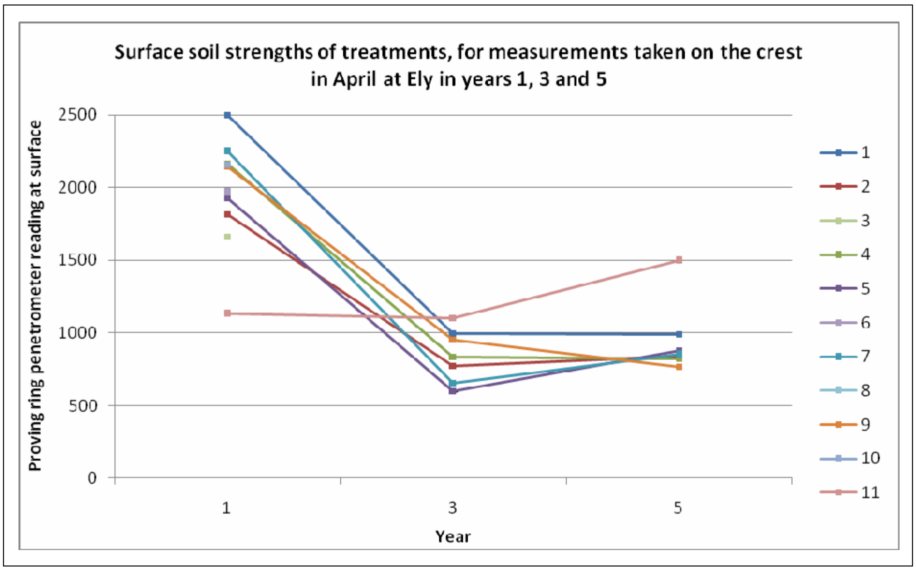

Figure 4.50 Surface soil strengths using a proving ring penetrometer for the crest of the embankment at Ely Ouse in survey Years 1, 3 and 5

Values in gauge units (see conversion chart in Appendix 4).

On the landward face of the embankment (Figure 4.51), surface soil strength decreased with all treatments between Years 1 and 3. Treatment 7 showed the smallest decrease in soil strength. Between Years 3 and 5, surface soil strength increased with all treatments; Treatments 5, 7 and 11 showed the smallest increase.

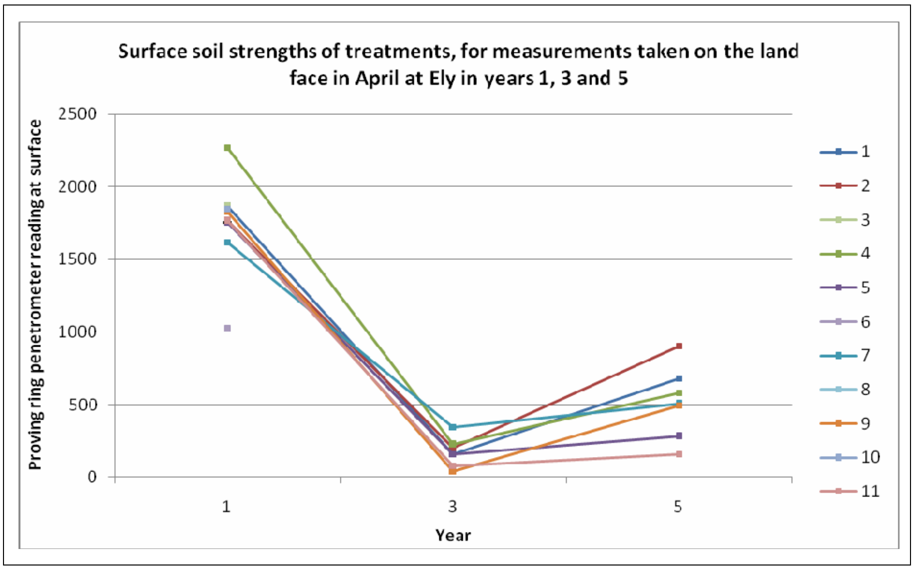

Figure 4.51 Surface soil strengths using a proving ring penetrometer for the landward face of the embankment at Ely Ouse in survey Years 1, 3 and 5

Values in gauge units (see conversion chart in Appendix 4).

Soil strength at depth

At each of the trial sites, the soil strength taken at 0.07 m depth was significantly and positively correlated ($p<0.05$) with the surface soil strength when using the same instrument (pocket penetrometer) in Year 5 surveys. Therefore, it was not necessary to test whether treatments produced significantly different changes in soil strengths at 0.07 m over time, as the results would show trends similar to those found for surface soil strengths.

At the Billingborough and Reach Lode trial sites, the soil strength taken at 0.25 m depth (using a hand vane) was significantly and positively correlated ($p<0.01$) with the soil strength at 0.3 m depth (using a pocket penetrometer) in Year 5 surveys. At Ely Ouse, however, the two soils strengths taken at depth did not significantly correlate with each other.

Therefore, it was only necessary to test if treatments produced significantly different changes in soil strengths at either 0.25 or 0.3 m over time at Billingborough and Reach Lode, whereas at Ely Ouse, it was necessary to test if treatments produced significantly different changes in soil strength at both 0.25 m and 0.3 m over time.

<u>Billingborough</u>

Treatment areas only had significantly ($p<0.01$) different soil strengths at depth (using the hand vane) in one of the three years tested (Year 1). However, the change in these soil strengths between the treatments was significantly different over time from Year 1 to Year 3 ($p=0.002$), and from Year 1 to Year 5 ($p=0.013$); the percentage change in soil strength was not significantly different from Year 3 to Year 5.

From Year 1 to Year 3, soil strength at depth decreased with all treatments apart from Treatments 1, 7 and 10 which increased. From Year 3 to Year 5, soil strength at depth fell with all treatments apart from Treatments 7, 9 and 11 (Figure 4.52).

Therefore, the results of this broad analysis show no consistent trends in relation to management influencing soil strength at depth.

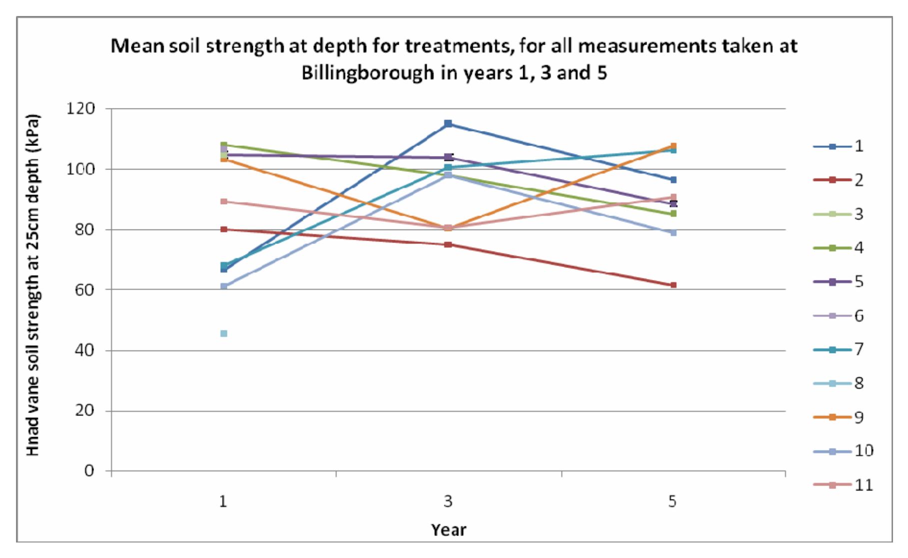

Figure 4.52 Mean soil strengths at 0.25 m depth (using a hand vane) for Billingborough in survey Years 1, 3 and 5

Examination of each embankment face (from April surveys) also revealed few trends for the soil strengths at depth of the treatments. The limited data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.53), soil strength at depth increased with all treatments between Years 1 and 3, with the exception of Treatments 9 and 11. Treatment 11 showed a particularly large decrease in soil strength (which may be a result of the test hitting a subterranean vole burrow), while Treatments 1 and 10 showed the greatest increase. Between Years 3 and 5, soil strength at depth decreased with most treatments but Treatments 1, 9 and 11 exhibited an increase.

Once again it is difficult to interpret any clear trends from these data as those treatments with the highest soil strength values at depth do not share similar management techniques (such as all being cut more than once or all having arisings removed).

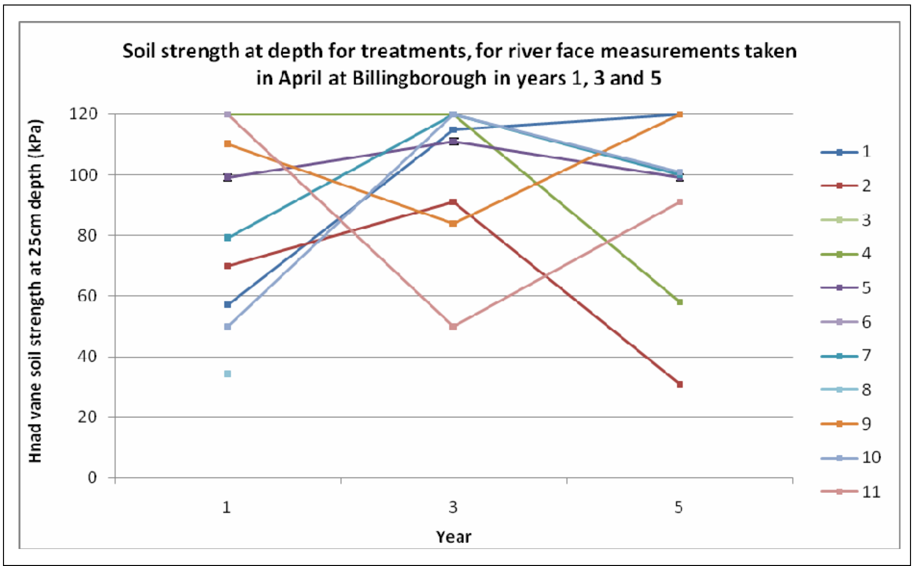

Figure 4.53 Soil strengths at 0.25 m depth (using a hand vane) for the river face of the embankment at Billingborough in survey Years 1, 3 and 5.

On the embankment crest (Figure 4.54), soil strength at depth decreased with four of the treatments (2, 4, 9 and 10) between Years 1 and 3; it increased or remained stable with the other treatments. Treatment 1 had the greatest increase in strength and Treatment 9 had the greatest decrease in strength. Between Years 3 and 5, all treatments increased in soil strength except Treatments 1 and 5 where it decreased.

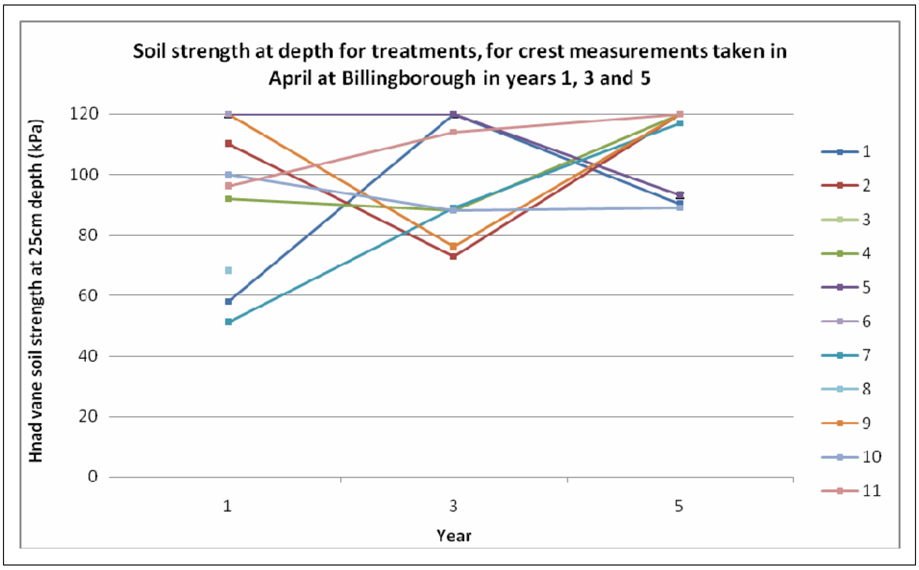

Figure 4.54 Soil strengths at 0.25 m depth (using a hand vane) for the crest of the embankment at Billingborough in survey Years 1, 3 and 5.

On the landward face of the embankment (Figure 4.55), soil strength at depth increased between Years 1 and 3 with all treatments apart from Treatments 2, 4 and 9. Treatment 4 showed the greatest decrease and Treatment 1 the greatest increase in soil strength. Between Years 3 and 5, soil strength at depth decreased with Treatments 1, 5 and 11 while the others remained stable or increased. Treatment 7 showed the greatest increase and Treatment 1 the greatest decrease in soil strength.

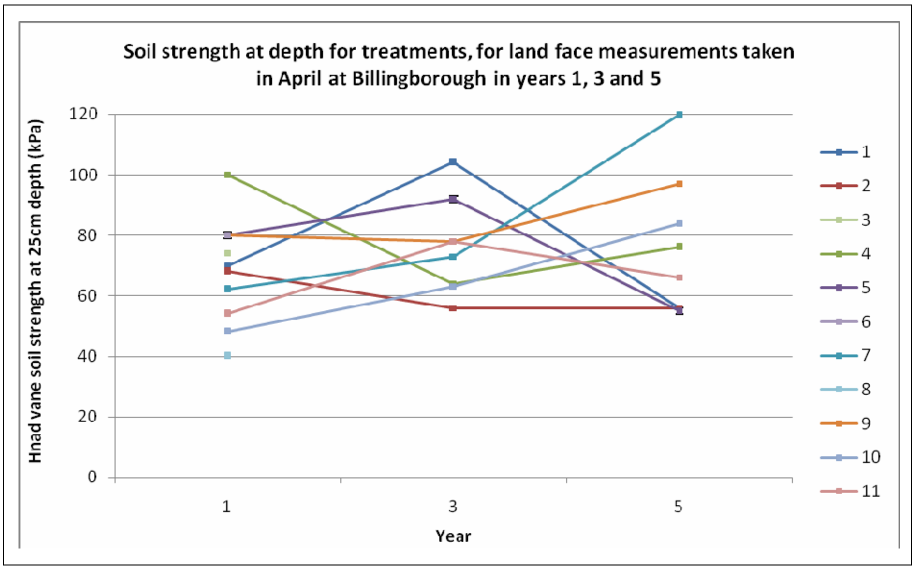

Figure 4.55 Soil strengths at 0.25 m depth (using a hand vane) for the landward face of the embankment at Billingborough in survey Years 1, 3 and 5.

Reach Lode

Treatment areas did not have significantly ($p<0.01$) different soil strengths at depth (using the hand vane) in any of the three years tested. Additionally, the change in these strengths, between the treatments, was not significantly different over time from Year 1 to Year 3, from Year 3 to Year 5 and from Year 1 to Year 5.

From Year 1 to Year 3, soil strength at depth decreased with all treatments except Treatment 7, which increased. This may indicate that, unlike Billingborough, Reach Lode soils are more vulnerable to climatic differences at depth as well as on the surface of the banks. Treatments 1 and 10 showed a particularly large decline in soil strength. From Year 3 to Year 5, there was a further decrease in soil strength at depth with most treatments except Treatments 1, 7 and 10 where it increased (Figure 4.56).

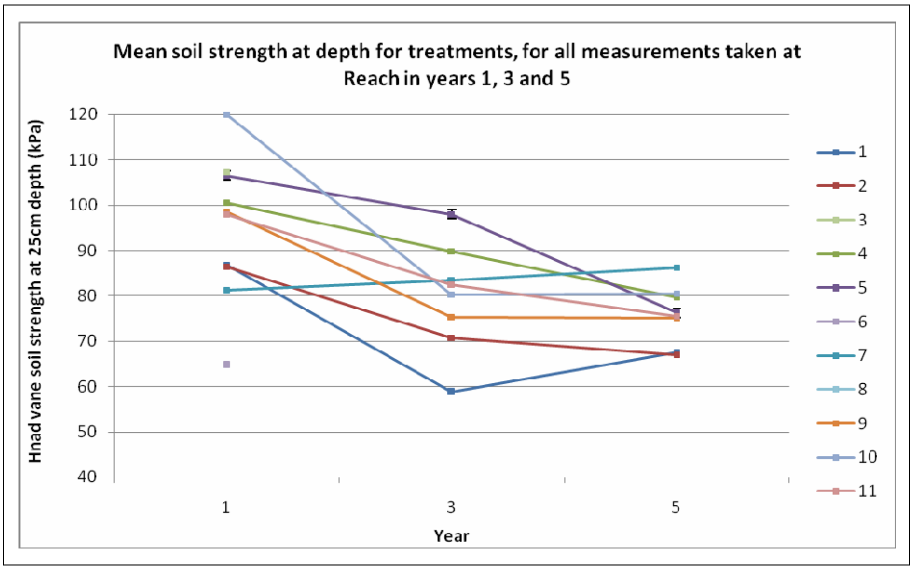

Figure 4.56 Mean soil strengths at 0.25 m depth (using a hand vane) for Reach Lode in survey Years 1, 3 and 5.

Examination of each embankment face (from April surveys) revealed some further trends for the soil strengths at depth for the treatments. However, the limited data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.57), soil strength at depth decreased with all treatments between Years 1 and 3 apart from Treatments 5 and 7 (both of which involve removal of arisings after mowing). Treatments 9 and 10 showed a particularly large decrease in soil strength. Between Years 3 and 5, soil strength at depth fell further with all the treatments, with Treatments 4 and 5 exhibiting the greatest decrease.

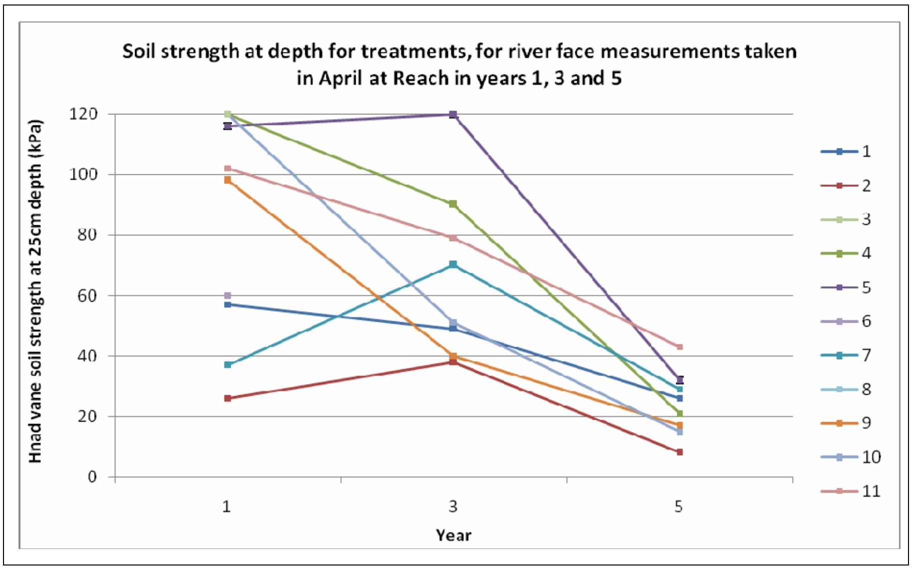

Figure 4.57 Soil strengths at 0.25 m depth (using a hand vane) for the river face of the embankment at Reach Lode in survey Years 1, 3 and 5.

On the embankment crest (Figure 4.58), soil strength at depth decreased with all the treatments between Years 1 and 3, with Treatments 10 and 11 showing the greatest decrease and Treatment 1 the smallest decrease. Between Years 3 and 5, soil strength at depth increased with all treatments apart from Treatment 1, where it decreased.

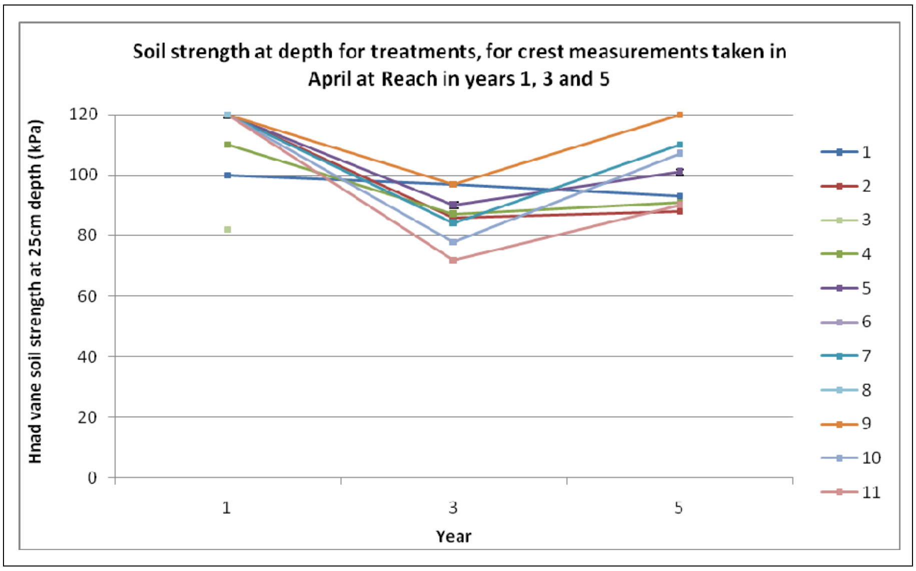

Figure 4.58 Soil strengths at 0.25 m depth (using a hand vane) for the crest of the embankment at Reach Lode in survey Years 1, 3 and 5.

On the landward face of the embankment (Figure 4.59), soil strength at depth between Years 1 and 3 decreased with all treatments apart from Treatment 11 where it increased. Treatment 1 showed the greatest decrease in soil strength. Between Years 3 and 5, soil strength at depth increased with most treatments, though it decreased with Treatments 5, 10 and 11. Treatment 1 showed the greatest increase in soil strength. Unlike at the surface, the soil strength at depth on the landward face of Reach Lode does not appear to be affected to the same extent by aquatic dredgings.

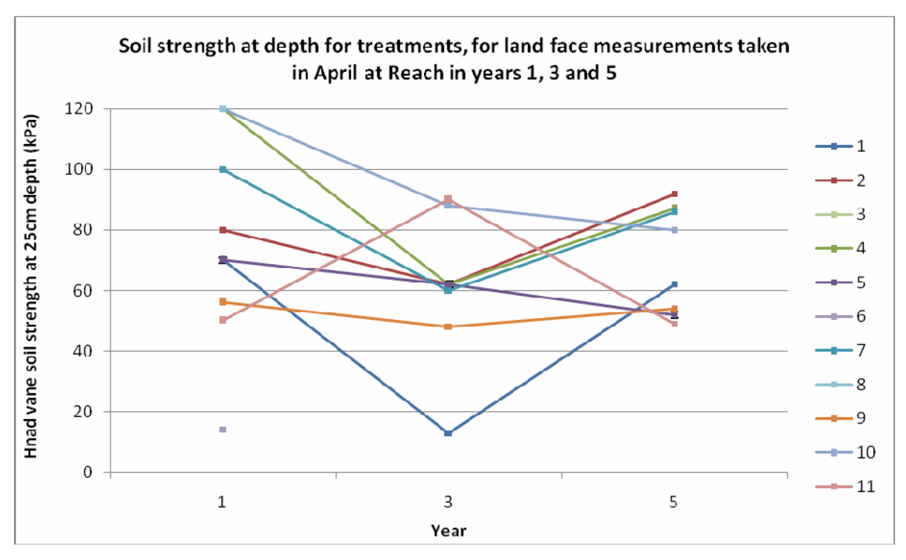

Figure 4.59 Soil strengths at 0.25 m depth (using a hand vane) for the landward face of the embankment at Reach Lode in survey Years 1, 3 and 5.

Ely Ouse: 0.25 m depth

Treatment areas only had significantly ($p<0.01$) different strengths at depth (using the hand vane) in one of the three years tested (Year 3). Additionally, the change in these soil strengths, between the treatments, was not significantly different over time (either from Year 1 to Year 3, from Year 3 to Year 5 or from Year 1 to Year 5).

From Year 1 to Year 3, soil strength at depth decreased with all treatments apart from Treatments 1 and 2. This was felt to be at least partly the result of climatic differences between Years 1 and 3. Treatments 7 and 11 showed the most marked decrease in soil strength at depth between the first and second survey. From Year 3 to Year 5, soil strength at depth increased with Treatments 1, 7 and 11 and decreased with Treatments 2, 4, 5 and 9 (Figure 4.60).

As with the other two trial sites, the results of this broad analysis at Ely Ouse show no consistent trends in relation to management influencing soil strength at depth.

Examination of each embankment face (from April surveys) revealed few trends for the soil strengths at depth for the treatments. The limited data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.61), soil strength at depth decreased with Treatments 1, 7 and 11 between Years 1 and 3, and increased or remained stable with Treatments 2, 4, 5 and 9. Treatments 1 and 7 showed the greatest change. Between Years 3 and 5, soil strength at depth increased or remained stable with Treatments 1, 7, 9 and 11 and decreased with Treatments 2, 4 and 5 (the opposite to the trends found between Years 1 and 3).

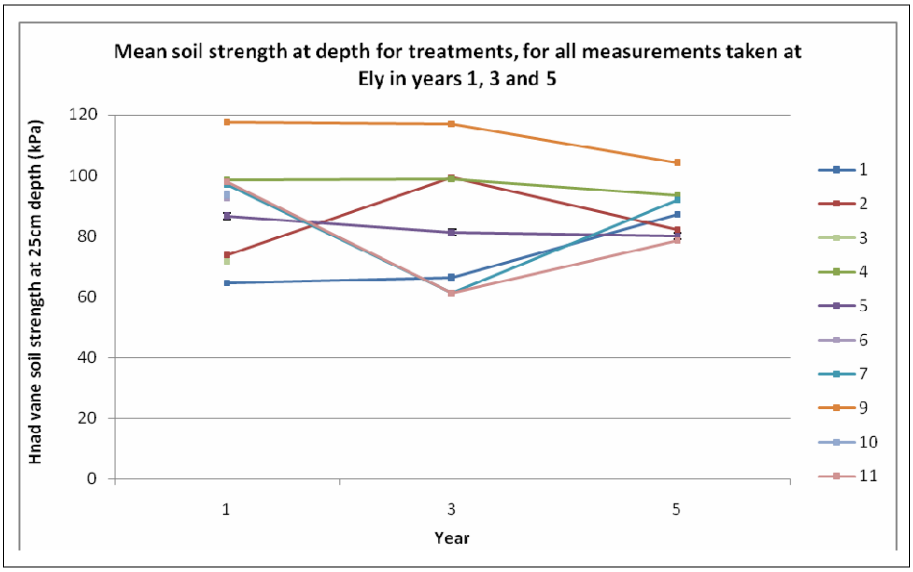

Figure 4.60 Mean soil strengths at 0.25 m depth (using a hand vane) for Ely Ouse in survey Years 1, 3 and 5.

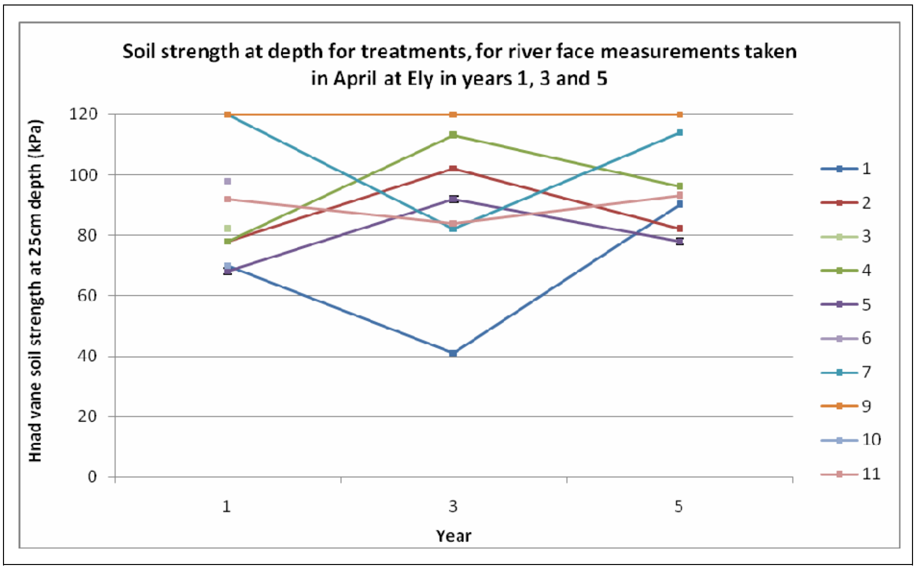

Figure 4.61 Soil strengths at 0.25 m depth (using a hand vane) for the river face of the embankment at Ely Ouse in survey Years 1, 3 and 5.

On the embankment crest (Figure 4.62), soil strength at depth increased or remained stable with all treatments between Years 1 and 3 apart from Treatments 5 and 7. Treatment 1 showed the greatest increase in soil strength at depth. Between Years 3 and 5, soil strength at depth increased with Treatments 1 and 11 and decreased with Treatment 7; more stable soil strengths were seen with the remaining treatments.

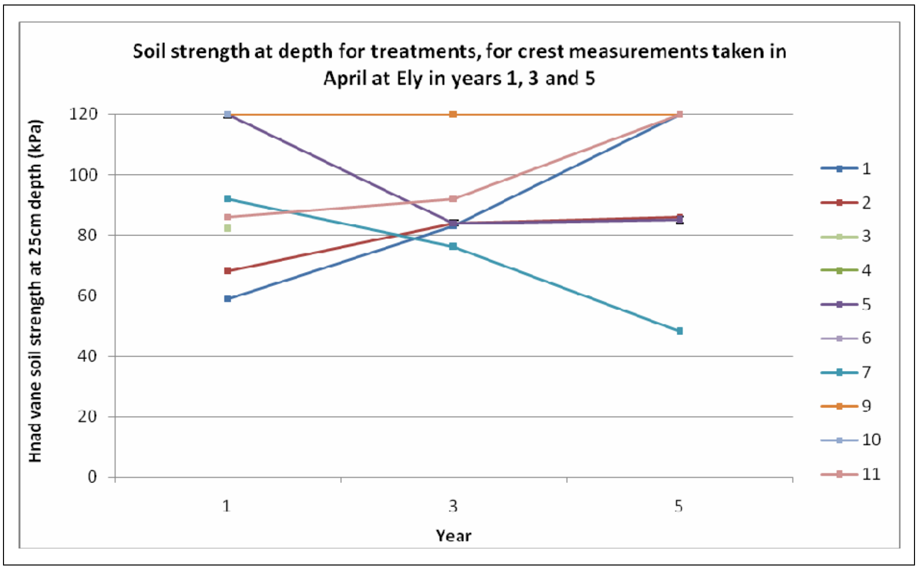

Figure 4.62 Soil strengths at 0.25 m depth (using a hand vane) for the crest of the embankment at Ely Ouse in survey Years 1, 3 and 5.

On the landward face of the embankment (Figure 4.63), soil strength at depth decreased between Years 1 and 3 with Treatments 5, 7 and 11 and increased with Treatments 1, 4 and 9. Treatment 11 showed the greatest decrease in soil strength (believed to be the result of sampling hitting subterranean vole burrows). Between Years 3 and 5, soil strength at depth decreased with all treatments apart from Treatments 1 and 7 where it increased. Treatment 9 showed the greatest decrease and Treatment 7 the greatest increase in soil strength.

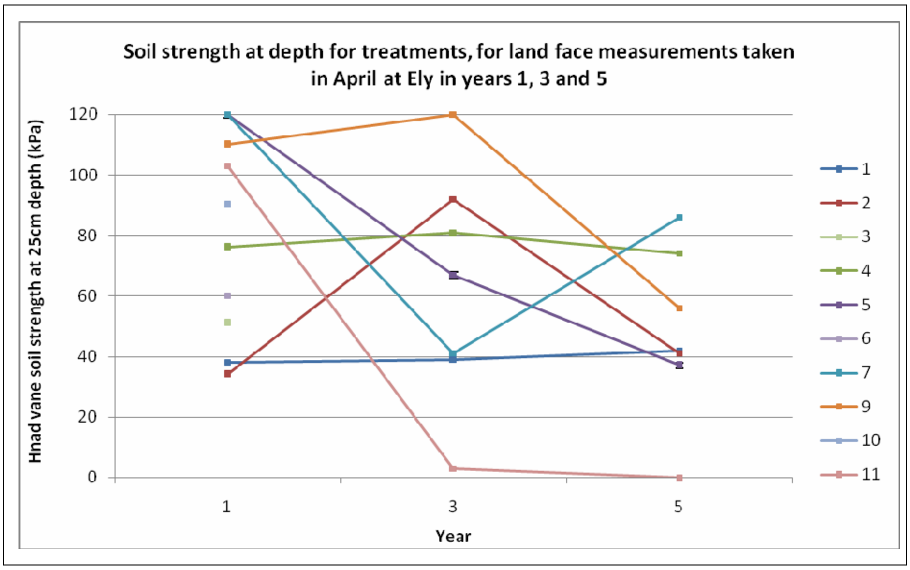

Figure 4.63 Soil strengths at 0.25 m depth (using a hand vane) for the landward face of the embankment at Ely Ouse in survey Years 1, 3 and 5.

<u>Ely Ouse: 0.3 m depth</u>

Treatment areas did not have significantly ($p<0.01$) different strengths at depth (using the pocket penetrometer) in any of the three years tested. In addition, the change in these soil strengths between the treatments was not significantly different over time from Year 1 to Year 3, ($p=0.061$) or from Year 1 to Year 5. However, there were significant changes between treatments from Year 3 to Year 5 ($p=0.024$).

From Year 1 to Year 3, soil strength at depth increased with all treatments except Treatments 5 and 7. From Year 3 to Year 5, there was a further increase in soil strength at depth with all the treatments except Treatment 11, with Treatments 5 and 7 showing the greatest increase (Figure 4.64).

When compared with Figure 4.60 (soil strength at Ely Ouse at 0.2 m depth), these data illustrate the variability of soil strength values recorded even within the same treatments. It was therefore almost impossible to discern any meaningful trends with regard to management affecting soil strength at depth.

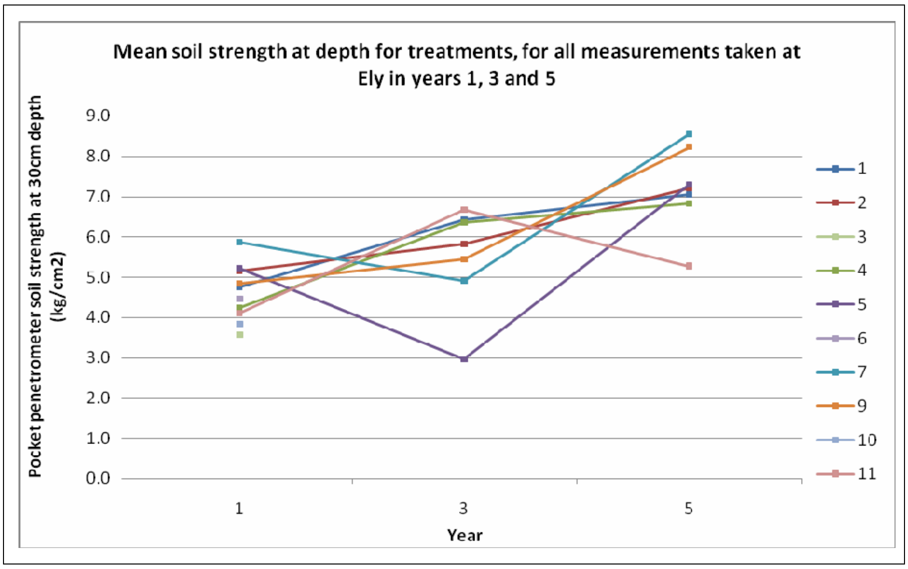

Figure 4.64 Mean soil strengths at 0.3 m depth (using a pocket penetrometer) for Ely Ouse in survey Years 1, 3 and 5.

Examination of each embankment face (from April surveys) revealed few trends for the soil strengths at depth for the treatments. The limited data available meant it was not possible to test the significance of the trends.

On the river face (Figure 4.65), soil strength at depth increased with most treatments but fell with Treatments 2, 5 and 7. Between Years 3 and 5, soil strength at depth increased with all treatments apart from Treatments 1 and 11. Treatments 7 and 9 showed the most marked increase in soil strength.

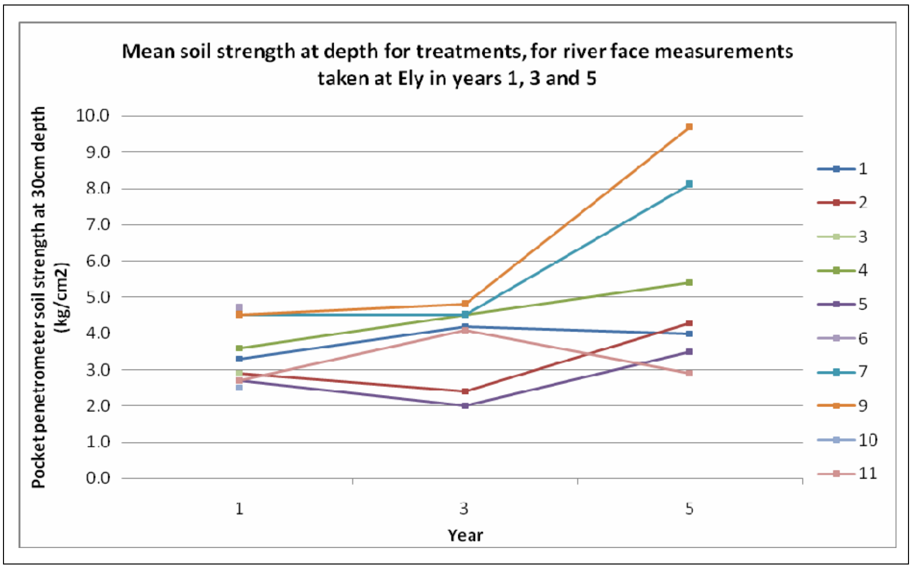

Figure 4.65 Soil strengths at 0.3 m depth (using a pocket penetrometer) for the river face of the embankment at Ely Ouse in survey Years 1, 3 and 5.

On the embankment crest (Figure 4.66), soil strength at depth increased with all treatments between Years 1 and 3 apart from Treatments 5 and 7 (the same trend found for surface strength). Treatment 11 showed the greatest increase in soil strength at depth. Between Years 3 and 5, soil strength at depth increased with all treatments except Treatment 9 where it decreased. Treatment 5 showed the greatest increase in soil strength.

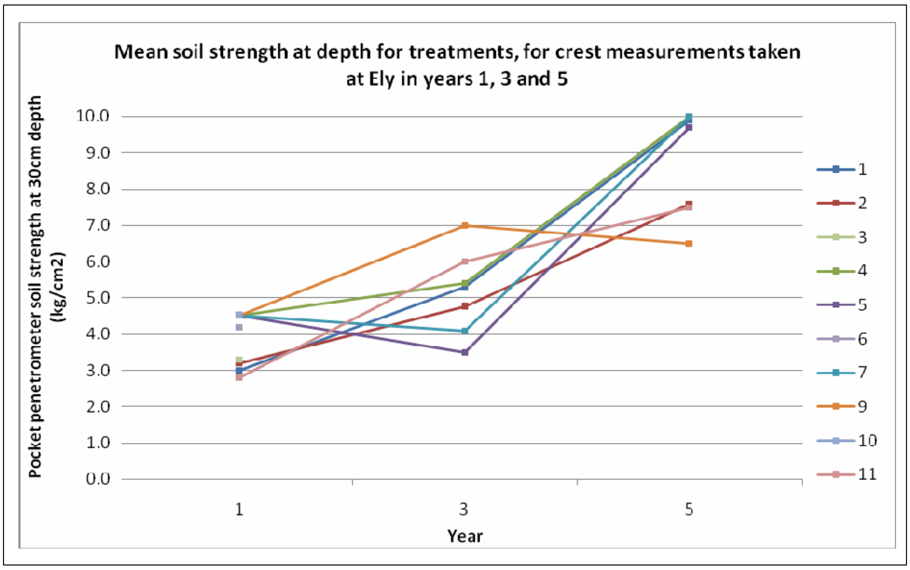

Figure 4.66 Soil strengths at 0.3 m depth (using a pocket penetrometer) for the crest of the embankment at Ely Ouse in survey Years 1, 3 and 5.

On the landward face of the embankment (Figure 4.67), soil strength at depth increased between Years 1 and 3 with most treatments and decreased with Treatments 5 and 9. Treatment 4 showed the greatest increase in soil strength. Between Years 3 and 5, there was a further increase in soil strength at depth, with the exception of Treatment 1 where it decreased. Treatment 9 showed the greatest increase in soil strength.

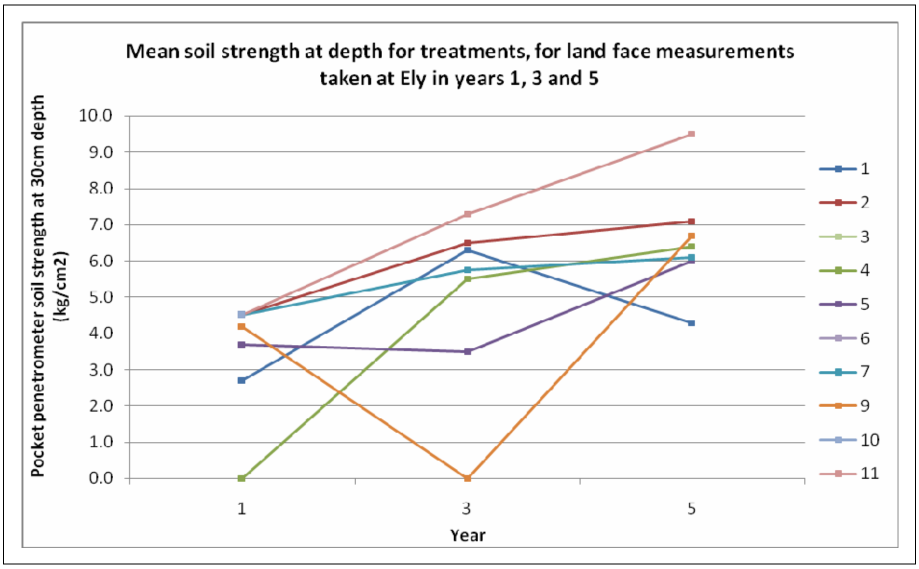

Figure 4.67 Soil strengths at 0.3 m depth (using a pocket penetrometer) for the landward face of the embankment at Ely Ouse in survey Years 1, 3 and 5.

4.4.3 Summary of changes over time

No significant differences were found in the changes over time (from Years 1 to 5) of nutrient status, organic matter or root content between treatments (for all sites combined) as described in Section 4.4.1 and summarised in Table 4.22.

- On average, phosphorus, magnesium and nitrate decreased over time with all the treatments.
- On average, potassium and root content increased over time with all the treatments.
- The soil organic matter was the only factor that increased or decreased depending on the treatment. It decreased with all treatment except Treatments 10 and 11 where it increased over time (although this was not significant).

Table 4.22 Direction of average change (per cent) in soil status over time (survey Years 1 to 5) for treatments at all sites.

Treatment	Phosphorus	Potassium	Magnesium	Organic matter	Nitrate	Root content
1	↓	↑	↓	↓	↑	↑
2	↓	↑	↓	↓	↑	↑
3						
4	↓	↑	↓	↓	↑	↑
5	↓	↑	↓	↓	↑	↑
6						
7	↓	↑	↓	↓	↑	↑
8						
9	↓	↑	↓	↓	↑	↑
10	↓	↑	↓	↑	↑	↑
11	↓	↑	↓	↑	↑	↑

↑ = increase in soil strength ↓ = decrease in soil strength

The changes in geotechnical parameters (soil strength) over time, both on the surface and at depth, showed very few significant differences between the treatments at each of the trial sites. Most of the treatments showed a decrease in soil strength at the surface after Year 1 due to the dry conditions in this year. However, this trend was not found consistently in the soil strengths at depth. Discerning trends in the soil strength at depth within treatments was complicated not only by the presence of subterranean vole burrows, but also by the high variability of the bank substrate (particularly at Reach Lode and Ely Ouse).

Billingborough

At Billingborough, the general trend (as described in Section 4.4.2) was for surface soil strengths to decrease between Years 1 and 3 and to increase between Years 3 and 5 (though no treatments had significantly different changes from one another). At depth, the direction of change in soil strength was more variable for treatments than on the surface; strength tended to decrease between Years 1 and 3 (treatments had significantly different changes from one another, $p<0.05$) and between Years 3 and 5 (treatments had no significantly different changes from one another).

The direction of change in soil strengths at Billingborough between the trial years is summarised in Table 4.23.

Table 4.23 Direction of average change (per cent) in soil strength over time on the surface (using a proving ring penetrometer) and at depth (at 0.25 m using a hand vane) for treatments at Billingborough.

	Surface soil strength		Soil strength at depth	
Treatment	**Year 1 to Year 3**	**Year 3 to Year 5**	**Year 1 to Year 3**	**Year 3 to Year 5**
1	↓	↓	↑	↓
2	↓	↑	↓	↓
3				
4	↓	↑	↓	↓
5	↓	↑	↓	↓
6				
7	↓	↑	↑	↑
8				
9	↓	↑	↓	↑
10	↓	↑	↑	↓
11	↓	↑	↓	↑

↑ = increase in soil strength ↓ = decrease in soil strength

Reach Lode

At Reach Lode, no significant differences were found between treatments for the change in soil strength over time (as described in Section 4.4.2).

The direction of the change in soil strength is shown in Table 4.24. Surface soil strengths decreased with all treatments between Year 1 and Year 3; there was a trend for increased strength between Year 3 and Year 5. At depth, as at the surface, soil strength decreased with most treatments between Years 1 and 3. The direction of change for soil strength at depth was more variable between treatments between Year 3 and Year 5.

Table 4.24 Direction of average change (per cent) in soil strength over time on the surface (using a proving ring penetrometer) and at depth (at 0.25 m using a hand vane) for treatments at Reach Lode.

	Surface soil strength		Soil strength at depth	
Treatment	**Year 1 to Year 3**	**Year 3 to Year 5**	**Year 1 to Year 3**	**Year 3 to Year 5**
1	↓	↓	↓	↑
2	↓	↓	↓	↓
3				
4	↓	↑	↓	↓
5	↓	↓	↓	↓
6				
7	↓	↑	↑	↑
8				
9	↓	↑	↓	↓
10	↓	↑	↓	↑
11	↓	↑	↓	↓

↑ = increase in soil strength ↓ = decrease in soil strength

Ely Ouse

Generally, no significant differences were found between treatments for the change in soil strength over time at Ely Ouse; directions of change are shown in Table 4.25 (as described in Section 4.4.2). There was a decrease in surface soil strength with all treatments between Year 1 and Year 3, and an increase between Year 3 and Year 5.

The data for changes in soil strength at depth taken using the two methodologies did not correlate with each other. Therefore, both data sets were analysed individually. Hand vane soil strength tests taken at depth showed a general decrease in values from Year 1 to Year 3 and from Year 3 to Year 5 (though the latter was more variable). Unlike the hand vane, pocket penetrometer soil strength tests taken at depth showed a general increase in values from Year 1 to Year 3 and from Year 3 to Year 5 (the latter revealed significant differences between the treatments).

Table 4.25 Direction of average change (per cent) in soil strength over time on the surface (using a proving ring penetrometer) and at depth (at 0.25 m using a hand vane and at 30cm using a pocket penetrometer) for treatments at Ely Ouse.

Treatment	Surface soil strength		Soil strength at depth (hand vane)		Soil strength at depth (pocket penetrometer)	
	Year 1 to Year 3	Year 1 to Year 3	Year 1 to Year 3	Year 3 to Year 5	Year 1 to Year 3	Year 3 to Year 5
1	↓	↑	↑	↑	↑	↑
2	↓	↑	↑	↓	↑	↑
3						
4	↓	↑	↓	↓	↑	↑
5	↓	↑	↓	↓	↓	↑
6						
7	↓	↑	↓	↑	↓	↑
8						
9	↓	↑	↓	↓	↑	↑
10	↓	↑	↓	↓	↑	↑
11	↓	↑	↓	↑	↑	↓

↑ = increase in soil strength ↓ = decrease in soil strength

4.5 Comparison of geotechnical and soil biological parameters

The analysis of data over five years of trials identified remarkably few statistically significant effects of treatment, season or aspect on the geotechnical or soil biological parameters of the floodbanks. Such differences that were observed were often specific to particular embankment locations and were the result of climatic differences between years, or were not shown by the other sites.

One consistent observation was that the crests had significantly greater mechanical strength, as measured by a range of parameters, than the landward or river faces. This was most likely due to compaction from vehicle travel along the tops of the embankments. August surveys tended to have higher strength and lower soil moisture than April or June, but this pattern was not universal.

Of the soil biological parameters, there were no consistent patterns at all with soil nutrients, organic matter and root content. Only at Reach Lode did vegetation management appear to affect the level of nutrients, but each macronutrient generally showed a different reaction to particular management treatments.

Overall, therefore, the results suggest that the management regime does not strongly affect biological and geotechnical parameters. Few factors do, and these are outside the control of floodbank managers.

When change over time was examined, nearly all the soil biological and geotechnical parameters were shown to be stable, with little statistically significant change. Phosphorous, magnesium and nitrate showed slight across the board decreases, while potassium and root content showed increases.

It is generally considered that:

- where cuttings are removed, nutrients should be depleted;
- where cuttings remain, nutrients should accumulate.

The data analysis does not confirm this proposition, as there were no statistically significant differences over time between treatments that left or removed arisings.

Similarly, measures of soils' strength at the surface and at depth showed little or no significant change over time in relation to management. They also showed no significant differences between treatments over that period. There was a consistent pattern across all sites of a decline in surface strength between Years 1 and 3, with a subsequent but smaller increase between Years 3 and 5. The response was more variable at depth and without a consistent pattern.

The data indicate that, after five years, there is no evidence that key geotechnical and soil biological parameters were affected by long-term management. Rather, they are most likely determined by the material the bank is made from, its design and the construction method.

4.6 Statistical analysis of vegetation data

It is also reasonable to assume that any changes in vegetation composition and sward structure in response to management treatment were likely to be most pronounced in Year 5 of the trials (i.e. the maximum amount of time under each management technique). However, it is also important to consider

- whether the vegetation on the embankment was naturally variable even in Year 1;
- whether there has been a consistent change in the vegetation over the course of the trials depending on the treatment received.

Therefore, this section concentrates firstly on analysis of the Year 5 vegetation data to identify interactions and differences under each management treatment, across each embankment face and between survey months. Year 1 data are used to assess if these differences are in response to management and Year 3 data are used to assess if these changes follow a steady trend with regard to species composition.

The TWINSPAN ordination package (WINTWINS software, version 2.3) was used initially to separate out groups of similar vegetation recording plots within each site, based on their floristic composition during the June survey[4] and irrespective of management technique.

The divisions made were subjected to Principal Component Analysis (PCA)[5] (using Canoco 4.5 software) to confirm whether the TWINSPAN divisions were meaningful.

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[4] This month was considered to be the optimal month for analysis of the three when surveys were made because the majority of species present would be showing at this time.

Each division was then examined by eye as a final confirmation that the divisions made were sufficiently distinctive to be identified on the ground and to construct synoptic tables (i.e. summaries of the principal species and their frequency within each community).

Multifactor ANOVAs (analysis of variance) were conducted (using StatGraphics Centurion software version XV professional edition) for each site independently, using treatment and TWINSPAN communities as defining factors.

In this way, sites that showed more than one plant community occurring in a single treatment could be analysed to establish whether certain plant communities were related to other sward variables such as the extent of bare ground, bryophyte cover or plant species-richness.

This section also attempts to assess the diversity of plant species recorded. In studies where direct numbers of individuals were counted, Simpson's Diversity Index and Shannon's Diversity Index can be calculated using the formulae given in the boxes below.

Simpson's Diversity Index

$$D = \sum_{i=1}^{S} p_i^2.$$

where p_i is the fraction of all organisms belonging to the i[th] species.

If n_i is the number of individuals of species i counted and N is the total number of all individuals counted, then the formula below is an estimator for Simpson's index for sampling without replacement:

$$\sum_{i=1}^{S} \frac{n_i(n_i - 1)}{N(N - 1)}$$

Shannon's Diversity Index:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where p_i is the fraction of individuals.

But because plant species data were in the Domin format (i.e. a value of 1–10 based on an estimate of the percentage cover of each species; Table 2.3), some manipulation of the data was required before these diversity indexes could be applied.

For the purposes of this report, each Domin value was replaced by the median percentage cover for that class, and this number was taken to be the 'number of individuals' needed to apply Simpson's and Shannon's Diversity Indices.

Although this method provides a useful rough approximation for the purposes of comparing treatments in this trial, it does not strictly follow the specified usage of these diversity

[5] Detrended Correspondence Analysis was initially performed but found to be inappropriate due to the low values for the length of gradient achieved.

indicators and therefore the results given in this report should not be compared with other diversity indicator values outside of this study.

As an addition to the directly recorded soil biological variables, Ellenberg Indicator Values were used to indicate soil pH, moisture, light and nitrogen levels under each treatment. Ellenberg has defined a set of indicator values for a wide range of vascular plants. Table 4.26 outlines how the indicator values have been assigned. These values, if applied to sample data, can help to explain the environment in which the vegetation is found, reducing the need to directly record variables. They are particularly useful because they represent what conditions the vegetation is exposed to during the plant's lifetime, rather than a snapshot picture provided by limited soil sampling.

Table 4.26 Guide to Ellenberg's Indicator Values[1].

Ellenberg Indicator[2]	Description
Light	
1	Plant in deep shade.
3	Shaded plant, mostly less than 5% relative illumination (e.g. *Mercurialis perennis*).
5	Semi-shade plant, rarely in full light, but generally with more than 10% relative illumination when trees are in leaf (e.g. *Primula vulgaris*).
7	Plant generally in well-lit places, but also occurring in partial shade (e.g. *Arrhenatherum elatius, Poa trivialis*).
9	Plant in full light, found mostly in full sun (e.g. *Poa compressa*).
Moisture	
1	Indicator of extreme dryness, restricted to soil that often dries out for some time (e.g. *Koeleria vallesiana*).
3	Dry-site indicator, more often found on dry ground than in moist places (e.g. *Centaurea scabiosa*).
5	Moist-site indicator, mainly on fresh soils of average dampness (e.g. *Anthriscus sylvestris*).
7	Dampness indicator, mainly on constantly moist or damp, but not wet soils (e.g. *Ranunculus repens*).
9	Wet-site indicator, often on water-saturated, badly aerated soils (e.g. *Myosotis scorpioides*).
10	Indicator of shallow water sites that may lack standing water for extensive periods (e.g. *Typha latifolia*).
11	Plant rooting under water, but at least for a time exposed above, or plant floating on the surface (e.g. *Lemna minor*).
12	Submerged plant.
Reaction (pH)	
1	Indicator of extreme acidity, never found on weakly acid or basic soils (e.g. *Ulex minor*).
3	Acidity indicator, mainly on acid soils, but exceptionally also on nearly neutral ones (e.g. *Galium saxatile*).
5	Indicator of moderately acid soils, only occasionally found on very acid or on neutral to basic soils (e.g. *Cirsium palustre*).

Ellenberg Indicator[2]	Description
Light	
7	Indicator of weakly acid to weakly basic conditions; never found on very acid soils (e.g. *Phleum pratense*).
9	Indicator of basic reaction, always found on calcareous or other high pH soils (e.g. *Primula farinose*).
Nitrogen	
1	Indicator of extremely infertile sites (e.g. *Agrostis curtisii*).
3	Indicator of more or less infertile sites (e.g. *Centaurea scabiosa*).
5	Indicator of sites of intermediate fertility (e.g. *Trifolium pratense*).
7	Plant often found in richly fertile places (e.g. *Stellaria media*).
9	Indicator of extremely rich situations, such as cattle resting places or near polluted rivers (e.g. *Rumex obtusifolius*).

Notes [1] Adapted from Hill et al. (1999)
[2] Values 2, 4, 6 and 8 all represent intermediate conditions between the numbers shown above.

Where average Ellenberg Indicator Values are given in this report for a community (e.g. in the synoptic tables for each site), the value assigned for each species has been weighted (using its abundance) to given an overall value for each replicate.

Comparison of the Ellenberg Indicator Values for soil pH, soil moisture and soil nitrogen levels with measured data on these variables within the soil recording plots proved interesting. There was no significant correlation (at $p<0.05$) between the Ellenberg Indicator Values and the measured variables. In fact, the Ellenberg Indicator Values showed considerably greater numbers of correlations with other variables (e.g. cutting frequency, vegetation height and vegetation composition) than, for example, the measured data on macronutrient levels.

One possible explanation for this is that the Ellenberg Indictor Values reflect environmental conditions before the trials began, while actual measured soil data reflect recent changes in the environment. However, the more likely explanation is that taking a single 0.07 m diameter sample of soil on each aspect of the bank for biological testing twice a year was inadequate to reflect overall conditions on the bank because of natural variability in the bank substrate. In contrast, the Ellenberg Indicator Values infer conditions throughout the year across a stretch of bank 3 m × 6 m long (i.e. three vegetation recording plots) and are therefore much more likely to show average conditions.

4.6.1 Billingborough

Floristic composition

The plant species list for Billingborough was the shortest of the three sites, limiting the effectiveness of any TWINSPAN divisions because there were so few species to work with.

The first three divisions made by TWINSPAN resulted in eight community groups.

When Principal Component Analysis (PCA) was performed on the data set, several of the community groups appeared to occupy the same space on the PCA diagram,[6] indicating that they contained only minor differences in species composition. These groups were amalgamated because examination of the individual vegetation recording plots by eye suggested there were insufficient differences in species composition between the overlapping groups. The result was that only four distinctive communities were identified (A, B, D and E), with a further one community (C) representing those recording plots in an intermediate position on the PCA diagram (see Figure 4.68).

A number of vegetation recording plots were classified as 'marginal' to their assigned community where they occurred on the PCA diagram in a different location to the core recording plots for that community. In such circumstances, examination of these recording plots by eye showed that their floristic composition, although similar to the core recording plots, varied sufficiently in the presence of key characteristic species to make them intermediate between communities. It was confirmed that these 'marginal' recording plots did not represent the full suite of key characteristics for that community when the TWINSPAN ordination identified them as 'misclassified'. These recording plots have therefore not been included in the synoptic table to avoid obscuring the community's key characteristics.

A synoptic table (Table 4.27), identical to those used in the National Vegetation Classification (NVC) system was constructed for the Billingborough data. Brief descriptions of each community are provided below.

[6] Although the first and second axis show the greatest variation between replicates and therefore are of most interest, the third axis was examined where plant communities appeared to overlap to ensure they were not distinctive on different axes.

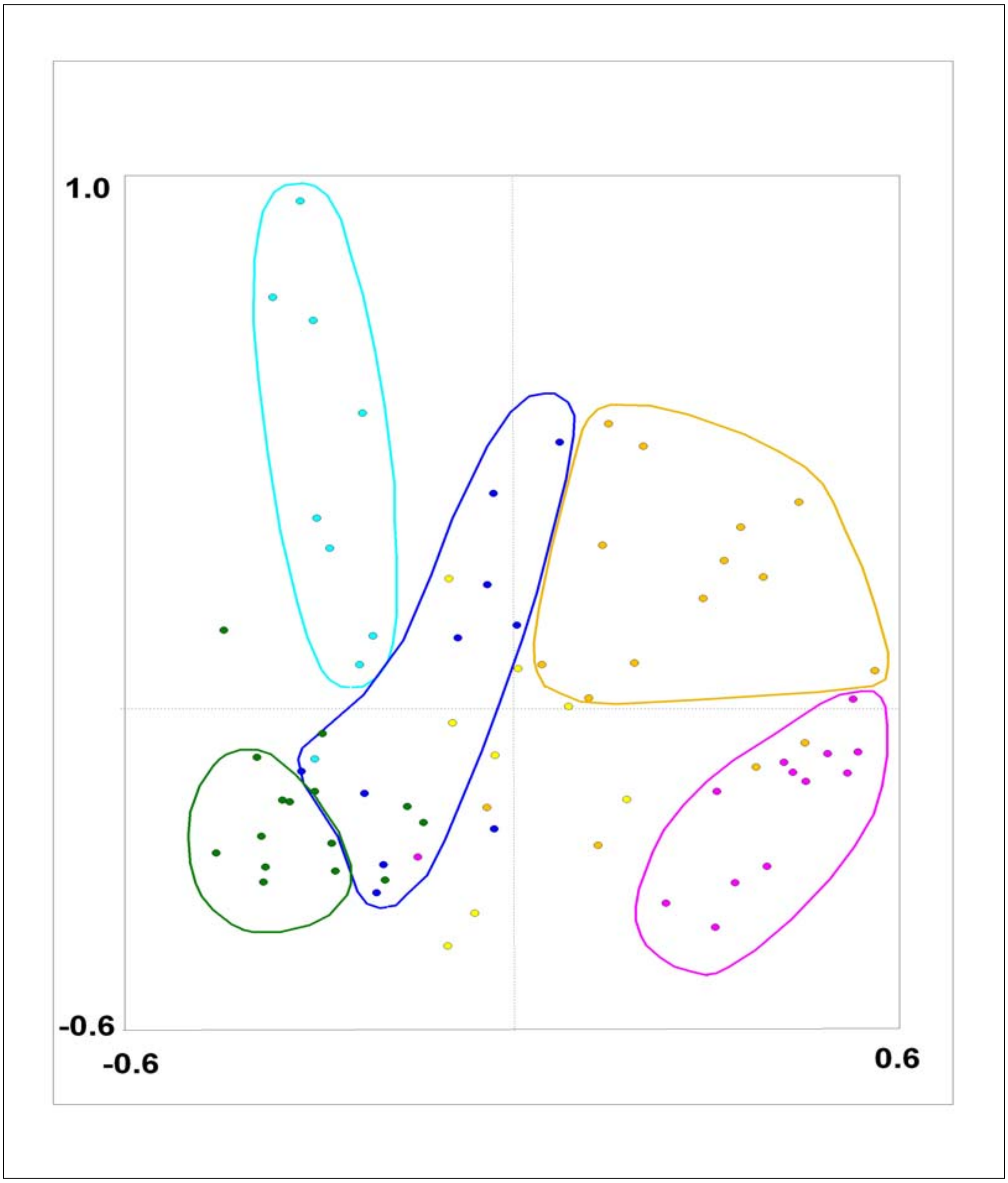


Figure 4.68 PCA diagram of vegetation recording plots for Billingborough using June data from Year 5 (showing axes 1 and 3)

Samples are represented by dots (Community A = green, B = light blue, C = dark blue, D = orange, E = pink). Yellow dots are a TWINSPAN division that was found on further examination to be floristically indeterminate. Coloured lines represent the core zone occupied by that community.

Table 4.27 Synoptic table for plant communities recorded at Billingborough[1].

	Plant community				
	A	B	C	D	E
Bare ground cover	24%	22%	20%	33%	26%
Bryophyte cover	8%	0%	2%	3%	0%
Leaf litter cover	34%	53%	47%	47%	61%
Aquatic litter cover	0%	0%	0%	0%	0%
Total vegetation cover	94%	98%	100%	95%	80%
Plant species-richness	13	11	11	9	9
Ellenberg Indicator Value for light	6.87	6.69	7.01	6.72	6.81
Ellenberg Indicator Value for moisture	5.22	5.11	5.26	5.35	5.16
Ellenberg Indicator Value for reaction	6.76	6.76	6.92	7.07	7.02
Ellenberg Indicator Value for nitrogen	6.57	6.53	6.69	7.28	7.06
Arrhenatherum elatius	V (4–8)	IV (5–8)	**V (5–10)**	V (4–8)	V (3–7)
Poa trivialis	**V (4–7)**	**V (4–6)**	V (3–5)	III (2–4)	I (2–2)
Dactylis glomerata	**V (4–7)**	**V (3–7)**	V (3–7)	II (2–5)	II (3–3)
Elytrigia repens	**V (4–7)**	III (3–5)	V (2–6)	IV (2–7)	III (2–5)
Anthriscus sylvestris	**V (2–5)**	III (2–4)	V (1–4)	V (2–7)	III (1–3)
Sonchus asper	**V (1–4)**	II (3–3)	IV (1–3)	II (1–3)	**V (1–5)**
Sonchus oleraceus	**V (1–3)**	–	–	–	II (2–2)
Lapsana communis	**III (1–4)**	–	III (1–4)	–	III (2–6)
Taraxacum officinale	**III (1–4)**	–	I (1–1)	–	–
Geranium molle	**II (1–3)**	**III (1–3)**	I (1–4)	–	I (1–2)
Poa pratensis	**II (2–4)**	**II (2–2)**	–	–	–
Ranunculus repens	**I (1–1)**	**I (2–2)**	**I (3–3)**	–	–
Lolium perenne	**I (6–7)**	–	I (2–2)	I (3–3)	–
Alopecurus pratensis	**I (2–2)**	–	–	–	–
Poa annua	**I (4–5)**	–	–	–	–
Trifolium campestre	**I (1–3)**	–	–	–	–
Trifolium pratense	**I (4–4)**	–	–	–	–
Senecio jacobaea	**I (1–1)**	–	–	–	–
Plantago lanceolata	**I (1–1)**	–	–	–	–
Anisantha sterilis	I (2–3)	**V (2–7)**	IV (1–5)	IV (1–4)	–
Heracleum sphondylium	III (1–5)	**IV (2–7)**	III (1–3)	II (1–2)	–
Lepidium draba	–	**IV (2–5)**	I (4–4)	–	–
Bromus hordeaceus	I (2–2)	**II (2–4)**	I (2–2)	I (3–3)	–
Glechoma hederacea	I (1–2)	**II (1–1)**	I (1–1)	–	–
Holcus lanatus	–	**II (2–6)**	–	I (2–2)	–
Rumex obtusifolius	I (1–1)	**II (1–6)**	–	I (1–1)	I (1–2)
Trisetum flavescens	–	**I (3–3)**	–	–	–
Equisetum arvense	–	**I (2–2)**	–	–	–

	Plant community				
	A	B	C	D	E
Apium nodiflorum	–	**I (2–2)**	–	–	–
Convolvulus arvensis	II (2–4)	–	**III (2–4)**	II (1–3)	**III (1–3)**
Festuca rubra	–	I (3–3)	**II (2–4)**	–	–
Persicaria maculosa	–	–	**I (3–3)**	I (2–2)	–
Triticum aestivum	–	–	**I (1–1)**	–	–
Sinapis arvensis	II (1–2)	–	**V (1–8)**	**V (2–9)**	**V (4–10)**
Galium aparine	II (1–2)	III (1–2)	IV (2–4)	**V (3–8)**	**V (1–6)**
Urtica dioica	IV (2–5)	V (2–5)	III (2–6)	**V (3–8)**	**V (2–5)**
Cirsium arvense	II (1–1)	–	I (3–3)	–	**II (1–3)**
Rubus fruticosus	–	–	–	–	**I (2–3)**
Malva sylvestris	–	–	–	–	**I (2–2)**
Papaver rhoeas	–	–	–	–	**I (2–2)**
Calystegia sepium	I (2–2)	I (2–2)	I (2–2)	I (2–2)	–
Geranium dissectum	–	–	I (2–3)	I (1–1)	I (2–2)
Lamium album	II (1–5)	I (1–1)	–	I (2–2)	I (2–3)
Picris echioides	I (2–2)	I (1–1)	–	–	I (1–1)
Stellaria media	I (1–1)	I (1–1)	–	–	I (1–1)

Notes [1] Bold text denotes characteristic species of the community.

<u>Community A</u>

This sward was characterised by the absence of a single dominant species, but instead contained mixtures of *Poa trivialis, Dactylis glomerata, Elytrigia repens* and *Arrhenatherum elatius.* Herbaceous competitive ruderals of *Sonchus asper, S. oleraceus* and *Anthriscus sylvestris* were constant but never at high abundances. This community was marked by the frequent presence of small herbs such as *Taraxacum officinale, Geranium molle* and occasionals of *Ranunculus repens, Trifolium campestre, T. pratense* and *Plantago lanceolata*. Fine-leaved grasses such as *P. pratensis, Alopecurus pratensis* and *P. annua* were also found here, making it the most species-rich of the communities recorded at Billingborough. Bryophytes were generally present in small numbers. See Figure 4.69.

<u>Community B</u>

This was a mixed sward similar to Community A, with co-dominance by *Poa trivialis, Dactylis glomerata* and *Arrhenatherum elatius*; *Anisantha sterilis* and abundant *Lepidium draba* are additional constants. This community had the greatest occurrence of *Bromus hordeaceus* and *Holcus lanatus* but also contained very occasional fine grasses of *Trisetum flavescens*, *Festuca rubra* and *P. pratensis*. Like Community A, small herbs such as *Geranium molle* and *Glechoma hederacea* also occurred in small numbers. The sward had a very high total vegetation cover and bryophytes were absent. See Figure 4.70.

<u>Community C</u>

This community can be seen as an intermediate between the *Sinapis arvensis* dominated swards of Communities D and E, and the more species-rich grassy swards of Communities A and B. Here *Arrhenatherum elatius* dominated, accompanied by constant *Poa trivialis, Dactylis glomerata* and *Elytrigia repens*. Tall herbs of *Anthriscus sylvestris, Heracleum sphondylium* and *Sinapis arvensis* were common, with *Urtica dioica* and *Galium aparine* frequent but not dominating. Very occasionally small herbs and fine grasses such as

Taraxacum officinale, Geranium molle, Festuca rubra and *Lolium perenne* could be found, but bryophytes were scarce. This community had the highest mean total vegetation cover (100 per cent). See Figure 4.71.

Community D

In this community *Sinapis arvensis* was the dominant species, with *Urtica dioica* and *Galium aparine* generally very abundant, and with an understorey of scattered *Poa trivialis.* Tall herbs such as *Anthriscus sylvestris* and *Heracleum sphondylium* were also abundant here, giving the sward a greater total vegetation cover than was recorded in Community E. Bryophytes were also recorded in very low numbers. See Figure 4.72.

Community E

Like Community D, *Sinapis arvensis* was the dominant species here, constantly accompanied by abundant *Urtica dioica* and *Galium aparine* (but at lower abundances than occurred in Community D). Other frequent associates included small amounts of *Anthriscus sylvestris, Lapsana communis, Sonchus asper, Convolvulus arvensis* and *Cirsium arvense*. Coarse grasses such as *Elytrigia repens* remained but there was a noticeable absence of fine-leaved grasses and the sward was very species-poor. No bryophytes were recorded and the sward had the lowest mean total vegetation cover recorded at Billingborough. See Figure 4.73.

Figure 4.69 Billingborough Community A, photographed on the river face of Treatment 1 in June 2007.

Figure 4.70 Billingborough Community B, photographed on the river face of Treatment 2 in June 2007.

Figure 4.71 Billingborough Community C, photographed on the landward face of Treatment 9 in June 2007.

Figure 4.72 Billingborough Community D, photographed on the landward face of Treatment 10 in June 2007.

Figure 4.73 Billingborough Community E, photographed on the river face of Treatment 11 in June 2007.

The distribution of these plant communities across the embankment is shown in Figure 4.74. It demonstrates that, where cutting frequency was low (0–1 cuts per year), the landward, river and crest faces were characterised by different communities, suggesting that the embankment face controlled this vegetation type. Community D characterised the landward face, Community C the crest and Community E the river face. But where vegetation was cut frequently (3–6 times a year), the influence of treatment overrode that of embankment face and the more species-rich, diverse swards of Communities A and B established on all these faces. Collection or leaving arisings *in situ* was not a significant factor in any treatment.

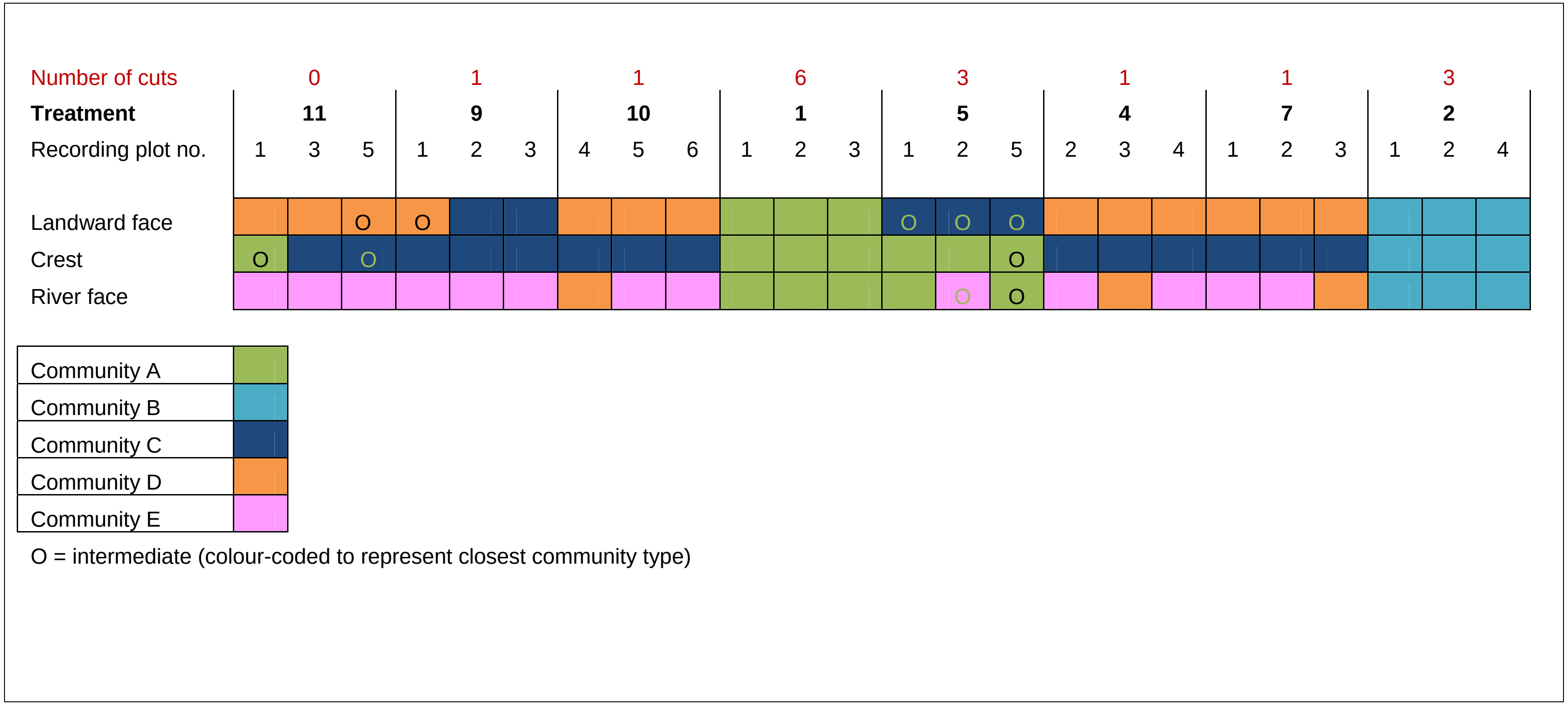
<u>Changes over time</u>

To eliminate the possibility that these plant community differences were present in Year 1 of the trials, it was necessary to establish whether there had been a change in the floristic compositions over the five years. Because no June survey was made in Year 1, information from the optimum month for a comparison of vegetation data between Years 1 and 5 was unfortunately not available. However, April surveys were conducted in both years and these data were used.

When analysing these data, it is important to note that the weather of the months preceding each vegetation survey was often crucial in determining the cover of certain species. The April survey in Year 1 was preceded by relatively little rainfall in February and March (<20 mm per month, see Figure 3.11), whereas the rainfall level in the same period in Year 5 was 40–70 mm per month. Therefore some differences in the vegetation were inevitable.[7] For this reason, Year 3 vegetation data (rainfall = 20–40 mm per month in February and March) were also included in the PCA diagram to help illustrate any transition between communities over the past five years. If rainfall was the only determining factor in a shift in vegetation composition between Years 1 and 5, it can be expected that all vegetation recording plots will move in the same direction on the PCA diagram. As this is not the case, it is reasonable to assume that another factor (i.e. management) was affecting composition.

Data from Years 2 and 4 are not included in the PCA diagram because they add little to the trends readily observable in Years 1, 3 and 5. As an example, Appendix 5 contains the PCA for Ely Ouse for all five years.

[7] The apparent shift from *Poa pratensis* in Year 1 to *P. trivialis* in all subsequent years is believed largely to be the result of misidentification in Year 1 due to the timing of the surveys. For this reason, all *P. pratensis* and *P. trivialis* records were combined into *Poa* sp. category during the PCA analysis so that no shift in replicate location would be due to this discrepancy.



Recording plot number indicates which part of the bank was monitored (i.e. which of the possible eight replicates was used).

Figure 4.74 Distributions of plant communities at Billingborough, Year 5.

The PCA diagram of species and environmental variables for Billingborough shown in Figure 4.75 can be used to interpret shifts in the following PCA diagrams of replicate data. Thus for this site:

- vegetation recording plots with a greater proportion of *Anthriscus sylvestris* and *Heracleum sphondylium* (competitive ruderals) occur in the top right corner;
- vegetation recording plots with a greater proportion of *Urtica dioica* and *Arrhenatherum elatius* (competitors) occur in the top left corner;
- vegetation recording plots dominated by *Sinapis arvensis* and *Galium aparine* (ruderals and competitive ruderals respectively) occur towards the bottom left corner;
- vegetation recording plots with a greater proportion of *Elytrigia repens* and *Anisantha sterilis* (competitive ruderals) occur in the bottom right corner.

Overlaying the values of other measured variables (e.g. bare ground cover) and estimated variables (e.g. Ellenberg Indicator Values for moisture) shows that those vegetation recording plots with a high Ellenberg Indicator Value for nitrogen occur on the left of the diagram (which also corresponds with high percentage cover values for leaf litter, even though this was at the start of the season before cutting took place). Alternatively, vegetation recording plots with high percentage covers for total vegetation occur in the lower half of the diagram.

Community A

Figure 4.76 shows the shift in vegetation within recording plots from Community A in Years 1, 3 and 5.

It illustrates that, in Year 1, vegetation that would later become one community occurred in two separate clusters on the diagram (namely the crest recording plots on the right containing more *Poa* sp. and the river and landward recording plots on the left containing more *Urtica dioica* and *Arrhenatherum elatius*).

By Year 5, the majority of recording plots had shifted towards the bottom right corner, the extent of which depended on their starting positions. This area of the diagram represents those recording plots with higher species-richness values and greater Ellenberg Indicator Values for light.

Community A is felt to represent a meaningful shift in vegetation composition.

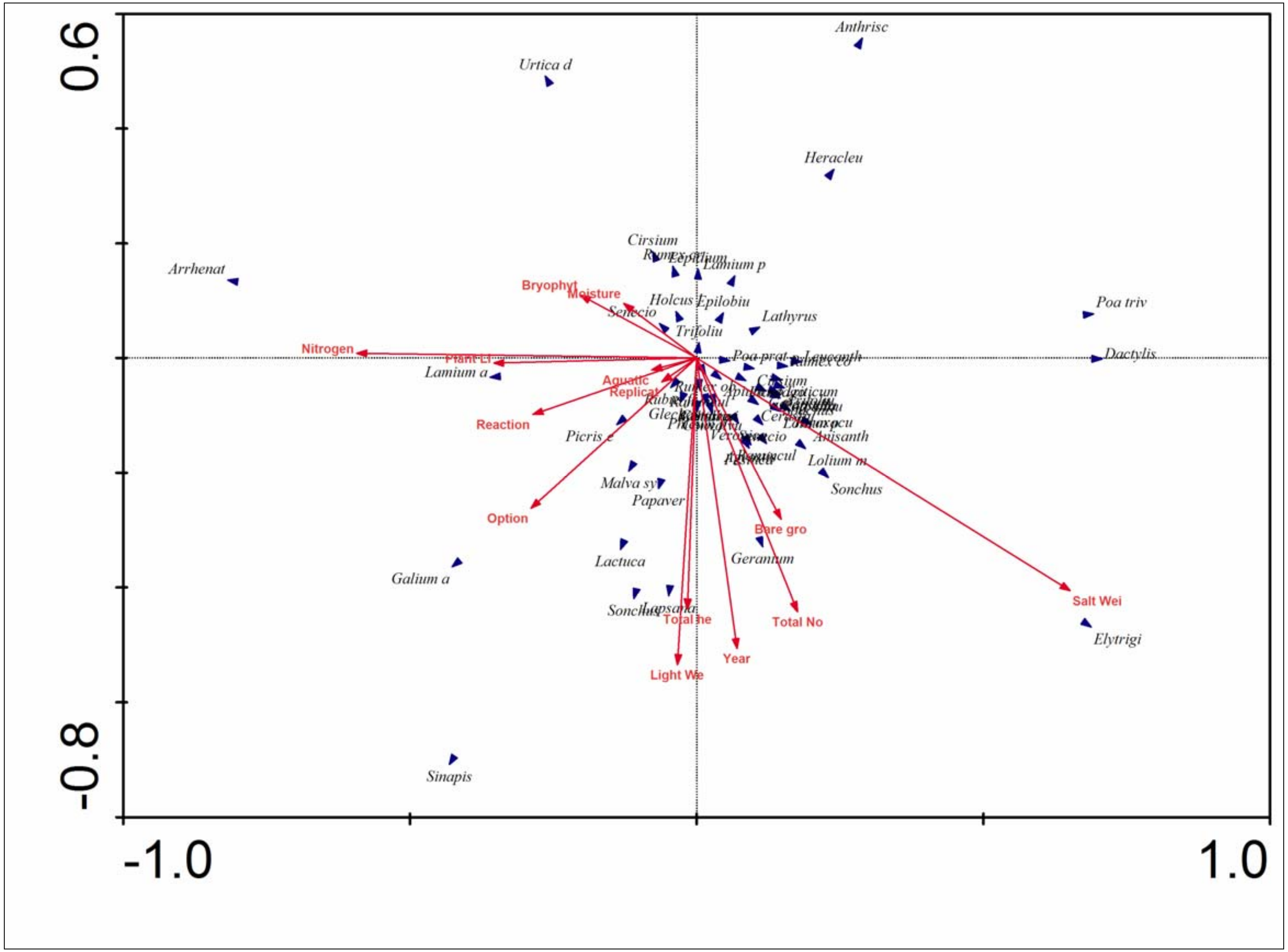


Figure 4.75 PCA diagram of vegetation data from April, Years 1, 3 and 5 at Billingborough – showing species and variables.

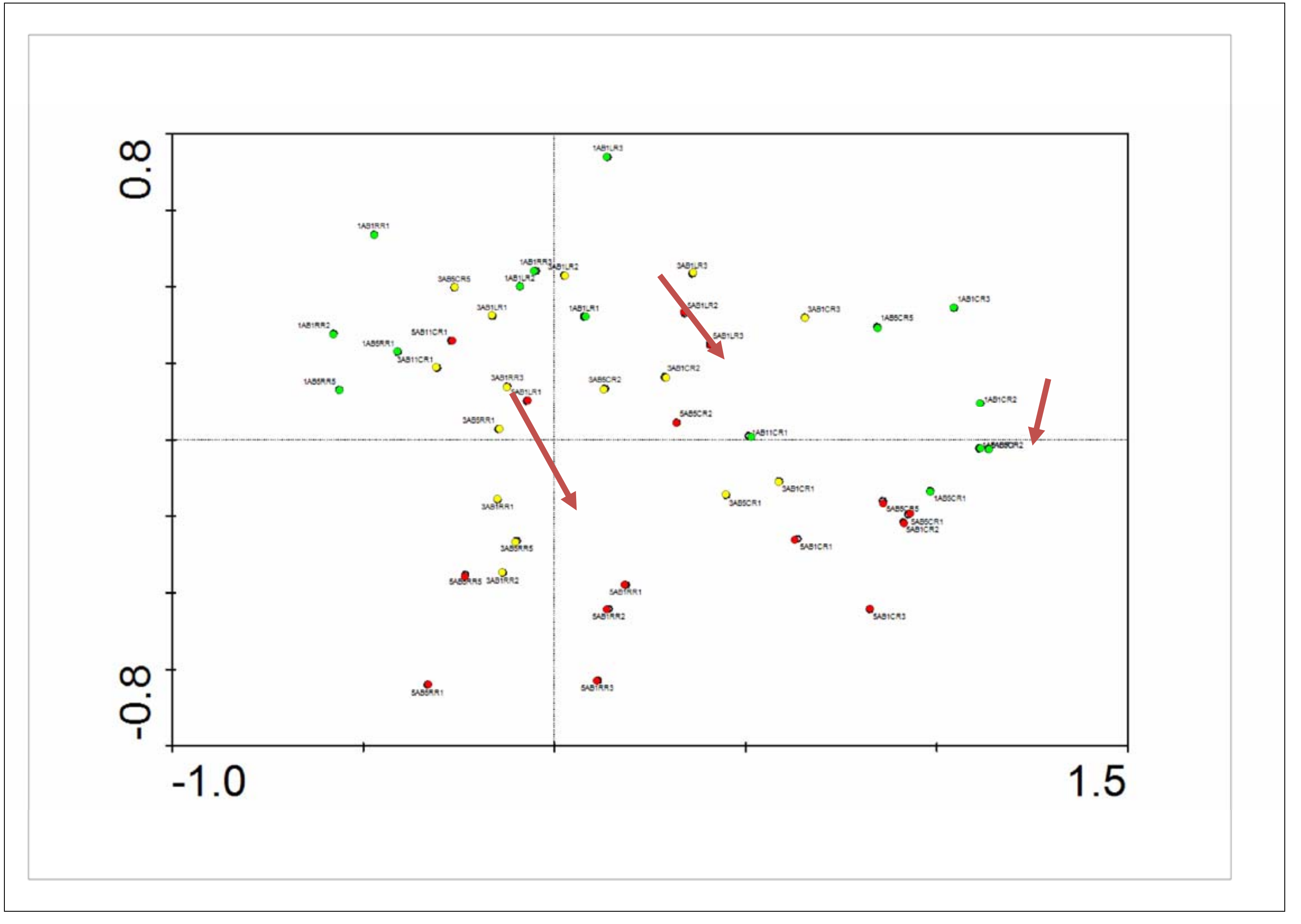


Figure 4.76 PCA diagram of April vegetation data at Billingborough for Community A in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Community B

Figure 4.77 shows the shift in Community B vegetation recording plots during the trials. Here a much clearer shift in recording plot location towards the bottom right corner of the diagram is evident (with some of the crest recording plots in Year 3 temporarily located in the extreme right of the diagram). Thus, like Community A, these recording plots moved towards a greater species-richness and higher percentage cover of bare ground.

Community B is felt to represent a meaningful shift in vegetation composition.

Community C

Figure 4.78 shows the shift in vegetation of recording plots from Community C in Years 1, 3 and 5. Although this is an intermediate community, with Year 1 recording plots scattered across the diagram, there is a general shift towards the bottom right corner by Year 5 (with some recording plots already in this area by Year 3). Interestingly, this community occurred where cutting was no more than once a year. Therefore the shift towards a more species-rich part of the diagram must in part be due to a low species count in the first year (possibly due to drier conditions).

Community C may represent a meaningful shift in vegetation composition, but one which may in part be due to climatic conditions.

Community D

Figure 4.79 shows the location of vegetation recording plots in Years 1, 3 and 5 classified as Community D. There was no consistent shift in vegetation by Year 5, with some replicates moving towards the bottom right while others moved towards the bottom left. This community occurred only in recording plots cut no more than once a year and typically on the landward face. It is therefore possible that a second factor was influencing some of the recording plots.

Community D is not felt to exhibit a meaningful shift in vegetation composition.

Community E

Figure 4.80 shows the shift in Community E recording plots during the trials. There is a clear shift of recording plots towards that part of the diagram indicative of *Sinapis arvensis* dominance. Some recording plots show a considerable change in their floristic composition to reach this point of the diagram, while others were already located in this area in Year 1.

Community E is felt to represent a meaningful shift in vegetation composition.

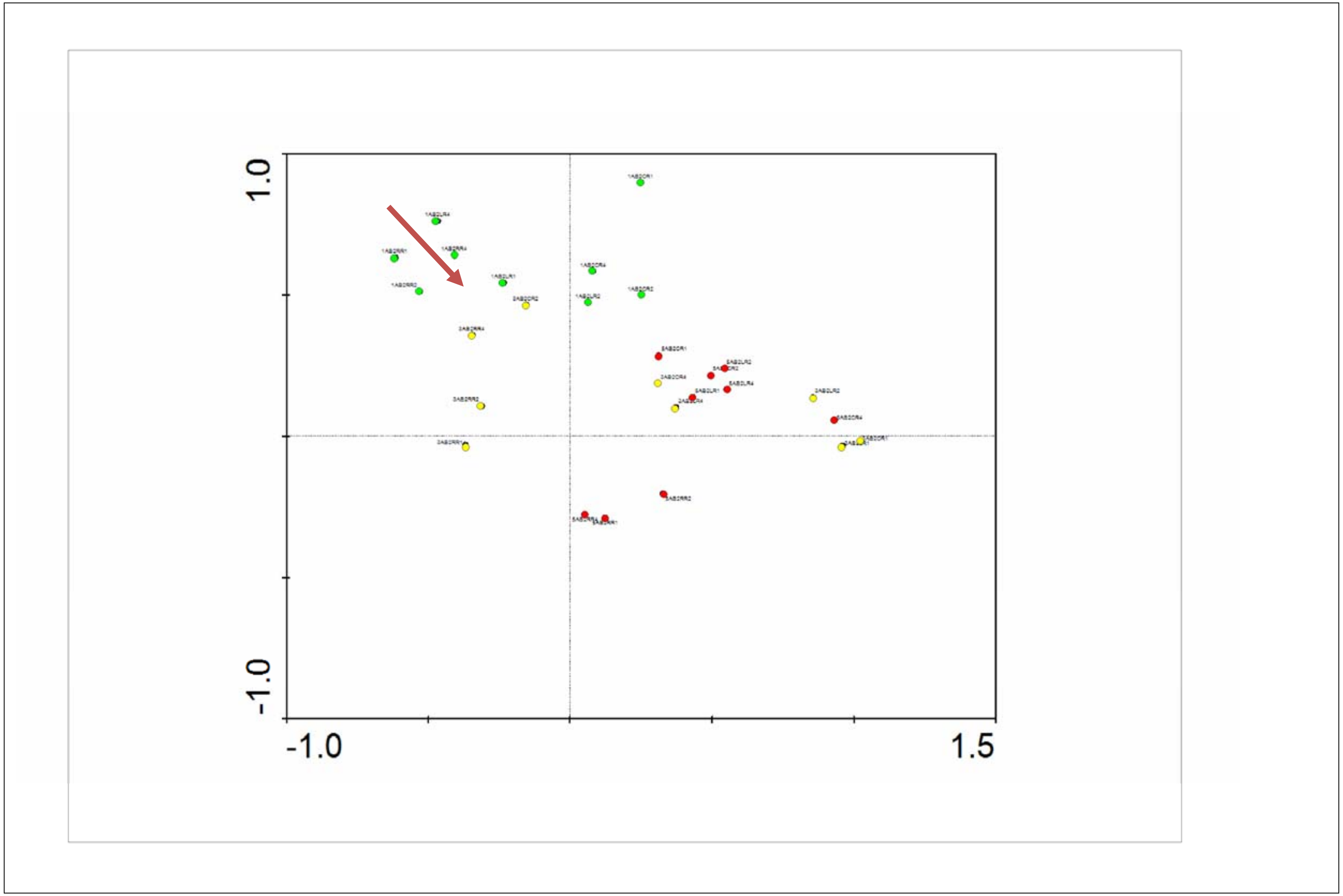


Figure 4.77 PCA diagram of April vegetation data at Billingborough for Community B in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

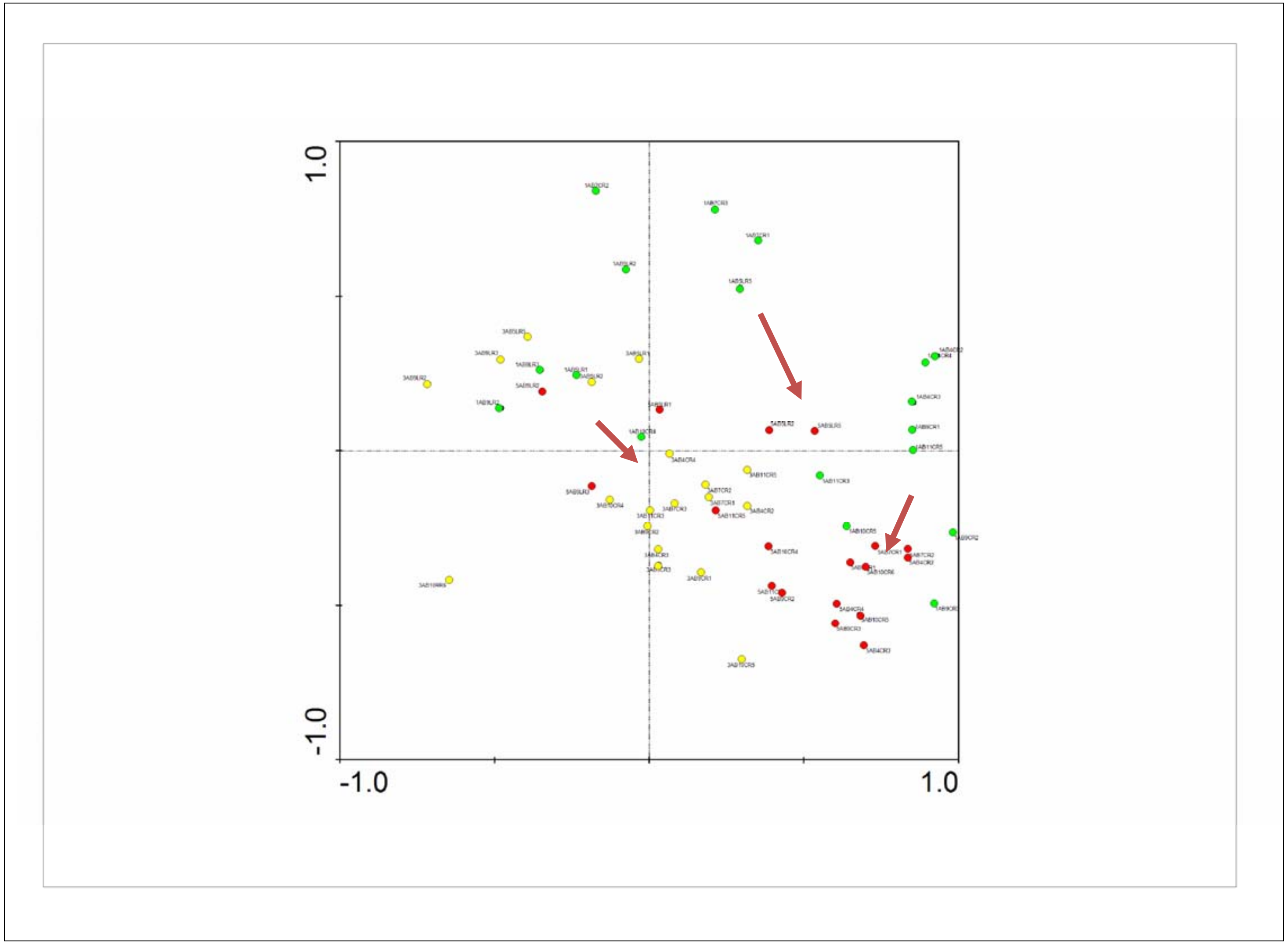


Figure 4.78 PCA diagram of April vegetation data at Billingborough for Community C in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

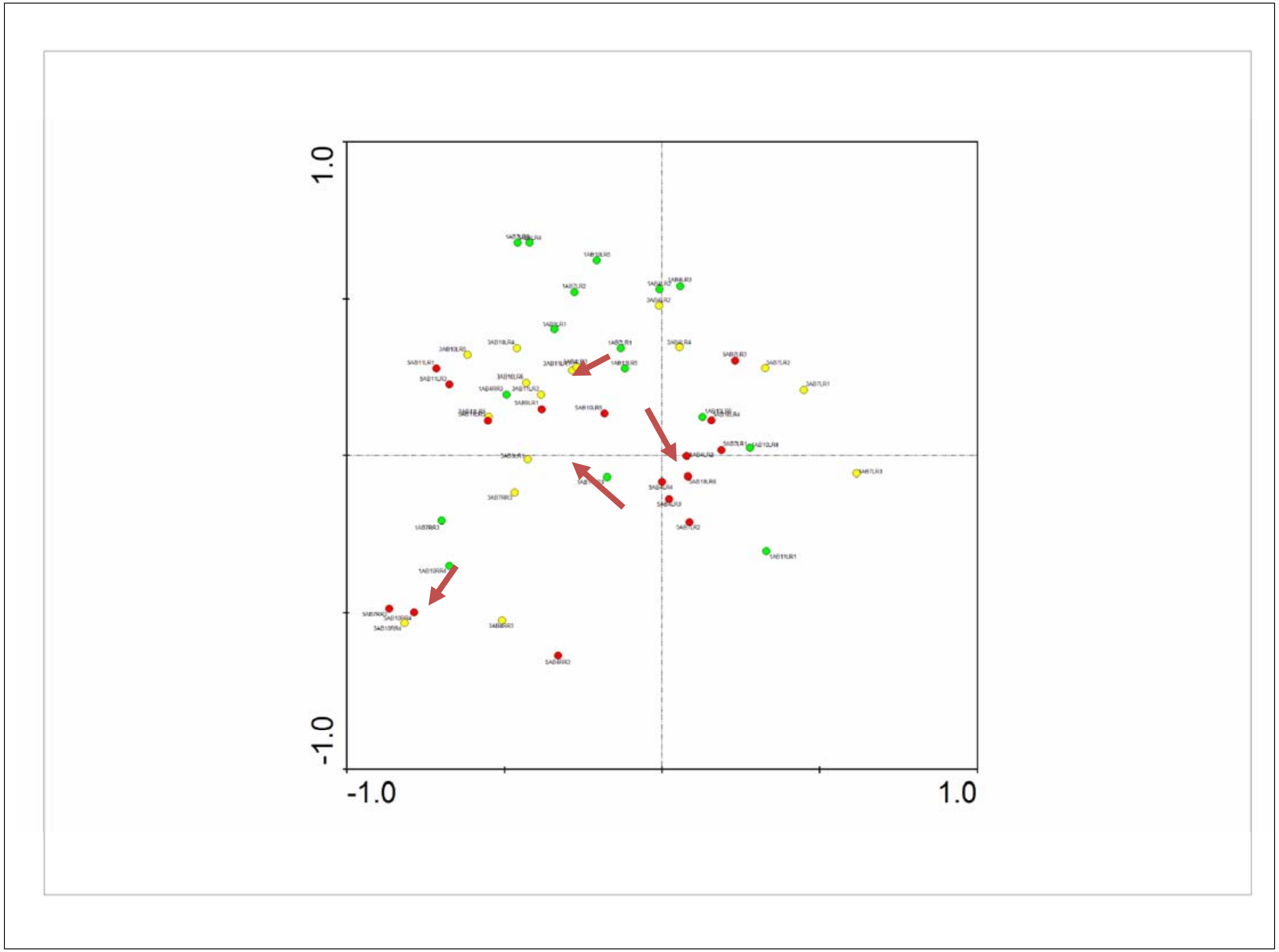


Figure 4.79 PCA diagram of April vegetation data at Billingborough for Community D in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

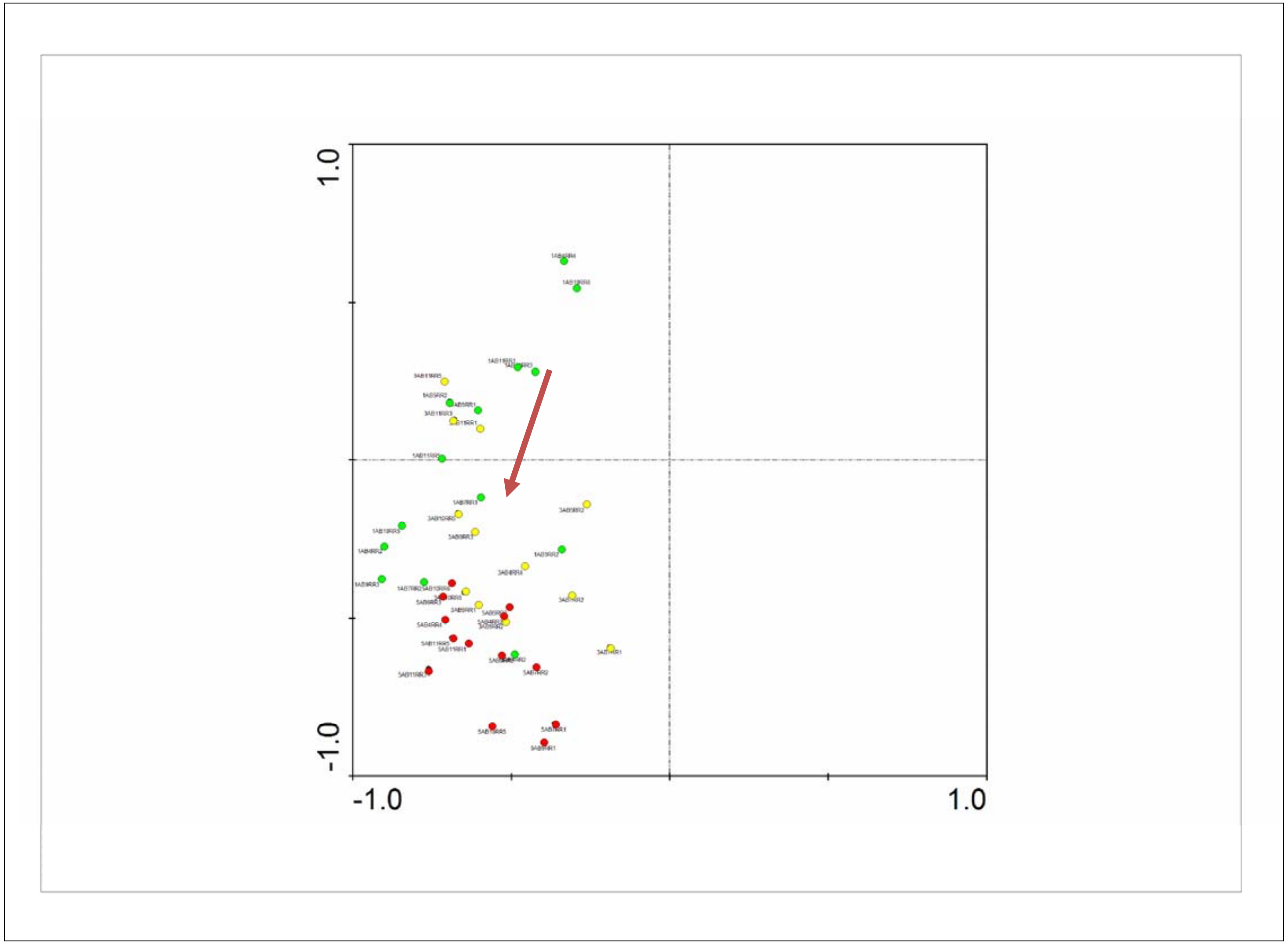


Figure 4.80 PCA diagram of April vegetation data at Billingborough for Community E in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Plant species-richness

A significant difference ($p<0.05$) was found in the species-richness (i.e. the number of species in each recording plot) recorded at Billingborough in relation to treatment. Treatment 1 (cut six times a year) had a significantly higher species-richness than all other treatments, while the species-richness of Treatment 2 (cut three times a year with arisings left on) was significantly higher than Treatments 5, 7, 9 and 10. Treatment 11 (control) had significantly lower species-richness than all other treatments (Figure 4.81).

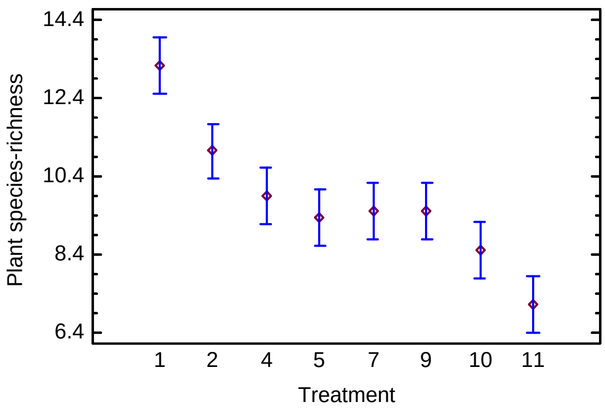


Figure 4.81 Mean plant species-richness of vegetation recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Significant differences ($p<0.05$) were also recorded in the plant species-richness between embankment faces (Figure 4.82) and between survey months (Figure 4.83):

- Both the crest and river faces were significantly more species-rich than the landward face.
- The August survey recorded significantly lower species-richness than the April or June surveys (due to many plants having their main growth period in late spring and early summer).

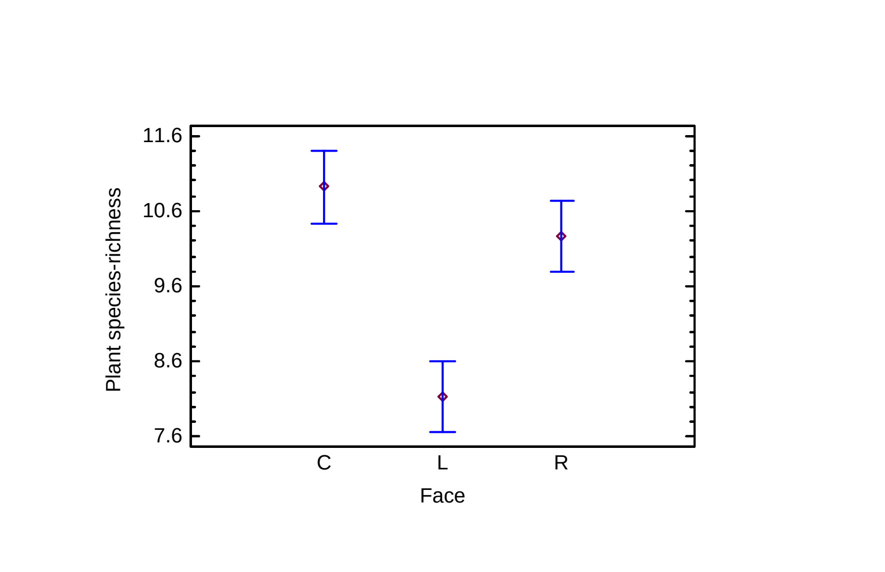


Figure 4.82 Mean plant species-richness of vegetation recording plots for embankment faces at Billingborough, Year 5.

Bars represent least significant differences (LSD).
C= crest, L= landward, R= river face

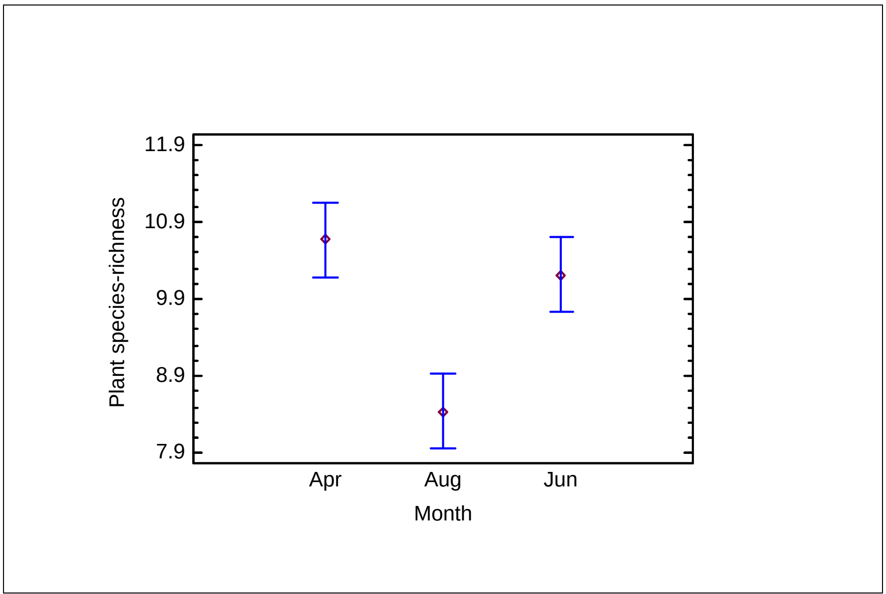


Figure 4.83 Mean plant species-richness of vegetation recording plots for survey months at Billingborough, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

All the recording plots appeared to increase in species-richness by Year 5 regardless of whether they received one or three cuts per year. The greatest increase was seen in Treatments 1, 2 4 and 10 (1–6 cuts per year) (Figure 4.84). The data show that there were meaningful differences in plant species-richness between some of the treatments in Year 5 which were not established in Year 1. However, the species-richness in all vegetation recording plots (regardless of treatment) was lower in the Year 1 baseline than all subsequent years. One explanation for this could be that the dry conditions preceding the

April survey in Year 1 meant that fewer species had emerged by this time and species identification was harder. Alternatively, the difference in species-richness may be due to different surveyors used in the first year.

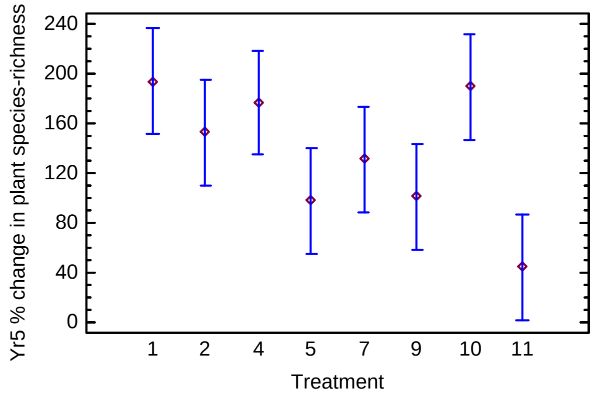


Figure 4.84 Percentage change of mean plant species-richness between Years 1 and 5 for treatments at Billingborough.

Bars represent least significant differences (LSD).

Plant species diversity[8]

Both Simpson's Diversity Index and Shannon's Diversity Index were calculated for all vegetation recording plots. But because of the high level of consistency between the results of the two approaches, only those with Shannon's Diversity Index are shown here.

Analysis showed that Treatment 1 had significantly higher diversity values than all other treatments (with the exception of Treatment 2). Treatments 4–9 all had similar plant diversity values, while Treatment 11 showed significantly lower diversity values than all other treatments (Figure 4.85).

This is a similar pattern to that observed in plant species-richness for Billingborough. Thus, tests on diversity in relation to survey month, embankment face and changes over time are presumed to be similar to the results of plant species-richness.

[8] Species diversity takes into account the abundance of each species as well as the number of species. Therefore a species that occurs only once in a sward adds little to its diversity.

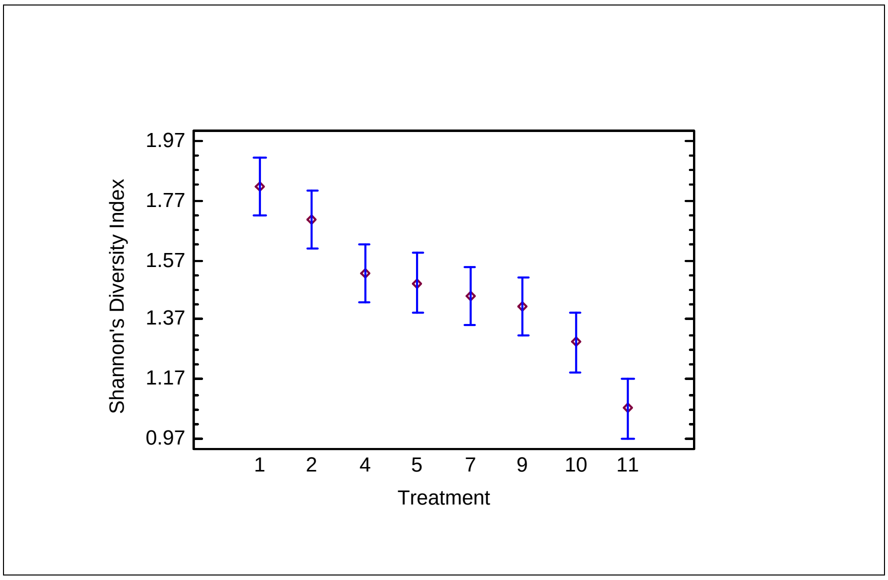


Figure 4.85 Mean plant diversity values (using Shannon's Diversity Index) of vegetation recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

When analysed in terms of plant community type, Communities A and B were found to have significantly higher ($p<0.05$) plant diversity values than Community C, with Community D and E showing significantly lower diversity values than all other communities (Figure 4.86).

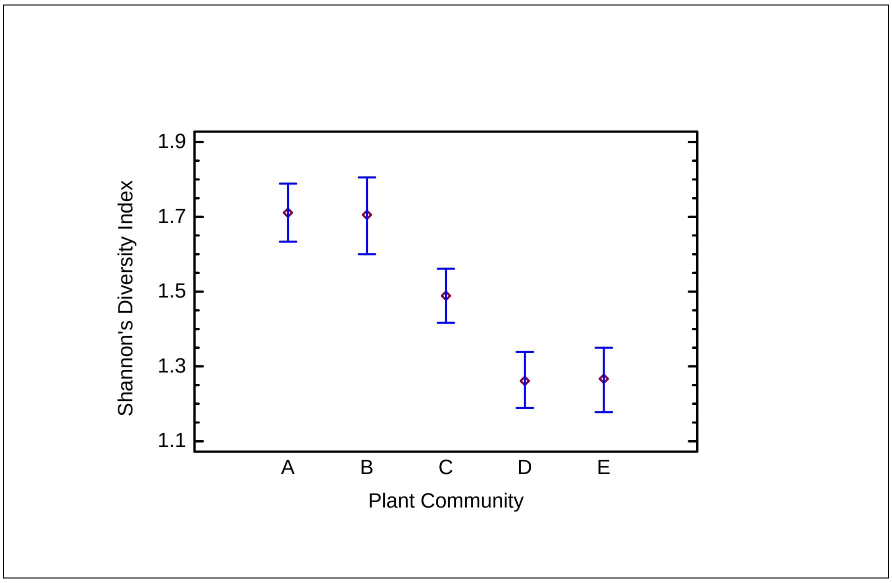


Figure 4.86 Mean plant diversity values (using Shannon's Diversity Index) of vegetation recording plots for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Leaf litter cover

When leaf litter cover was analysed against treatment (Figure 4.87), Treatment 11 (control) was found to have significantly higher ($p<0.05$) leaf litter cover than Treatments 1, 4, 5 and

7; Treatments 1 and 5 in particular had significantly lower mean leaf litter cover values than all other treatments.

One explanation for the low percentage cover of leaf litter found in Treatment 1 is that the finer grasses found on a bank cut six times a year took less time to decompose after cutting. Treatment 5 showed low cover of leaf litter because the treatment included the collection of arisings after cutting. Treatment 7, which also included the collection of arisings, did not exhibit the same low leaf litter cover values because cutting/collection did not take place until August.

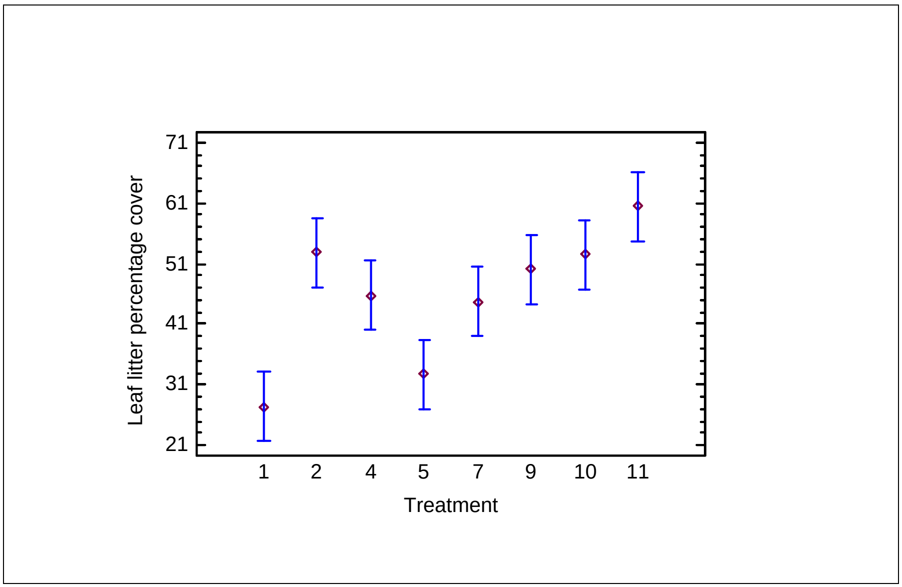


Figure 4.87 Mean leaf litter percentage cover of vegetation recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Leaf litter cover was also found to be significantly higher in August and significantly lower in April ($p<0.05$). However, no significant difference was found between leaf litter cover and the different embankment faces ($p<0.05$).

In terms of plant communities (Figure 4.88), only Community A was found to have a significantly lower ($p<0.05$) leaf litter cover value than the other communities. This suggests that high leaf litter cover in June did not always correspond with only the species-poor communities but that low percentage cover of leaf litter corresponded with the greatest chance of a species-rich vegetation.

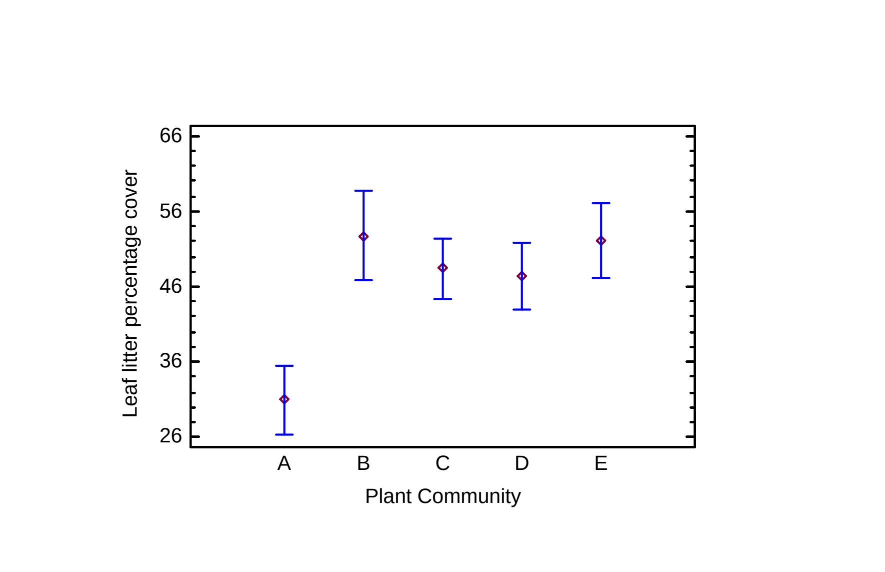


Figure 4.88 Mean leaf litter percentage cover of vegetation recording for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

As only April data were available for Year 1 to 5 comparisons, any difference between treatments is likely to be underestimated in the analysis because none of the treatments would have received a cut by this stage (and therefore had arisings removed in that survey year, etc.). The April results are therefore indicative of the sum of previous management (if any).

However, comparisons of the percentage change between Years 1 and 5 did show that Treatment 1 had experienced the greatest reduction in leaf litter cover by Year 5, at significantly different ($p<0.05$) levels to that of Treatments 2, 10 and 11 (Figure 4.89). Treatment 11 (control) was the only treatment to show a substantial increase in leaf litter cover by Year 5, at significant levels to almost all other treatments ($p<0.05$).

Thus there are meaningful differences in leaf litter cover between treatments in Year 5 which were not established in Year 1.

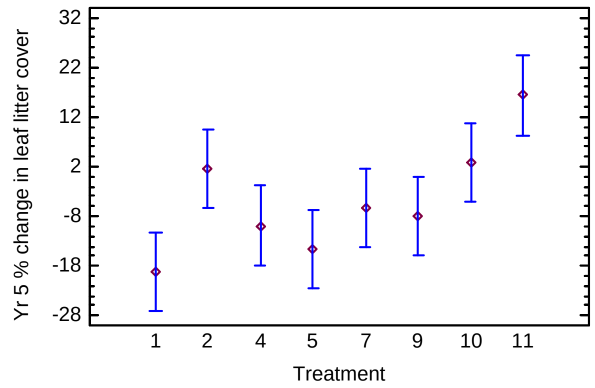


Figure 4.89 Percentage change of mean leaf litter cover between Years 1 and 5 for treatments at Billingborough.

Bars represent least significant differences (LSD).

Bare ground cover (percentage)

Analysis showed that Treatments 4 and 7 had significantly higher ($p<0.05$) bare ground percentage cover than Treatments 2 and 11 in June. The absence of difference between Treatments 4 and 7 (which both received one cut but only Treatment 7 incorporated the removal of arisings) was due to the cut not taking place until September. Treatments 1, 5, 9 and 10 all had moderate coverage of bare ground, despite some considerable variation in the cutting regimes of these treatments and Treatment 5 including arising removal (Figure 4.90).

A significant difference ($p<0.05$) was also found between the three survey months and the percentage cover of bare ground; it was highest in April (before any cutting had taken place) and lowest in August. This was due to two factors.

- Leaf litter cover is higher in August than in April and therefore the extent of bare ground will be at least partially obscured by the litter. This does not mean that bare ground is not present under the leaf litter in August.
- The extent of total vegetation cover would be expected to increase during the summer, thus limiting the extent of bare ground.

No significant difference (at $p<0.05$) was recorded between bare ground cover values across the embankment faces (despite the river face mean value being marginally higher than the other two faces). This higher cover of bare ground on the river face was likely to be a response to the greater abundance here of *Sinapis arvensis*, a species which puts on considerable vertical growth in spring (shading out shorter species) and then begins to die back in late July/early August, exposing large patches of bare ground.

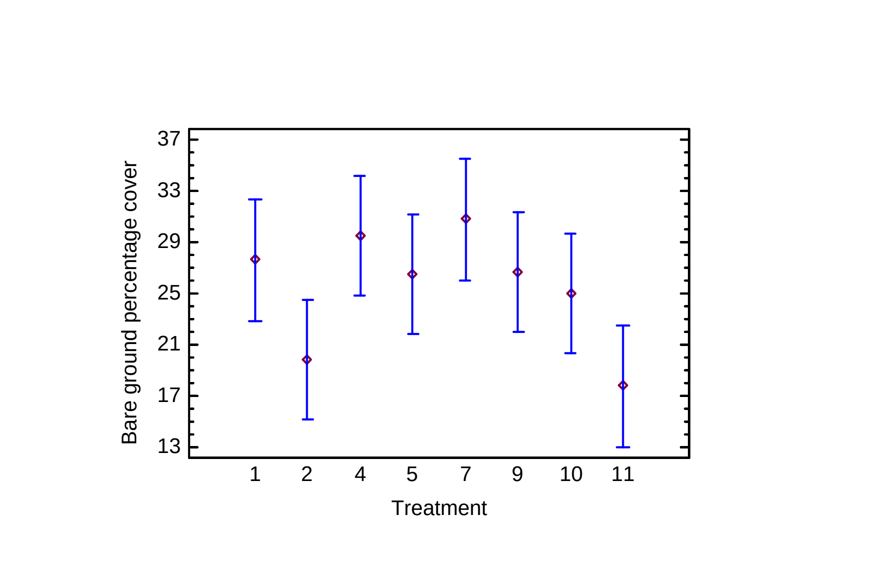


Figure 4.90 Mean bare ground percentage cover of replicates for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

When the data were analysed in terms of plant communities (Figure 4.91), Communities B and C were found to have significantly ($p<0.05$) less bare ground cover than Communities D and E (which contained higher abundances of *Sinapis arvensis*), with Community A on the margins of significance.

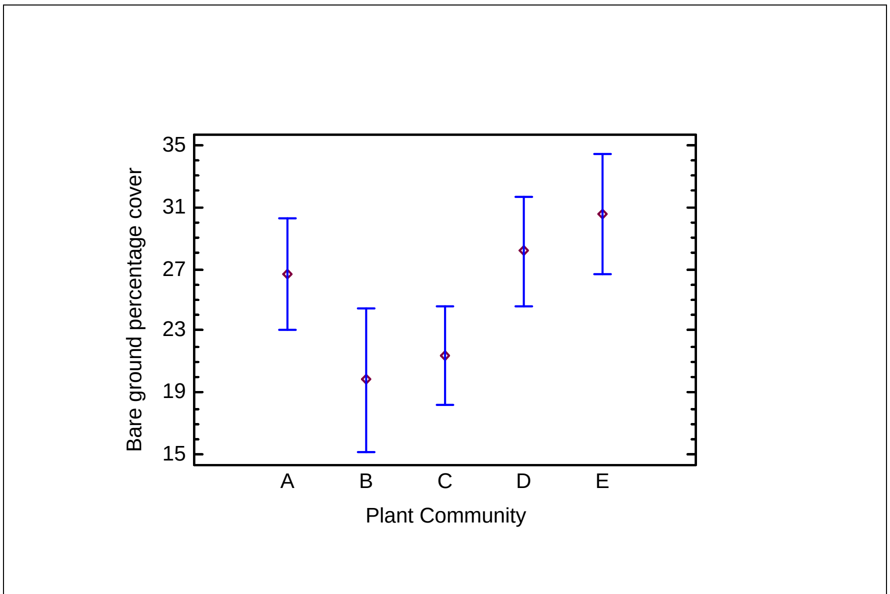


Figure 4.91 Mean bare ground percentage cover of vegetation recording plots for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

Once again, only April data were available for Year 1 to 5 comparisons. However, this survey month is likely to be most representative of over-winter sward conditions on the bank.

Comparisons between the years showed that only Treatment 11 remained at levels consistent after five years and was significantly different ($p<0.05$) from all other treatments in this respect. Treatments 1, 4, 5 and 7 showed the greatest increase in bare ground cover (c.18–40 per cent), followed by moderate increases of 14–30 per cent in Treatments 9 and 10. Significantly, Treatment 2 showed relatively little increase in bare ground by Year 5, which cannot be due solely to arisings obscuring the extent of bare ground because no cutting would have carried out by the April survey (Figure 4.92). Therefore, there were meaningful differences in bare ground cover between some of the treatments in Year 5 which were not established in Year 1.

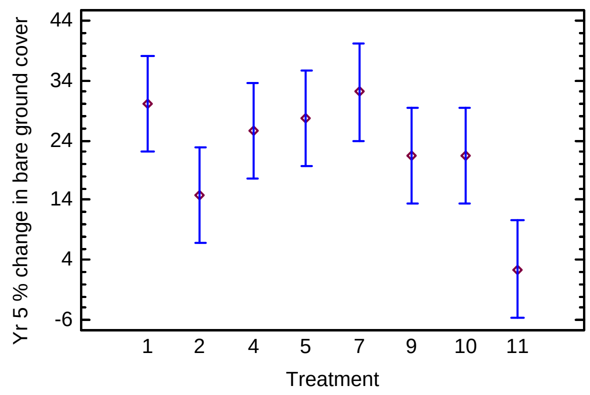


Figure 4.92 Percentage change of mean bare ground cover between Years 1 and 5 for treatments at Billingborough.

Bars represent least significant differences (LSD).

Bryophyte (moss and liverwort) cover

Bryophyte cover was generally very limited across the whole of the Billingborough site. However, Treatments 1 and 5 had significantly higher mean bryophyte cover than all other treatments ($p<0.05$) (Figure 4.93). As described in Section 4.7.1, the percentage cover of bryophytes was influenced at least in part by the moisture content of the soil, i.e. low bryophyte cover was recorded where soil moisture was low. However, it is also likely to be influenced by the availability of bare ground to colonise and the availability of light (principally through the absence of leaf litter). A difference was also recorded between the extent of bryophytes in Treatments 9 and 11 compared with the low bryophyte cover values of Treatments 2, 4, 7 and 10 but this was not found to be significant.

Significant differences ($p<0.05$) were also found in relation to survey months (with the June survey showing significantly lower bryophyte coverage than the other months) and in relation to embankment faces. The landward face had significantly higher cover values. The crest had values that were significantly lower ($p<0.05$) than the landward and river faces. Once again this relates directly to the soil moisture content (which was significantly higher on the landward face than on the river face.

Analysis showed that plant Community A had significantly higher ($p<0.05$) bryophyte cover than Communities B or E, with Communities C and D at intermediate levels (Figure 4.94).

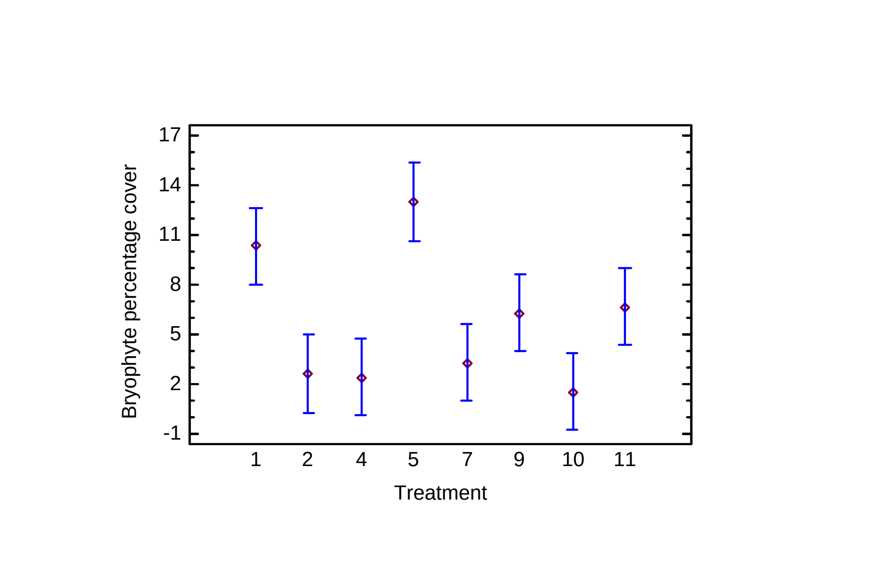


Figure 4.93 Mean bryophyte percentage cover of vegetation recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

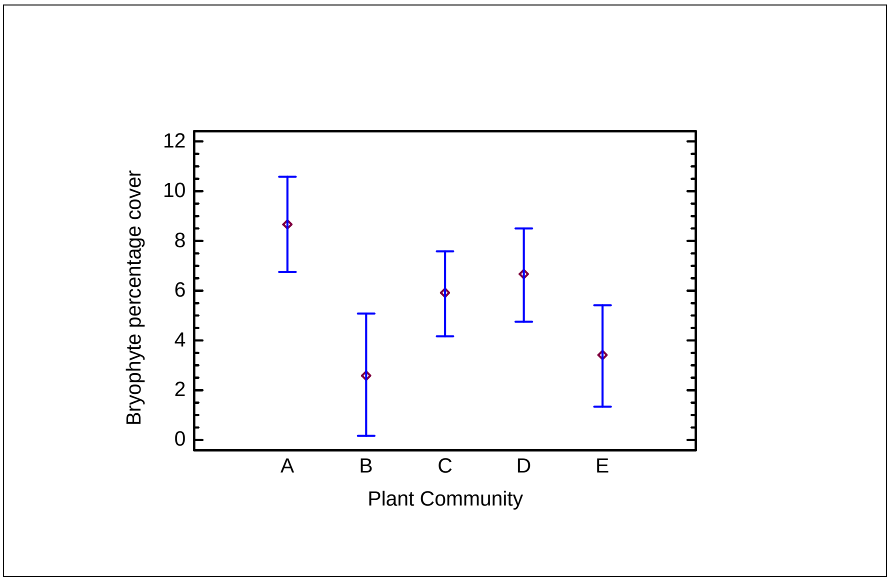


Figure 4.94 Mean bryophyte percentage cover of vegetation recording plots for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

Comparisons of April Year 1 and 5 data on bryophyte cover showed significant differences between some of the treatments (Figure 4.95). The control treatment had the highest percentage increase in bryophyte cover by Year 5, and Treatments 4, 7 and 10 (all cut once a year) showed the least change in bryophyte cover; this was significantly different (at $p<0.05$). Treatments 4 and 10 in particular showed a reduction of bryophyte cover by Year 5. Treatments 1, 5 and 9 (all of which received treatment in April of either cutting or application of herbicide) also showed significantly higher increases in terms of bryophyte cover than

Treatments 4 and 10. Thus there were meaningful differences in bryophyte cover between treatments in Year 5 which were not established in Year 1.

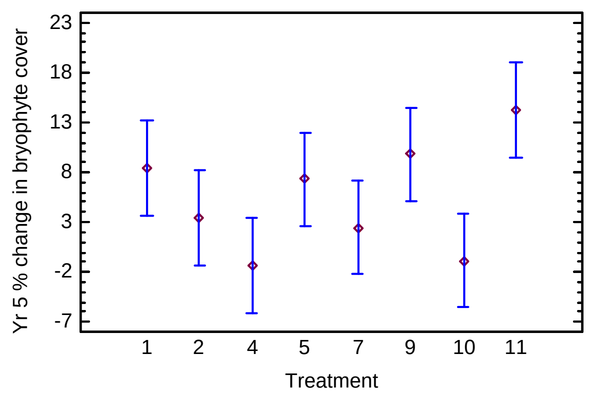


Figure 4.95 Percentage change of mean bryophyte cover between Years 1 and 5 for treatments at Billingborough

Bars represent least significant differences (LSD).

Mean vegetation height

As expected, there were significant differences ($p<0.05$) in the mean vegetation height between treatments in Year 5 at Billingborough due to the different cutting frequencies adopted. Treatments cut only once a year or less showed significantly higher mean vegetation height than treatments cut three times a year, with Treatment 9 (receiving herbicide application) in an intermediate position (Figure 4.96). Similarly, significant differences were recorded in the mean vegetation height between survey months ($p<0.05$) (with the tallest vegetation recorded in June and the shortest in April) and between embankment faces ($p<0.05$) (with the crest representing the shortest vegetation and the river face the tallest, due to the preference of *Sinapis arvensis* for this face).

These significant differences were also reflected in the different plant communities recorded in Year 5, with Communities D and E showing considerably taller ($p<0.05$) swards than Communities A, B and C (Figure 4.97).

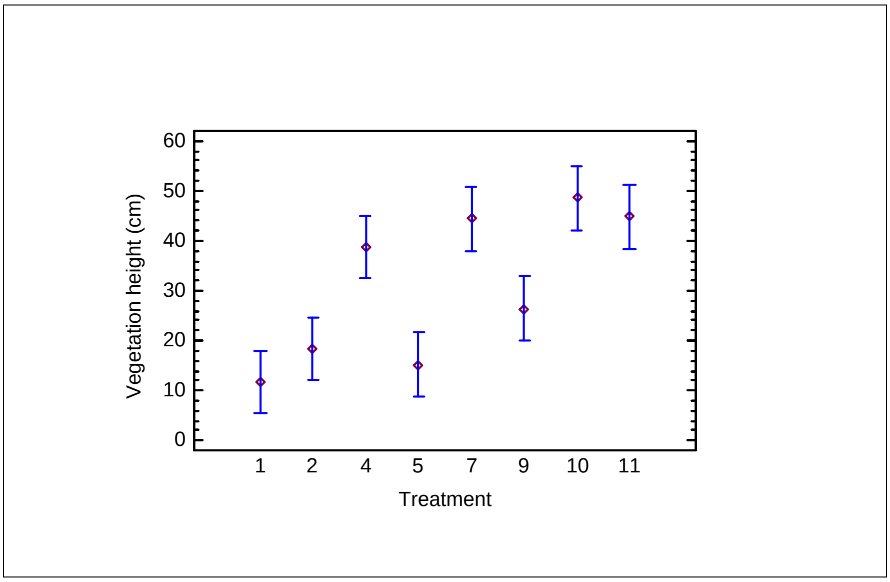


Figure 4.96 Mean vegetation height of vegetation recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

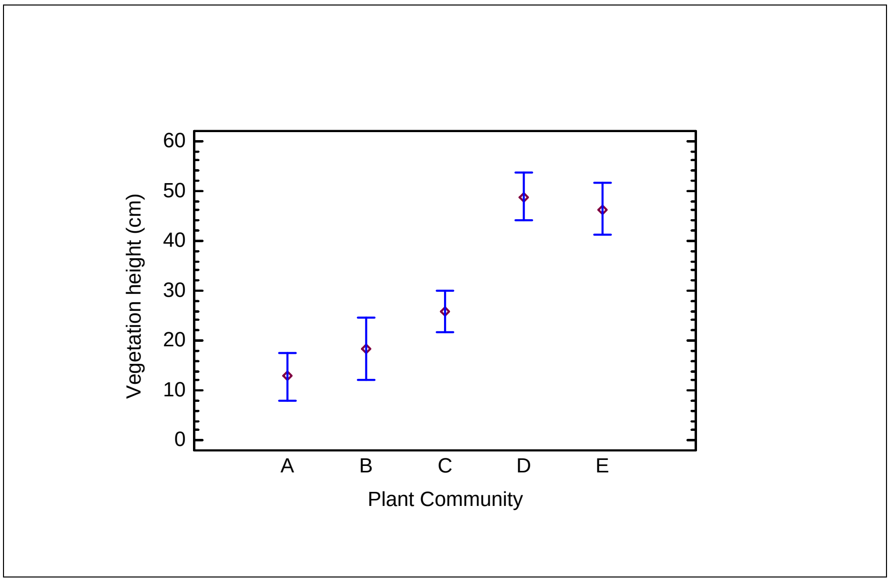


Figure 4.97 Mean vegetation height of vegetation recording plots for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Total vegetation cover

Analysis showed that only Treatment 9 (using herbicide) showed a significantly lower total vegetation cover value ($p<0.05$), with all other treatments being broadly comparable (Figure 4.98). Treatment 2 showed the highest total vegetation cover, which also confirmed the findings of lowest bare ground cover in this treatment.

With regard to embankment face, the landward side had significantly higher ($p<0.05$) vegetation cover than either the crest or the river face. On the crest, this was a result of trampling by pedestrians and horses (Figure 4.99). On the river face, it was at least in part due to the growth cycle of *Sinapis arvensis* creating large areas of bare ground.

April was found to have significantly lower ($p<0.05$) total vegetation cover than was observed in either June or August data. This was as expected given the early stages of growth at this time.

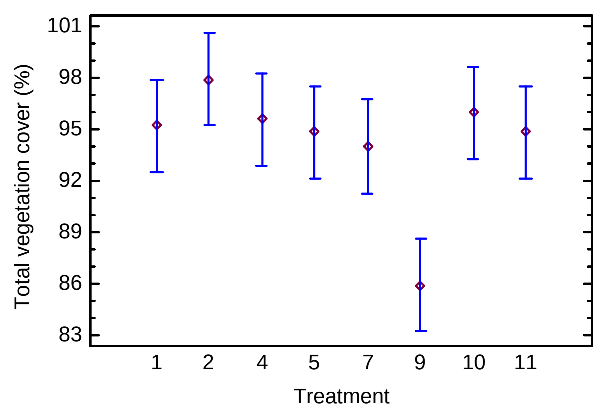


Figure 4.98 Mean total vegetation percentage cover of recording plots for treatments at Billingborough, Year 5.

Bars represent least significant differences (LSD).

In terms of plant community differences, Community E showed significantly lower ($p<0.05$) total vegetation cover than all other communities, with Community B showing the greatest range and highest values of all the communities. This suggests that Community B represents the most tightly knit sward recorded (Figure 4.100).

<u>Changes over time</u>

Comparisons between the total vegetation cover of Years 1 and 5 could not be made due to this variable only being adopted after the baseline survey had taken place.

Figure 4.99 Example of trampling on the crest at Billingborough, April 2007.

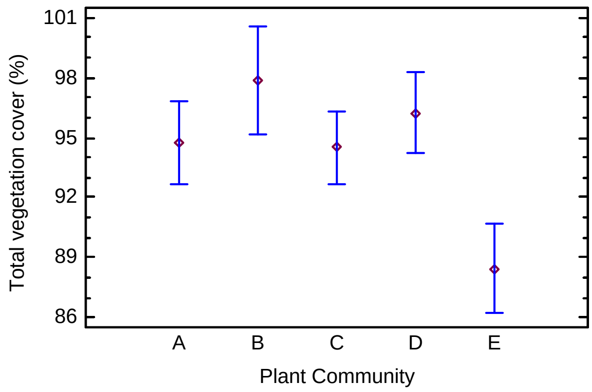


Figure 4.100 Mean total vegetation percentage cover of vegetation recording plots for plant communities at Billingborough, Year 5.

Bars represent least significant differences (LSD).

Dry weight of arisings

Arisings are a partial measure of the productivity of different treatment types. ANOVA calculations were not possible on arisings data due to their nature.

River face

However direct comparison between years showed that, on the river face, Treatment 1 remained one of the most productive in all three years with 1,000–1,400 g/m^2 gathered annually (Figure 4.101).

All treatments receiving less than three cuts per year (i.e. Treatments 3, 4 and 7) showed a decrease in arising production by Year 5.

Those treatments receiving chemical application showed dramatically different results, with Treatment 9 (receiving herbicide) showing a drop of approximately 600 g/m^2, while the treatment receiving growth retardant recorded a steady increase of approximately 300 g/m^2 by Year 5.

Treatments 1 and 2 (cut six and three times a year respectively) showed the least change in the five year period, both still generating high quantities of arisings by Year 5.

Arisings in Treatments 5 and 6 were not recorded in Year 1 and only partially recorded in Year 3. However the data suggest Treatment 5 produces the greatest dry weight of arisings annually, which was still increasing by Year 5.

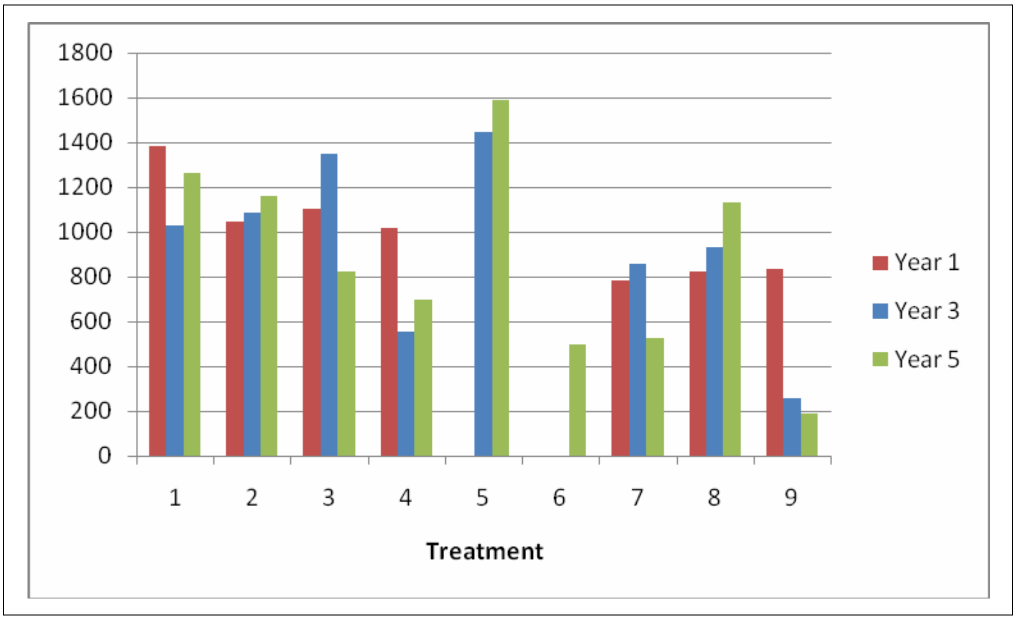


Figure 4.101 Total annual arisings (g/m^2) at Billingborough (river face) in Years 1, 3 and 5.

Landward face

The landward face showed similar trends in the dry weight of arisings collected by Year 5 to those found on the river face (Figure 4.102).

Once again, treatments cut less than three times a year showed a decline in arising production by Year 5, with the decline being greatest in those treatments where arisings were left on after cutting (Treatments 3 and 4).

As on the river face, the treatment receiving growth retardant on the landward face also showed an increase in arising weight in Year 5; although the treatment receiving herbicide showed a decline, this was considerably less than was experienced on the river face.

The decline recorded in the dry weight of arisings collected in Treatment 1 on the landward face was markedly more than recorded on the river face by Year 5.

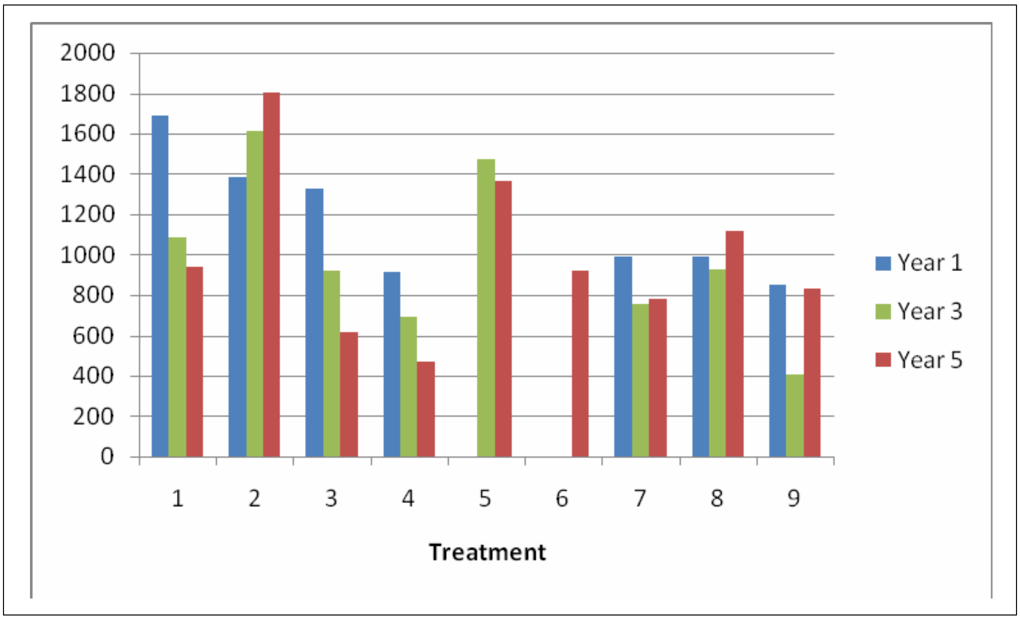


Figure 4.102 Total annual arisings (g/m^2) at Billingborough (landward face) in Years 1, 3 and 5.

Total arisings

Figure 4.103 shows the overall percentage change in total annual dry weight of arisings collected in each treatment from Years 1 to 5.[9] It shows that production of arisings increased only with Treatments 2 and 8, suggesting that Treatments 1 and 5 were already highly productive even in Year 1.

Once again the dramatic differences in dry weight of arisings collected in Treatments 8 and 9 demonstrates that applying growth retardant does in fact increase the amount of arisings produced each year, while the difference between Treatments 4 and 8 suggests that herbicide actually improved plant growth. The data clearly suggest that different treatments do affect the dry weight of arisings collected over time.

[9] With the exception of data for Treatments 5 and 6, which were unrecorded in Year 1.

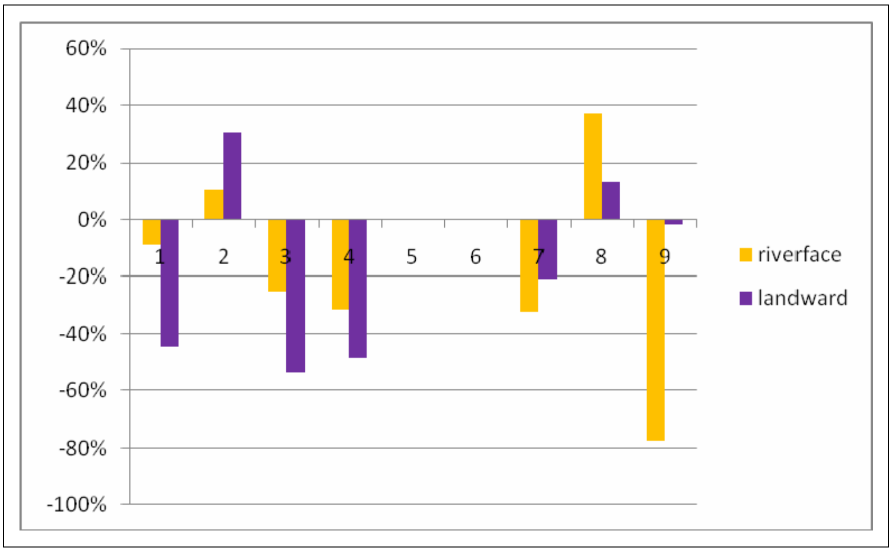


Figure 4.103 Percentage change in arisings collected in Years 1 and 5 at Billingborough.

Vegetation summary: Billingborough

Four distinctive plant communities were identified at Billingborough in Year 5: Communities A, B, D and E, plus the intermediate Community C. The species composition of each is presented in a synoptic table (Table 4.27). All the plant communities found were species-poor.

Overall, where treatments included one cut per year or less, the embankment face was the main control on plant community type rather than management treatment. Community C was mostly associated with the crest, Community D with the landward side and Community E, which contained a great abundance of *Sinapis arvensis,* occurred mainly on the river face.

Where management was more frequent, treatment was a stronger influence than embankment face. Community A covers all the vegetation recording plots in Treatment 1, mown six times per year, and was dominant in Treatment 5, mown three times per year with arisings removed. This is the richest community. Community B was entirely restricted to Treatment 2, cut three times per year with arisings left on. This treatment had the greatest total vegetation cover by Year 5 and the least cover of bare ground. Embankment face did not significantly affect these three treatments.

These data suggest that, where management is very strong with high frequency cutting, treatment type is the main determinant of vegetation community type. Where treatment is weak, with 0–1 cut per year, embankment face is the main driver of community type.

Table 4.28 summarises the effect of treatment on vegetation/sward variables. More frequent mowing produced higher plant species richness and diversity. Treatment 1 (cut six times per year) had the highest richness with Treatment 2 (cut three times per year) the next highest. Treatment 11 (receiving no management) had the lowest diversity, with all the remaining treatments with low frequency cuts lying somewhere in-between. These results were statistically significant ($p<0.05$). It was therefore concluded that frequent cutting produces distinctive plant communities of the highest species-richness.

For Communities A and B, analysis of the five-year data set showed floristic convergence by Year 5 from rather disparate samples in Year 1. Community E also showed convergence from varying start points, but in this case, it is more likely that the low frequency of cutting allowed the competitive *Sinapis arvensis* to dominate the treatment to the exclusion of other species. All three communities showed a generally stable direction of change. The other communities associated with low frequency cutting did not show significant convergence from starting conditions.

Whether or not arisings were removed had little bearing on either community type or richness/diversity, although as noted above, removal of arisings may have caused a separation between Communities A and B when cutting frequency was the same. However, vegetation height and leaf litter percentage cover may both be significant factors. The richer Community A (Treatments 1 and 5) had significantly shorter vegetation and less leaf litter cover than the others. It also had the sharpest reduction in leaf litter cover over the five years. In contrast, Treatment 11 (control treatment with no management) had the highest leaf litter cover, recorded the greatest increase in leaf litter cover by Year 5 and had the lowest species-diversity.

Table 4.28 Main differences ($p<0.05$) between treatments in Year 5 at Billingborough for vegetation/sward variables.

	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Plant species-richness	H	H	-			-		-		L	L
Plant diversity	H	H	-			-		-		L	L
Leaf litter cover	L		-		L	-		-			H
Bare ground cover		L	-	H		-	H	-			L
Bryophyte cover	H	L	-	L	H	-	L	-		L	
Vegetation height	L	L	-	H	L	-	H	-		H	H
Total vegetation cover			-			-		-	L		
Dry weight of arisings: river*	H	H			H	L	L	H	L	-	-
Dry weight of arisings: land*	H	H	L	L	H		L	H		-	-

* Not significance tested but observed differences.
H = relatively high value, L = relatively low value

4.6.2 Reach Lode

Floristic composition

At Reach Lode the list of plant species recorded was more extensive than that at Billingborough. The first three divisions made by TWINSPAN resulted in eight community groups.

When PCA was performed on the Reach Lode data set, a couple of the community groups appeared to occupy the same space on the PCA diagram. These groups were amalgamated where examination of the individual replicates suggested there were insufficient floristic differences between groups. In this way five distinctive communities were identified (A, B, C, D and E), with a number of vegetation recording plots being classified as 'marginal' to their assigned community because they occurred on the PCA diagram in a different location to the core recording plots for that community (Figure 4.104).

The synoptic table for the Reach Lode data is given in Table 4.29. Brief descriptions of each community are provided below:

<u>Community A</u>

This was a moderately species-rich community, dominated by fine-leaved grasses of *Lolium perenne* and *Poa trivialis*, accompanied by some *P. pratensis* and *Dactylis glomerata*. It was distinctive for the frequency of associates such as *Taraxacum officinale, Plantago lanceolata, Picris echioides, Centaurea nigra, Geranium dissectum, Ranunculus repens* and *Senecio jacobaea*. Tall herbs of *Heracleum sphondylium* and *Anthriscus sylvestris* were usually present but not in high numbers. It was the only community where occasionals of *Achillea millefolium, Crepis capillaris, Silene latifolia* and *Leontodon autumnalis* were recorded. The sward had moderate total vegetation cover (mean of 88 per cent) and fairly high levels of bare ground (mean of 29 per cent). It had a low percentage cover of leaf litter and consequently the highest cover of bryophytes recorded at this site (mean of 10 per cent). See Figure 4.105.

<u>Community B</u>

Community B represented some of the most species-rich vegetation recorded at Reach Lode. It was dominated by *Dactylis glomerata, Poa trivialis* and *Lolium perenne* (similar to that of Community A), accompanied by moderate amounts of *Equisetum arvense* and *Persicaria maculosa* as constants, as well as smaller amounts of *Plantago lanceolata, Potentilla erecta* and *Poa pratensis*. The community was particularly distinctive for its component of moisture-loving plants such as *Phragmites australis* and *Filipendula ulmaria*. However, it also had a coarser element (at low abundance) of *Urtica dioica, Arrhenatherum elatius, Anthriscus sylvestris* and *Calystegia sepium*. Total vegetation cover was good (averaging 90 per cent) but bare ground cover was also high, averaging 31 per cent. Very few bryophytes were recorded in this community. See Figure 4.106.

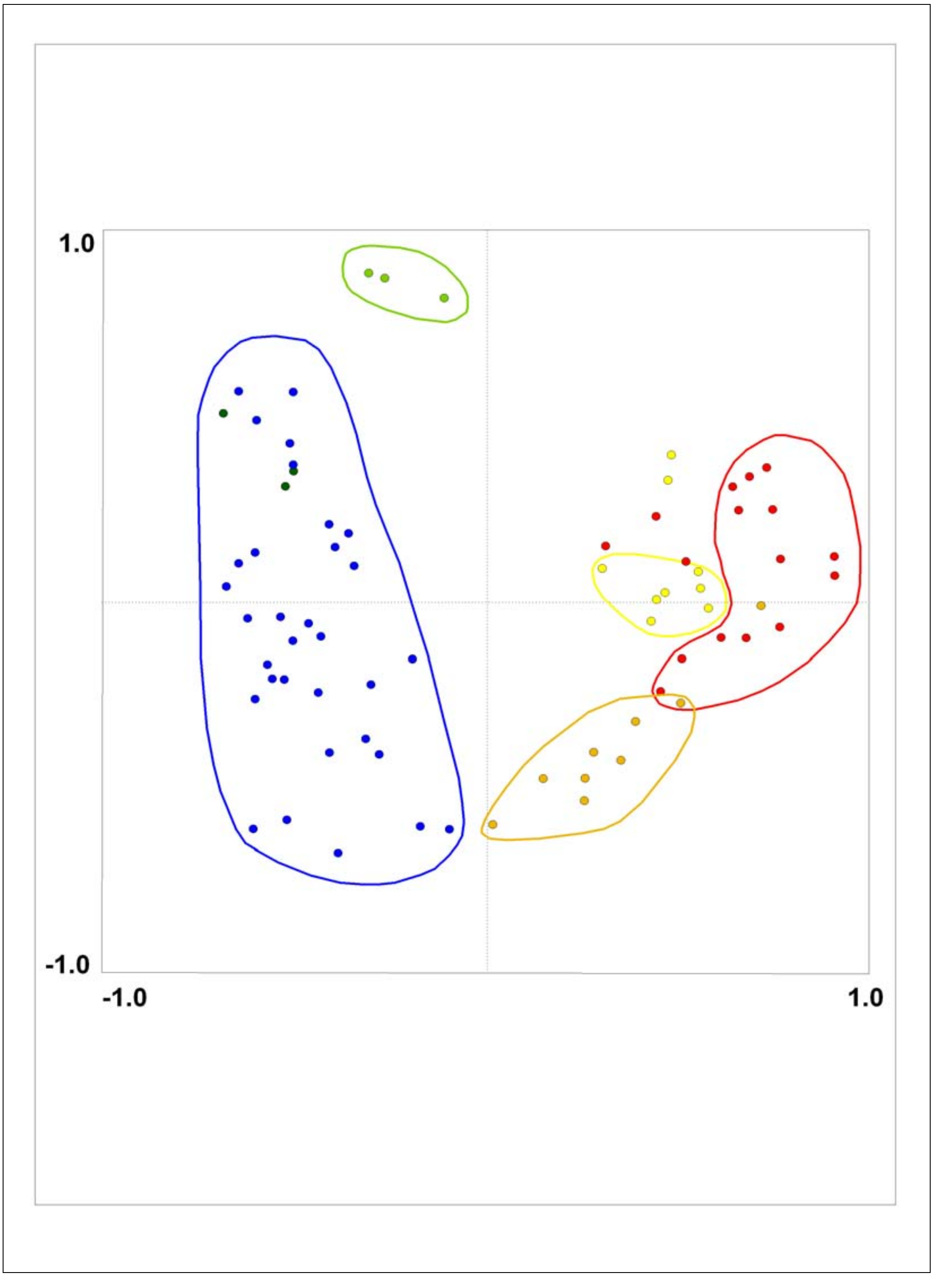


Figure 4.104 PCA diagram of vegetation replicates for Reach Lode using June data from Year 5 (showing axes 1 and 2).
Samples are represented by dots (Community A = red, B = orange, C = yellow, D = dark blue, E = light blue, F = light green).
Dark green dots are a TWINSPAN division **that** was found on further examination to be floristically similar to Community E.
Coloured lines represent the core zone occupied by that community.

Table 4.29 Synoptic table for plant communities recorded at Reach Lode[1].

	Plant community				
	A	**B**	**C**	**D**	**E**
Bare ground cover	29%	31%	13%	12%	38%
Bryophyte cover	10%	6%	0%	2%	0%
Leaf litter cover	28%	49%	57%	44%	32%
Aquatic litter cover	0%	0%	0%	16%	17%
Total vegetation cover	88%	90%	76%	92%	82%
Plant species-richness	15	16	11	14	16
Ellenberg Indicator Value for light	7.03	7.04	7.06	6.86	6.88
Ellenberg Indicator Value for moisture	5.47	5.73	5.54	5.71	5.09
Ellenberg Indicator Value for reaction	6.47	6.52	6.57	6.81	6.95
Ellenberg Indicator Value for nitrogen	6.02	6.21	6.43	6.67	6.70
Dactylis glomerata	V (3–6)	V (3–8)	V (4–6)	IV (3–8)	V (3–4)
Poa trivialis	V (3–7)	V (5–7)	V (3–7)	V (3–7)	II (2–2)
Heracleum sphondylium	V (1–4)	V (1–4)	II (1–3)	**V (1–6)**	II (1–1)
Lolium perenne	**V (7–9)**	**V (3–7)**	**V (7–9)**	II (2–5)	–
Taraxacum officinale	**IV (1–5)**	**IV (1–2)**	II (1–2)	II (1–3)	**V (2–4)**
Plantago lanceolata	**IV (1–5)**	II (2–3)	–	I (2–4)	–
Picris echioides	**IV (1–5)**	III (1–4)	I (1–1)	II (1–4)	**V (1–2)**
Poa pratensis	**III (3–4)**	II (4–4)	III (2–4)	–	–
Centaurea nigra	**III (3–5)**	I (2–2)	–	I (3–7)	–
Geranium dissectum	**III (2–3)**	II (2–3)	I (1–1)	I (1–4)	**IV (1–2)**
Ranunculus repens	**III (2–4)**	I (1–1)	I (2–2)	I (2–4)	II (1–1)
Senecio jacobaea	**III (2–3)**	I (2–2)	I (1–1)	–	–
Plantago major	**II (1–2)**	I (2–2)	I (2–2)	–	–
Rosa arvensis	**II (1–3)**	II (1–2)	–	I (1–2)	–
Tussilago farfara	**II (2–3)**	–	–	I (1–3)	–
Carex hirta	**I (3–3)**	–	–	I (4–4)	–
Achillea millefolium	**I (3–3)**	–	–	–	–
Crepis capillaris	**I (3–3)**	–	–	–	–
Galium mollugo	**I (2–2)**	–	–	–	–
Leontodon autumnalis	**I (2–2)**	–	–	–	–
Silene latifolia	**I (3–3)**	–	–	–	–
Equisetum arvense	IV (1–4)	**V (1–9)**	I (3–3)	IV (1–8)	II (2–2)
Persicaria maculosa	IV (1–4)	**V (3–4)**	IV (1–3)	III (2–5)	–

	Plant community				
	A	**B**	**C**	**D**	**E**
Phragmites australis	II (1–3)	**V (2–5)**	–	**III (1–7)**	–
Anthriscus sylvestris	III (1–3)	**V (2–4)**	**V (1–5)**	IV (1–8)	IV (3–5)
Filipendula ulmaria	II (1–3)	**IV (3–5)**	–	I (2–4)	–
Geranium molle	I (1–1)	**II (1–1)**	–	–	–
Potentilla erecta	–	**II (1–1)**	–	–	–
Glechoma hederacea	III (1–3)	III (1–3)	**IV (3–3)**	III (1–4)	–
Calystegia sepium	I (2–2)	III (1–3)	**IV (3–4)**	III (1–4)	**IV (2–3)**
Agrostis stolonifera	II (3–4)	II (3–5)	**III (2–4)**	II (3–5)	–
Arrhenatherum elatius	II (3–6)	V (2–5)	V (3–4)	**V (4–10)**	V (1–4)
Galium aparine	–	–	–	**IV (1–6)**	–
Anisantha sterilis	–	II (2–3)	–	II (1–4)	–
Alopecurus pratensis	–	–	–	I (4–4)	–
Carex acutiformis	–	–	–	I (2–2)	–
Silene vulgaris	–	–	–	I (1–1)	–
Elytrigia repens	III (3–5)	I (2–2)	I (4–4)	III (3–8)	**V (8–8)**
Convolvulus arvensis	I (2–2)	–	I (2–2)	II (1–4)	**V (2–3)**
Sinapis arvensis	I (2–2)	–	–	II (1–6)	IV (1–1)
Lamium album	–	I (1–1)	III (1–3)	II (1–4)	**IV (2–2)**
Urtica dioica	–	IV (1–4)	II (2–3)	III (2–6)	**IV (2–2)**
Lamium purpureum	–	–	–	**–**	**IV (1–1)**
Malva sylvestris	–	–	–	**–**	**IV (1–2)**
Stellaria media	–	–	–	I (1–1)	**IV (2–3)**
Scrophularia auriculata	–	–	–	**–**	**II (1–1)**
Rumex crispus	–	–	–	**–**	**II (1–1)**
Lactuca serriola	–	I (1–1)	–	**–**	**II (1–1)**
Crepis vesicaria	–	–	–	**–**	**II (1–1)**
Sonchus asper	I (1–1)	–	I (1–1)	I (1–4)	**II (1–1)**
Sonchus oleraceus	I (1–1)	–	–	I (1–1)	**II (1–1)**
Cirsium arvense	I (2–2)	–	–	I (1–3)	–
Holcus lanatus	I (4–4)	–	–	I (4–4)	–
Rubus fruticosus	II (1–1)	I (1–1)	–	I (1–4)	–
Rumex obtusifolius	–	II (1–1)	II (1–1)	I (1–1)	II (3–3)
Symphytum officinale	I (1–1)	I (1–1)	–	I (1–2)	–
Tragopogon pratensis	I (1–1)	–	–	I (1–2)	–

Notes [1] Bold text denotes characteristic species of the community.

Community C

This community was dominated by *Lolium perenne, Dactylis glomerata* and *Poa trivialis* (as in Community B) but lacked the small herb and moisture-loving components of the two previous communities. Instead, species such as *Glechoma hederacea, Calystegia sepium, Lamium album* and *Anthriscus sylvestris* were more frequent. Consequently this was a rather species-poor community, with high percentage cover of leaf litter and no bryophytes. It also had the lowest total vegetation cover, averaging only 76 per cent. See Figure 4.107.

Community D

This community was dominated by *Arrhenatherum elatius*, with associates of *Elytrigia repens*, *Dactylis glomerata*, *Poa trivialis*, *Anisantha sterilis* and *Agrostis stolonifera*. It had a strong tall herb component of *Heracleum sphondylium* and *Anthriscus sylvestris*, as well as a moderate frequency of climbers such as *Calystegia sepium*, *Galium aparine* and *Convolvulus arvensis*. *Sinapis arvensis* also occurred at low frequencies. Species characteristic of moist conditions such as *Phragmites australis*, *Filipendula ulmaria* and *Carex hirta* were also present in some recording plots on the river face. Community D was species-poor, with very few bryophytes recorded but a high percentage cover of vegetation, averaging 92 per cent. There was relatively little bare ground (averaging 12 per cent cover), with a high percentage cover of leaf litter, including some aquatic litter on landward recording plots. See Figure 4.108.

Community E

In this community, the sward was dominated by *Elytrigia repens*, with associates of *Dactylis glomerata* and *Arrhenatherum elatius*. Species-richness was moderately high due to the frequency of ruderals and competitive ruderals such as *Picris echioides*, *Sinapis arvensis, Stellaria media, Lamium album, Malva sylvestris, Convolvulus arvensis* and *Lamium purpureum*. Occasional species such as *Rumex crispus, Lactuca serriola, Crepis vesicaria, Sonchus asper* and *Sonchus oleraceus* were also present. The community was marked by large amounts of bare ground cover due to considerable quantities of silt from aquatic dredging being placed here. Consequently total vegetation cover was rather low compared with the other communities (averaging 82 per cent). See Figure 4.109.

Figure 4.105 Reach Lode Community A, photographed on the crest of Treatment 7 in April 2007.

Figure 4.106 Reach Lode Community B, photographed on the river face of Treatment 2 in June 2007.

Figure 4.107 Reach Lode Community C, photographed on the river face of Treatment 1 in June 2007.

Figure 4.108 Reach Lode Community D, photographed on the landward face of Treatment 4 in June 2007.

Figure 4.109 Reach Lode Community E, photographed on the landward face of Treatment 1 in June 2007.

Figure 4.110 shows the distribution of these plant communities across the embankment.

The embankment face provided the clearest divisions in the data, with Community D dominating the river and landward faces and Community A on the crest. As at Billingborough, frequent cutting overrode this pattern, with Communities C and E restricted to Treatment 1 which was cut six times per year. Treatments 2 and 5, which were both cut three times per year, gave rise to Community B.

The deposition of channel dredgings on the landward face was very heavy at Reach. This disrupted the dominance of the frequently cut treatments by a single community described at Billingborough, with other communities present on the landward face at Reach. It is also possible that the regular presence of geese and swans at Treatment 1 (and the substantial amounts of their droppings) may have affected the vegetation here.

There appeared to be no difference in which plant community was recorded in relation to the collection of arisings. Similarly the use of weedkiller in Treatment 9 appeared to have made no additional difference to those treatments cut once a year only.

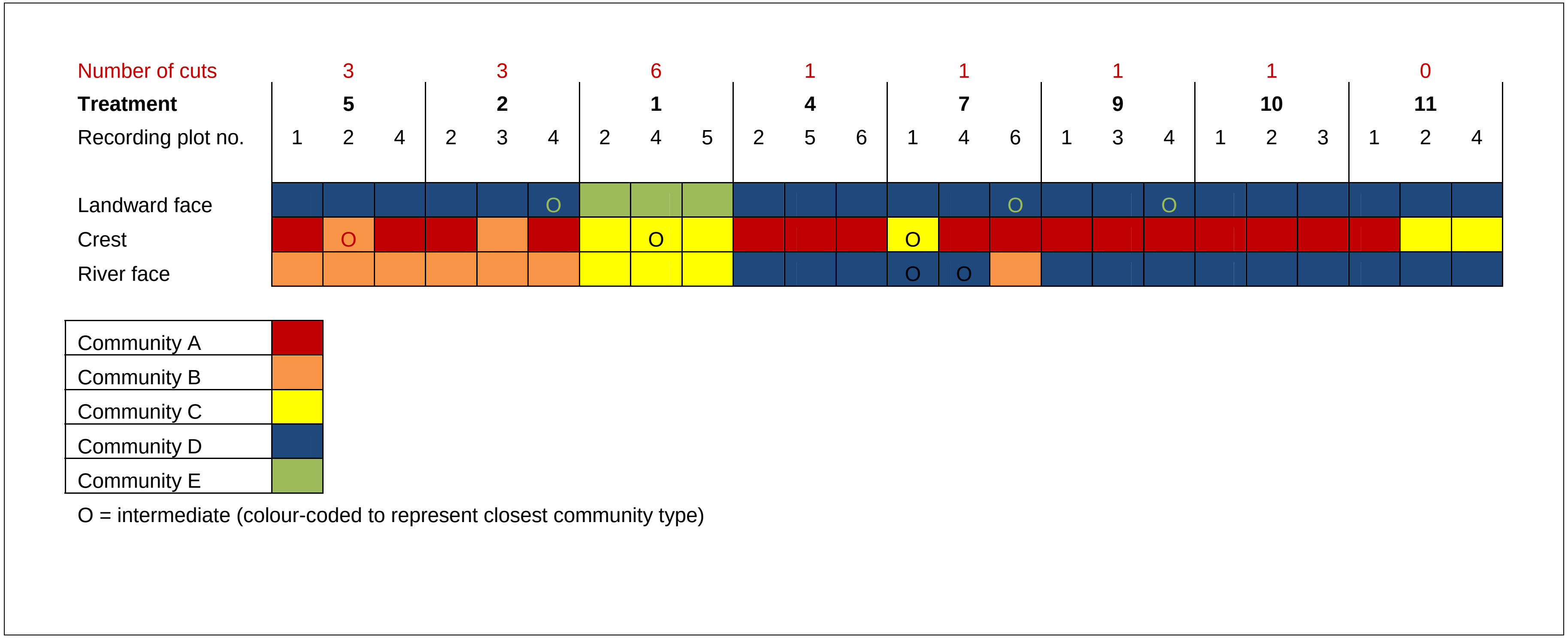


Figure 4.110 Distributions of plant communities at Reach Lode.

Changes over time

To eliminate the possibility that these plant community differences were present in Year 1 of the trials, it was necessary to establish whether there had been a change in the floristic compositions over the five years. Like Billingborough, April survey data at Reach Lode were used to conduct comparisons between the floristic composition of vegetation recording plots in Years 1, 3 and 5.

As stated previously, weather conditions prior to the April survey may have affected coverage of certain species in Year 1 and thus some differences are inevitable.[10] If rainfall is the main determining factor in a shift in vegetation composition between Years 1 and 5, it can be expected that all recording plots will move in the same direction on the PCA diagram.

At Reach Lode this was found to be the case in all communities. A shift to the left of the diagram occurred, indicating a movement from communities with eutrophic and ruderal species frequent, to a grassier, mesotrophic sward. However, the precise location of the recording plots on the left side of the diagram did vary depending on the community. For example, some recording plots shifted to the left but also down a little. This suggests that, although another factor other than treatment may have caused the vegetation within the recording plots to change by Year 5, treatment still appears to be a significant secondary factor[11] in certain situations.

The PCA diagram of species and environmental variables for Reach Lode shown in Figure 4.111 can be used to interpret shifts in the following PCA diagrams of vegetation recording plot data. Thus for this site:

- recording plots with a greater proportion of *Poa pratensis, Tussilago pratensis* and *Equisetum arvense* occur in the top right corner,
- recording plots with a greater proportion of *Lolium perenne, Festuca rubra* and *Plantago lanceolata* occur in the top left corner,
- recording plots dominated by *Arrhenatherum elatius* and *Elytrigia repens* occur towards the bottom left corner;
- recording plots with a greater proportion of *Phragmites australis, Urtica dioica* and *Filipendula ulmaria* occur in the bottom right corner.

Overlaying the values of other measured variables (e.g. bare ground cover) and estimated variables (e.g. as Ellenberg Indicator Values for moisture) shows that those recording plots with a high percentage cover of aquatic leaf litter and high Ellenberg Indicator Values for moisture occur in the bottom right corner of the PCA diagram. Conversely, those recording plots with the greatest bryophyte cover, the greatest species-richness and the highest Ellenberg Indicator Values for light are located towards the top left. Those recording plots with high levels of leaf litter cover and high Ellenberg Indicator Values for nitrogen occur in the bottom left corner of the diagram. This may indicate these two variables are related.

Community A

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[10] Although a substantial shift in the amount of *Poa pratensis* was recorded in April of Year 1 compared with subsequent years (which may indicate misidentification), *P. pratensis* continued to be recorded in moderate amounts throughout the trials. It is therefore impossible to determine whether misidentification occurred. Therefore, all *P. pratensis* and *P. trivialis* records remained as recorded in the field for the purposes of the PCA analysis.

[11] To eliminate the possibility that the difference in *Poa* species recorded was the main cause of the shift in the PCA diagram, the data were run through the same process of analysis with *P. trivialis* and *P. pratensis* records combined. The resulting PCA diagram was extremely similar to that of the original, indicating that the *Poa* species was not the main influencing factor here.

Figure 4.112 shows the shift in vegetation of recording plots from Community A in Years 1, 3 and 5. It illustrates that, in Year 1, vegetation that would later become one community generally occurred in a dispersed group in the top right of the PCA diagram.

This is unlike many of the recording plots of other Reach Lode communities in Year 1 and suggests this vegetation was already somewhat different from the rest of the embankment even in Year 1, which is particularly likely given that it occurred on the crest of the bank only.

By Year 3, all recording plots had begun to shift towards the left and, by Year 5, had converged in a tight cluster in the top left of the diagram. This suggests a shift towards a more species-rich sward, with some bryophyte coverage.

Community A is felt to represent a meaningful shift in vegetation composition because of the trend over the five-year period in this direction.

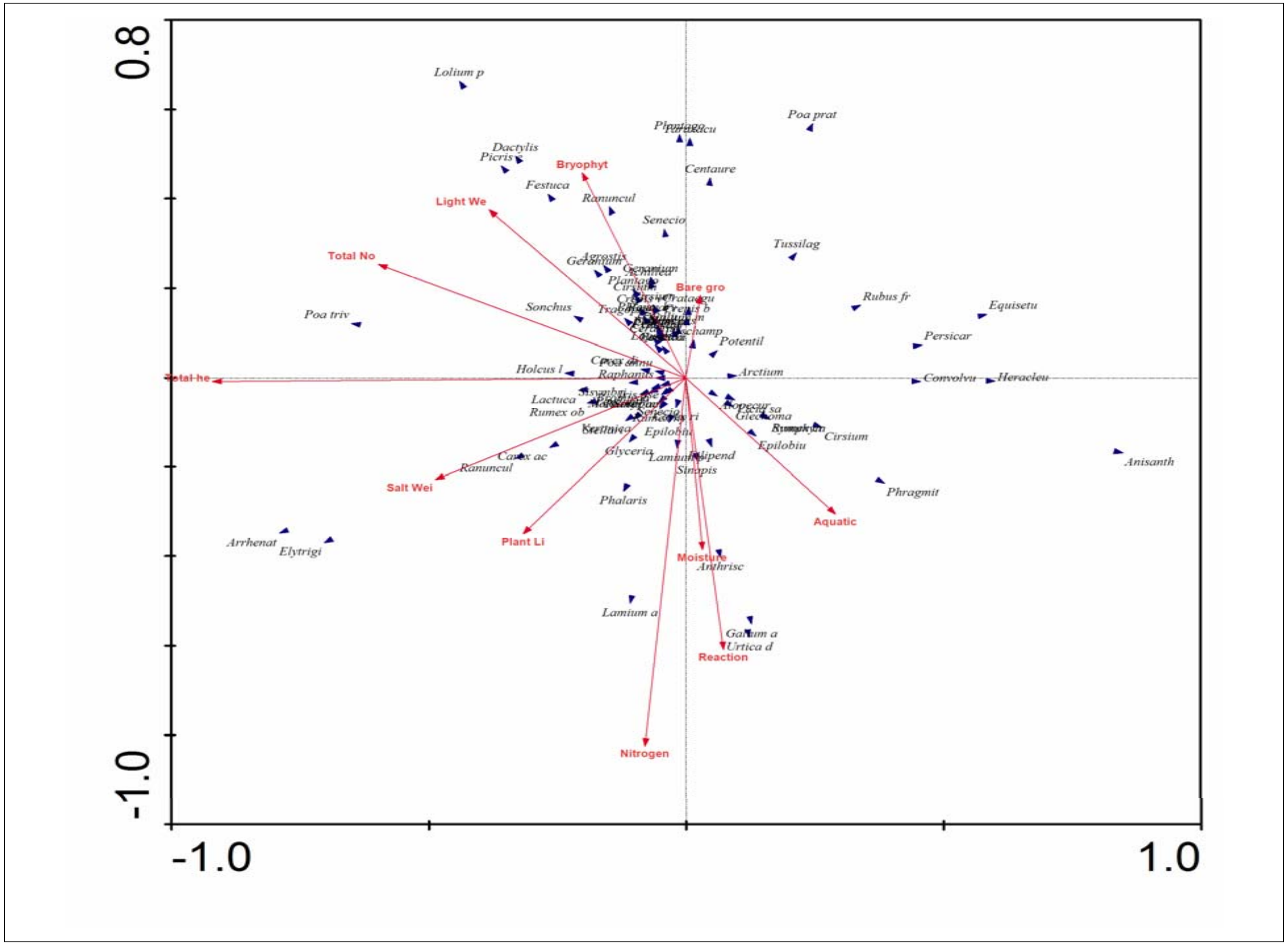


Figure 4.111 PCA diagram of vegetation data from April, Years 1, 3 and 5 at Reach Lode – showing species and variables.

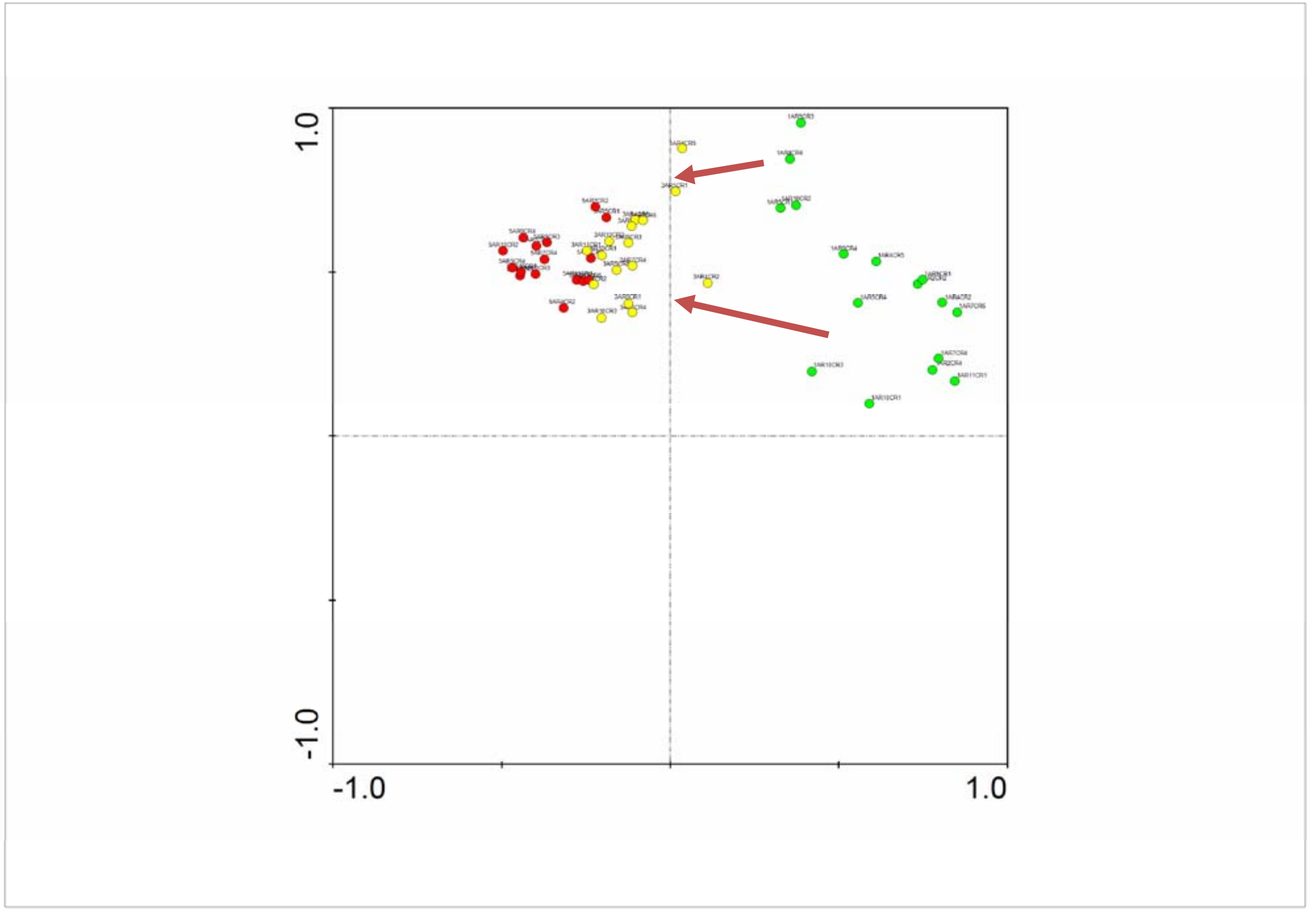


Figure 4.112 PCA diagram of April vegetation data at Reach Lode for Community A in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time**.**

Community B

Figure 4.113 shows the vegetation in Community B recording plots in Years 1, 3 and 5.

Once again, in Year 1 the recording plots are scattered across the right side of the diagram, over a wide area, indicating a considerable variation in the sward composition was present in Year 1.

By Year 5, the recording plots had shifted primarily to the left side of the diagram but also, more towards the top half of the diagram. As in Community A, this suggests a move towards a species-rich sward with higher Ellenberg Indicator Values for light. That this community occurs in this section of the diagram, despite containing species such as *Phragmites australis* (whose greatest occurrence is shown in the bottom right instead), is a reflection that the prominence of this species only became apparent after the April survey and therefore does not feature strongly in the illustrated PCA analysis.

Community B is felt to represent a meaningful shift in vegetation composition.

Community C

Figure 4.114 shows the shift in vegetation of recording plots from Community C in Years 1, 3 and 5.

The diagram shows that, as time passes from Years 1 to 3 to 5, the cluster becomes tighter. The shift in position occurs in Years 1 to 3 but, between Years 3 and 5, the main change is a tightening of the cluster, again showing increasing convergence.

Community D

Figure 4.115 illustrates the shift in vegetation during Years 1, 3 and 5 of the recording plots later classified as Community D.

In Year 1, several of the recording plots were already within the bottom right of the diagram in a dispersed group. Once again this indicates that the replicates of Community D were already different in floristic composition from those of say Community A in Year 1.

The main shift is between Years 1 and 3, where there is strong movement towards a sward with increased dominance of species such as *Arrhenatherum elatius* and *Elytrigia repens*.

Year 5 data are in a similar location on the PCA diagram to Year 3, with only modest convergence. This reflects the low intensity management.

Community E

Figure 4.116 illustrates the shift in vegetation during Years 1, 3 and 5 of the recording plots later classified as Community E. It shows a straight shift towards the left of the diagram. It is unclear to what degree this shift is due to additional factors such as differences in rainfall in Year 1 and whether Community E represents a meaningful shift in vegetation composition. However with only three recording plots indicating the core of this community and a catastrophic form of management (i.e. dumping of aquatic litter and silt), this community was never likely to show a consistent pattern.

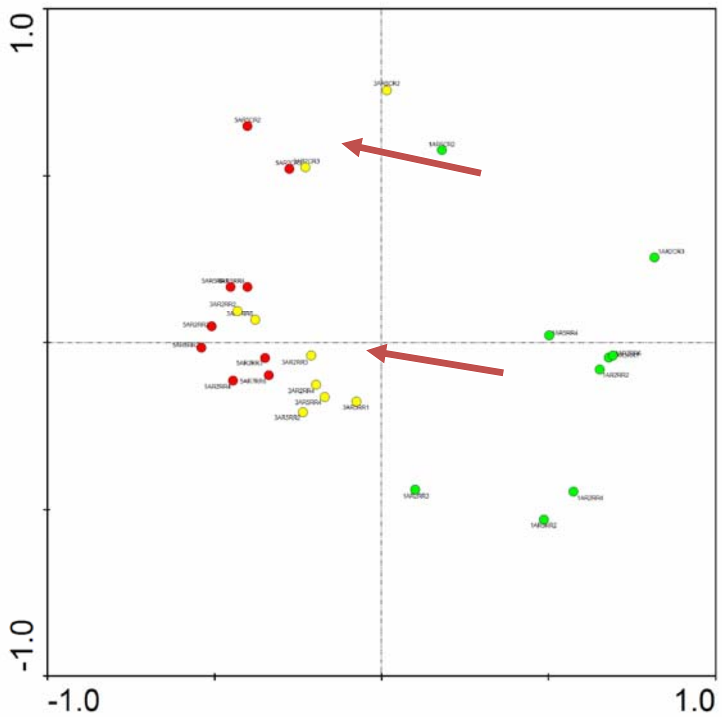


Figure 4.113 PCA diagram of April vegetation data at Reach Lode for Community B in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

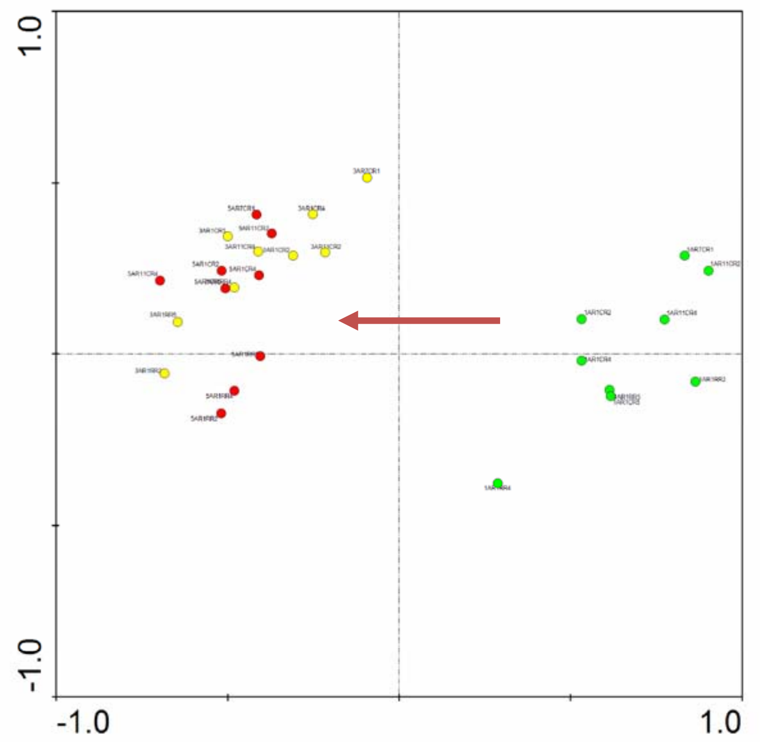


Figure 4.114 PCA diagram of April vegetation data at Reach Lode for Community C in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

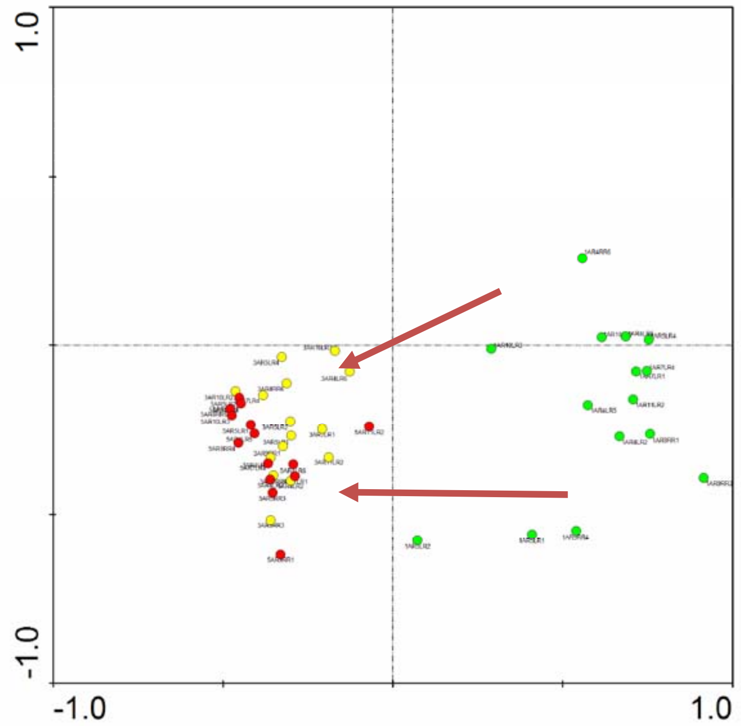


Figure 4.115 PCA diagram of April vegetation data at Reach Lode for Community D in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

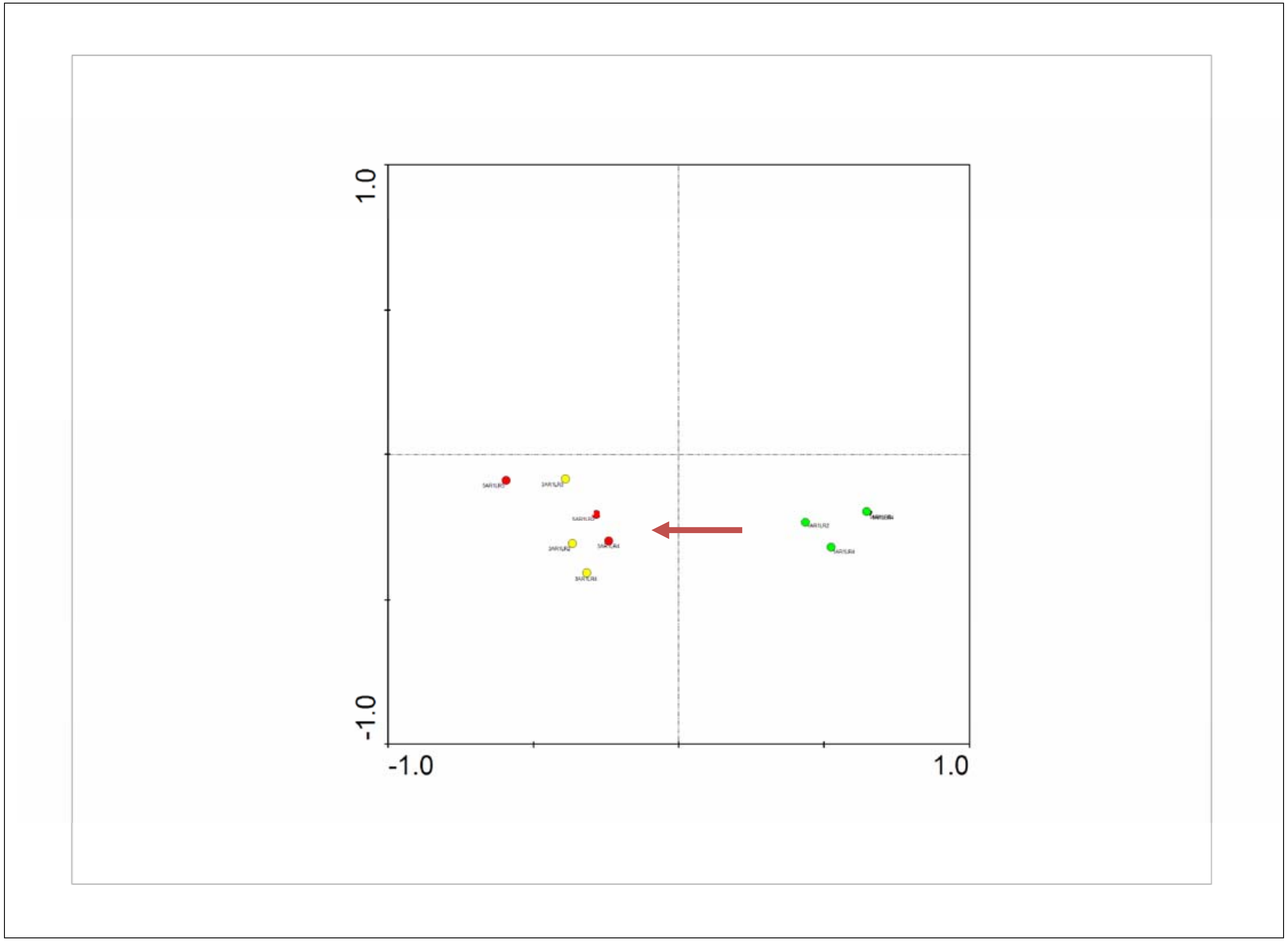


Figure 4.116 PCA diagram of April vegetation data at Reach Lode for Community E in Years 1, 3 and 5

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Plant species-richness

A significant difference ($p<0.05$) was found in the species-richness recorded at Reach Lode in relation to management treatment (Figure 4.117).

Treatment 5 was significantly higher in plant species-richness than almost all other treatments, with the exception of Treatment 4. In contrast, Treatment 11 (control) had significantly lower species-richness than all other treatments. No significant difference ($p<0.05$) was found between Treatments 1, 2, 4, 7, 9 and 10, which ranged in their management from six cuts per year to one cut per year. This may well be a result of embankment face being the primary factor in vegetation composition rather than treatment type. Certainly a significant difference was found in the species-richness of the crest and river face compared with the considerably poorer landward face.

Where treatments received three cuts per year, species-richness was significantly higher when arisings were removed after cutting (Treatment 5) than when they were left on the bank (Treatment 2). In contrast when treatments were cut only once per year, no difference in species richness was apparent.

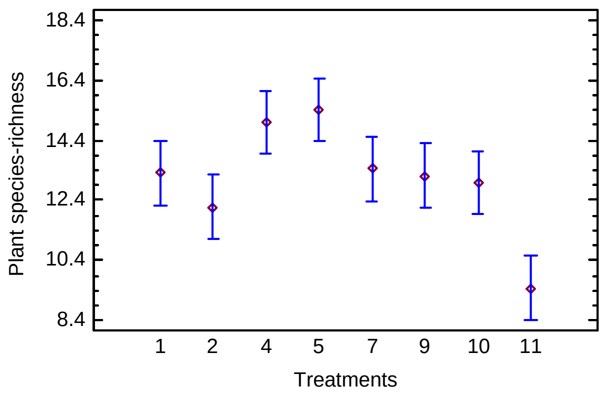


Figure 4.117 Mean plant species-richness of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Analysis of the species-richness in terms of plant communities illustrates that there was much more separation between plant communities than occurred between treatments (Figure 4.118), i.e. Community A had a significantly higher ($p<0.05$) species-richness than Communities C, D and E, while Communities C and D had significantly lower ($p<0.05$) species-richness than A, B or E.

The August survey also found significantly less species-richness than the April or June surveys ($p<0.05$).

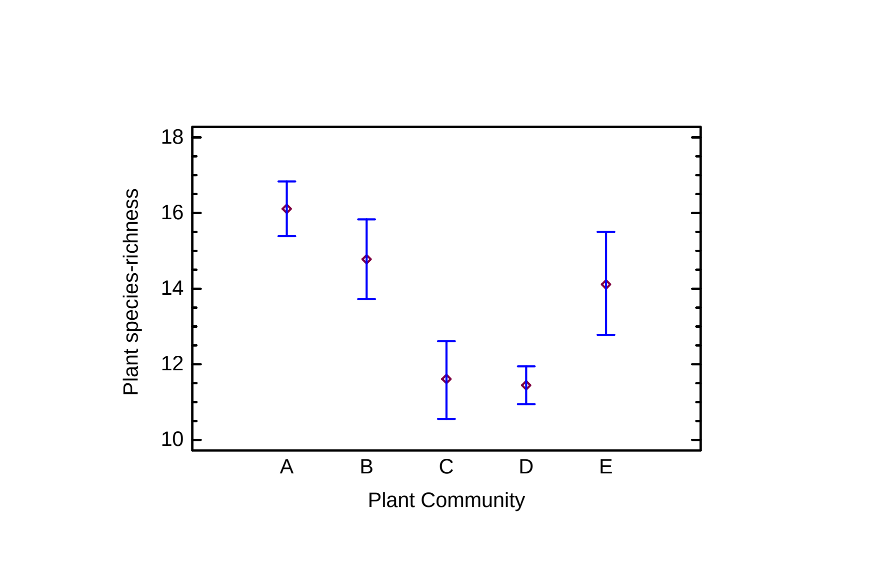


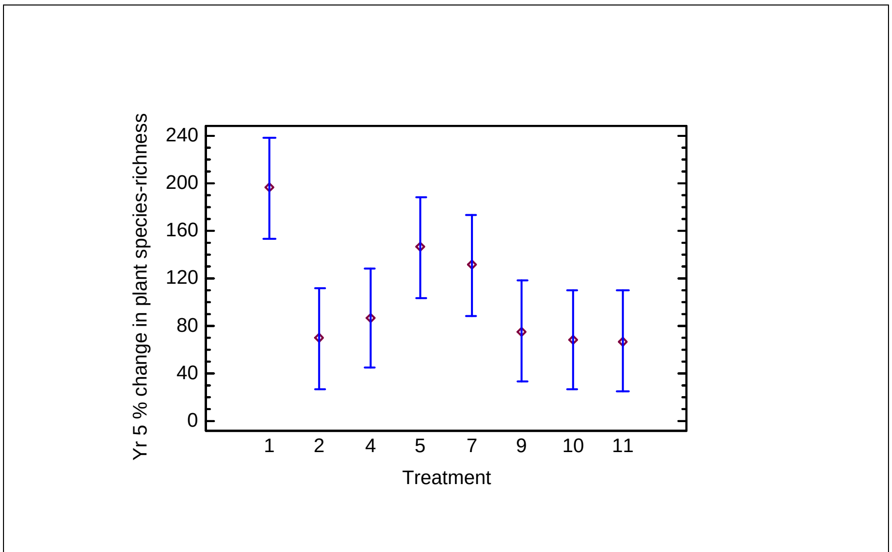
Figure 4.118 Mean plant species-richness of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Changes over time

When the percentage change in plant species-richness of each recording plot from Years 1 to 5 was analysed (Figure 4.119), all treatments showed an increase by Year 5, with the degree of change significantly more in Treatment 1 (significant to $p<0.05$[12]). Treatments 5 and 7 also showed a considerable increase in species-richness compared with Treatments 2, 4, 9, 10 and 11 (although this was not statistically significant at $p<0.05$). These data may therefore indicate that even treatments receiving only one cut a year can increase in plant species-richness with arising removal.

The fact that there was no significant difference between Treatments 2, 4, 9, 10 and 11 by Year 5 is felt to be somewhat misleading because the principal factor at this site appeared to embankment face rather than treatment type; thus grouping all embankment faces of a treatment together is likely to weaken evidence of a relationship with management.



[12] Significant difference at $p<0.05$ is indicated where the blue range lines do not overlap.

Figure 4.119 Percentage change of mean plant species-richness between Years 1 and 5 for treatments at Reach Lode.

Bars represent least significant differences (LSD).

Plant species diversity

Analysis of plant species diversity at Reach Lode showed similar results to those for plant species-richness, i.e. there were several differences in plant diversity between treatments (although only a few of them were significant at $p<0.05$) (Figure 4.120). Treatment 11 (control) had the lowest species diversity, but this was only significant when compared to Treatments 4, 5, 7 and 10. Treatment 1 showed some of the lowest species diversity values.

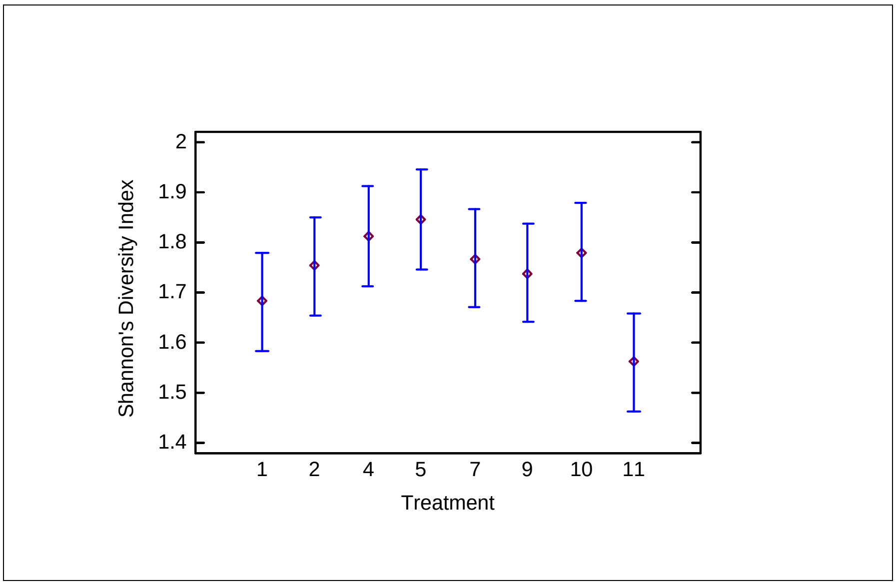


Figure 4.120 Mean plant diversity (using Shannon's Diversity Index) of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Clearer differences in plant diversity were evident between the embankment faces at Reach Lode than at Billingborough. The river face had the highest diversity and the landward face the lowest, both being statistically significant. Once again, the August survey recorded significantly lower ($p<0.05$) plant diversity scores than either the crest or river face.

When the data were analysed in terms of plant diversity within plant communities, similar differences were found to those of species-richness (Figure 4.121). Communities A and B had significantly higher plant diversity than the other communities ($p<0.05$). But whereas Community E had a relatively high species-richness, it showed one of the lowest average plant diversity scores. This is because the main sward in Community E was still strongly dominated by a few coarse grass and tall herb species, despite several ruderals species being present where aquatic dredgings had been deposited. The relatively low plant diversity values of Community C (which generally received six cuts per year) can be linked to higher Ellenberg Indicator Values for nitrogen, presumably in response to the frequent presence of geese and swans roosting on this part of the bank.

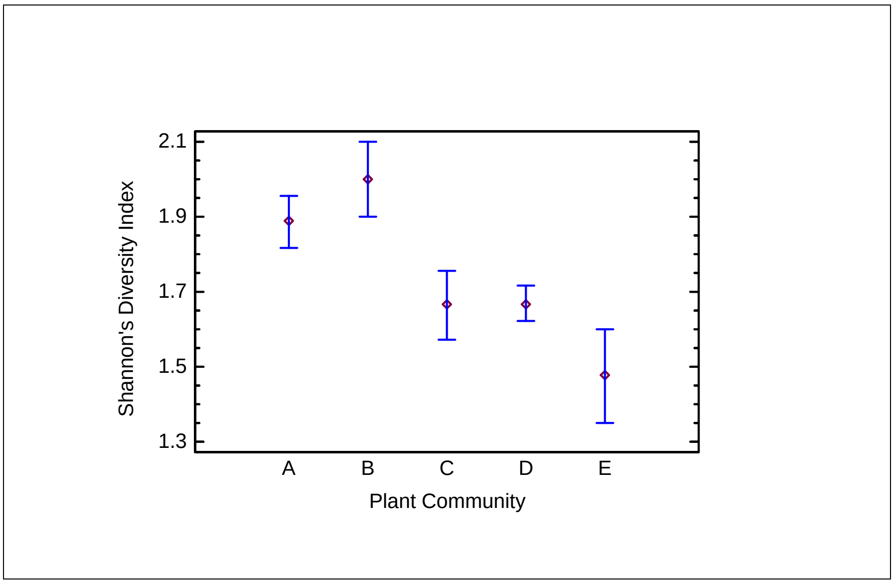


Figure 4.121 Mean plant diversity (using Shannon's Diversity Index) of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Leaf litter cover

ANOVA calculations showed that there were significant differences in the average percentage cover of leaf litter between treatments (Figure 4.122). Treatments 2 and 10 had the greatest percentage cover of leaf litter, which was significantly higher ($p<0.05$) than all but that for Treatment 1. Treatment 5 showed the lowest leaf litter cover values, which were significantly lower than all but those for Treatment 4. No significant difference was found in the percentage cover of leaf litter in Treatments 4, 7, 9 and 11, despite Treatment 7 including the collection of arisings after cutting.

Significant differences were recorded in the percentage cover of leaf litter between embankment faces ($p<0.05$). The river face had the highest values and the crest the lowest. However, no significant differences ($p<0.05$) were recorded between survey months.

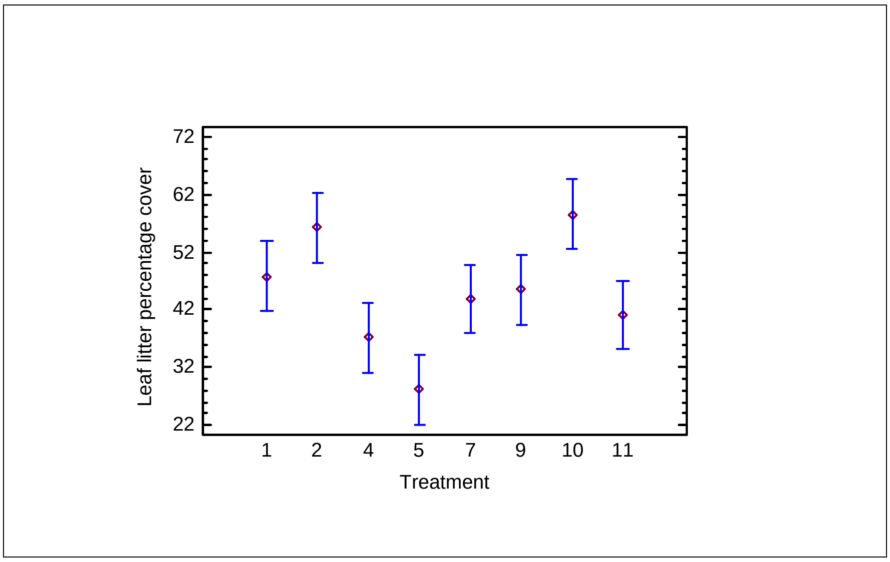


Figure 4.122 Mean leaf litter percentage cover of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

In terms of plant communities, only Community A had significantly lower ($p<0.05$) percentage cover of leaf litter than the other communities (Figure 4.123).

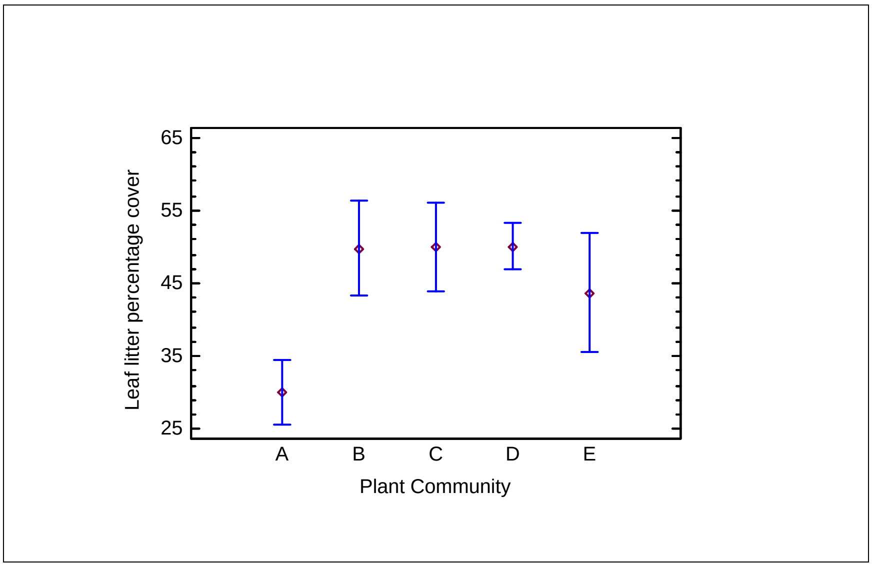


Figure 4.123 Mean leaf litter percentage cover of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

But when the percentage cover of aquatic litter was analysed, further differences became apparent. Communities D and E had significantly higher ($p<0.05$) aquatic litter cover than all other communities, with Communities A, B and C showing virtually no aquatic litter (Figure 4.124).

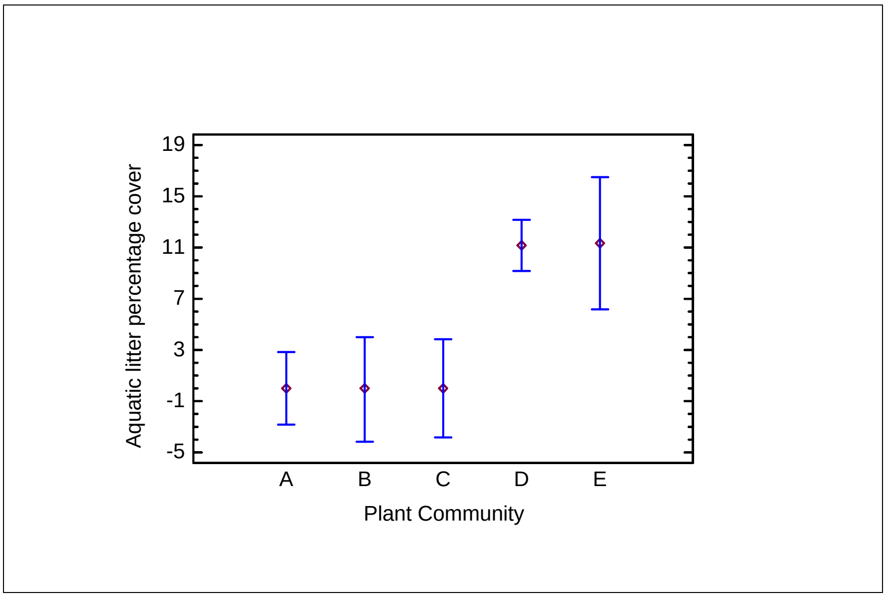


Figure 4.124 Mean aquatic litter percentage cover of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Changes over time

Leaf litter increased in all recording plots between Years 1 and 5, but the degree of change was not significantly different between treatments (Figure 4.125). This may be because the principal factor at this site appears to be the embankment face rather than treatment type. However, subtle differences were apparent between Treatments 2, 7 and 10 (which showed the greatest increase in leaf litter cover) and Treatments 1, 4, 5, 9 and 11 (which in some recording plots showed no increase in leaf litter at all).

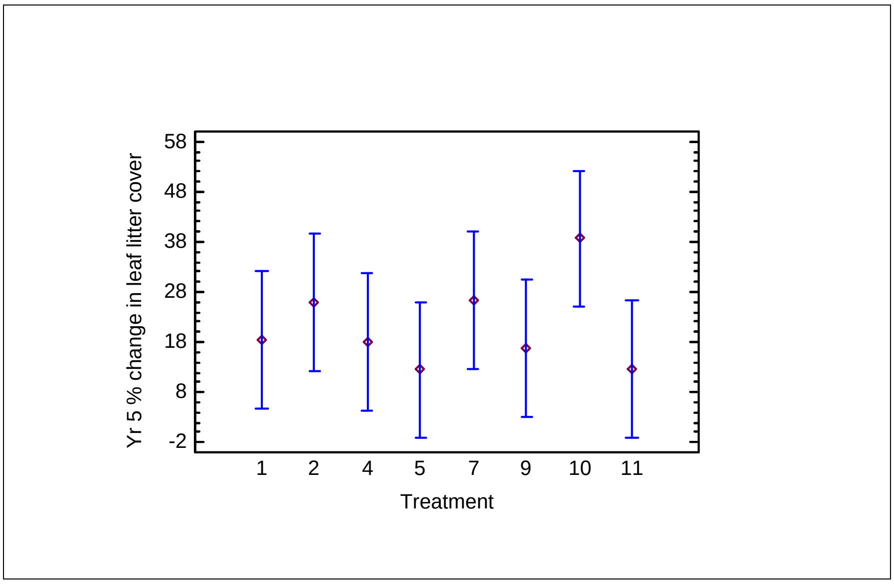


Figure 4.125 Percentage change of mean leaf litter cover between Years 1 and 5 for treatments at Reach Lode.

Bars represent least significant differences (LSD).

In contrast, significant differences ($p<0.05$) were found in the percentage change of aquatic litter cover by Year 5, with Treatment 11 (control) showing the greatest percentage increase (c.6 per cent) while Treatment 10 showed the greatest percentage decrease (c.30 per cent) (Figure 4.126).

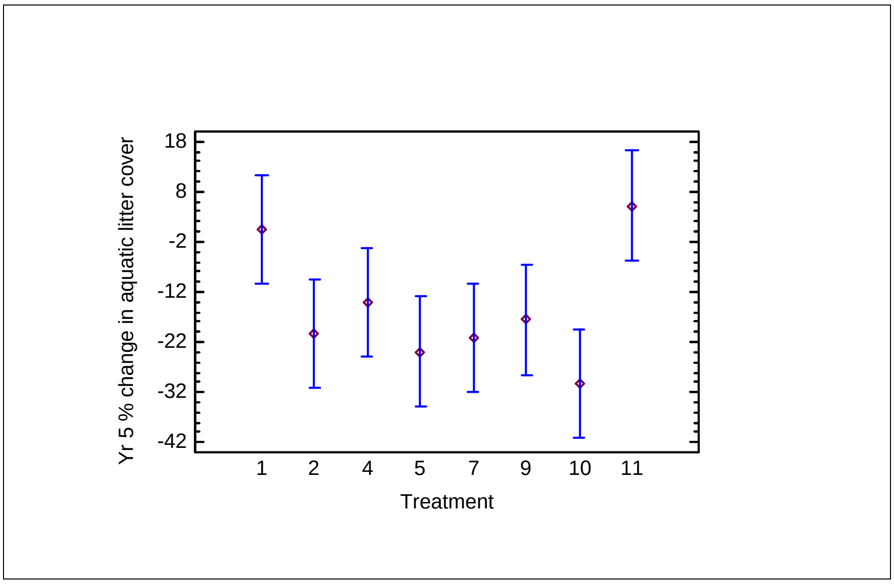


Figure 4.126 Percentage change of mean aquatic litter cover between Years 1 and 5 for treatments at Reach Lode.

Bars represent least significant differences (LSD).

Bare ground cover

Analysis showed that significant differences in the percentage cover of bare ground were recorded between treatments (Figure 4.127). Treatment 5 showed the greatest amount of bare ground cover, which was significantly higher ($p<0.05$) than found in Treatments 2, 4, 10 and 11. This may at least in part be due to the absence of leaf litter in this treatment, which might otherwise obscure the extent of bare ground visible. Treatment 1 also had substantial amounts of bare ground, though this did not appear to be due to an absence of leaf litter and so may reflect the vulnerability of the sward to erosion. Treatments 10 and 11 had the lowest percentage cover of bare ground.

Significant differences were found in the percentage cover of bare ground between embankment faces and survey months ($p<0.05$). The river face had significantly lower cover of bare ground than the crest or landward faces and August had significantly lower cover of bare ground than April or June.

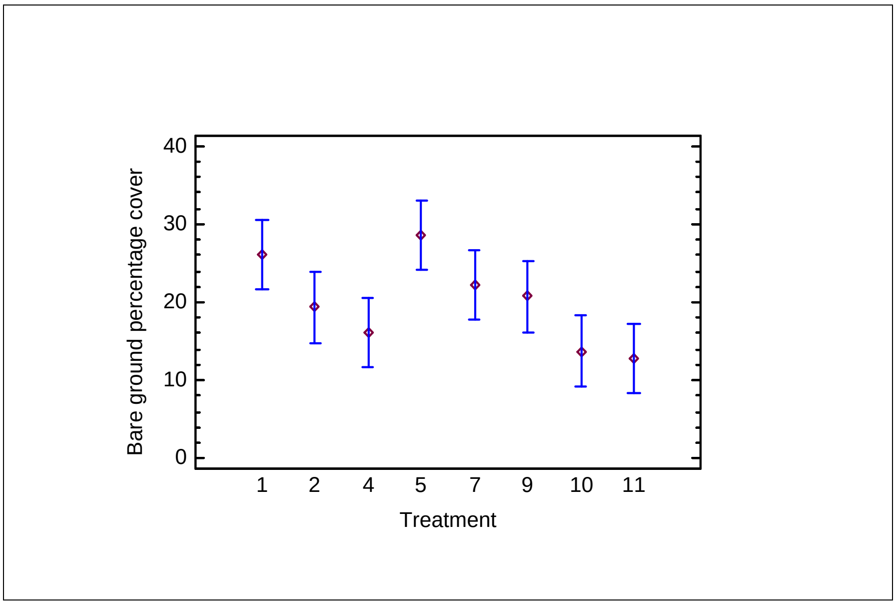


Figure 4.127 Mean bare ground percentage cover of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

In terms of plant communities, Community E had significantly higher ($p<0.05$) percentage cover of bare ground than Communities B, C or D, with Community A recording plots also containing significantly higher bare ground cover than D (Figure 4.128). As stated previously, the large amount of bare ground recorded in Community E is at least in part due to the presence here of large quantities of aquatic silt dredgings. Community D had the lowest percentage cover of bare ground (12–17 per cent).

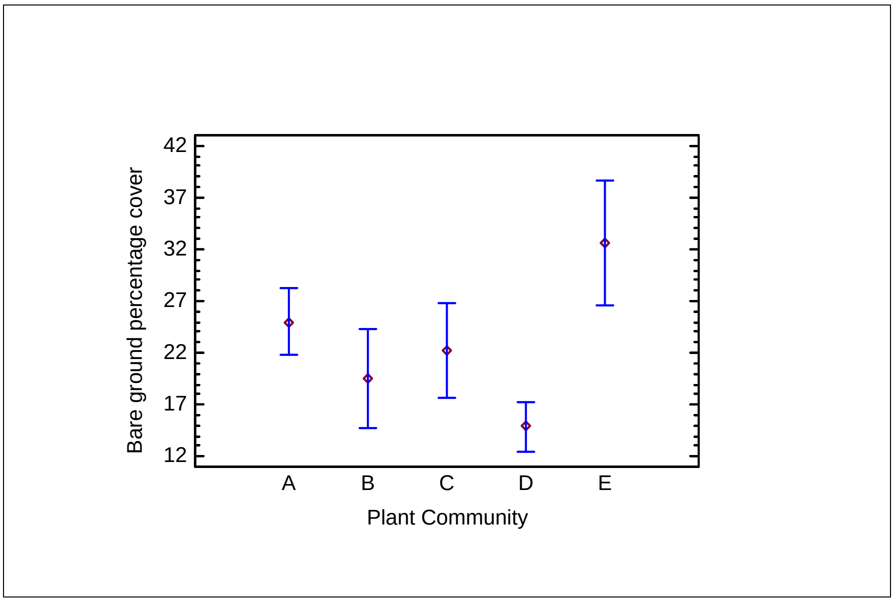


Figure 4.128 Mean bare ground percentage cover of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Changes over time

When the percentage change of bare ground from Years 1 to 5 was analysed, no significant differences ($p<0.05$) were found between treatments (Figure 4.129). Treatment 4 did show a noticeable drop in bare ground cover by Year 5, which may be due to the build up of leaf litter. Once again, the data indicate that the differences in bare ground percentage cover over the trial period were not substantial enough to be significant after five years. This may be because the principal factor at this site appears to be embankment face rather than treatment type.

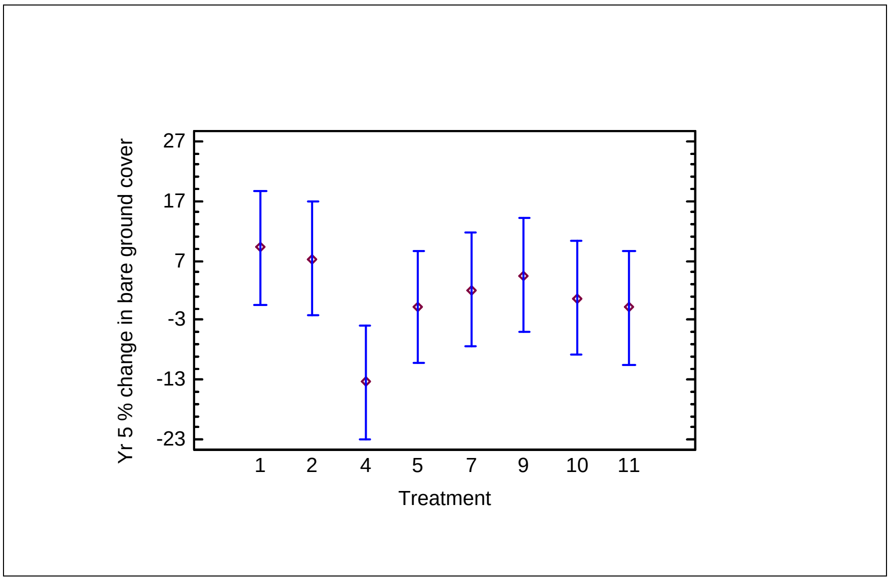


Figure 4.129 Percentage change of mean bare ground percentage cover between Years 1 and 5 for treatments at Reach Lode.

Bars represent least significant differences (LSD).

Bryophyte (moss and liverwort) cover

ANOVA calculations showed significant differences (p<0.05) in the percentage cover of bryophytes between treatments, although they were generally very scarce across the site as a whole (Figure 4.130). Treatment 5 showed the greatest cover of bryophytes (c.30 per cent), followed by Treatment 2 (c.8 per cent). Treatments 1, 10 and 11 were particularly poor for bryophytes.

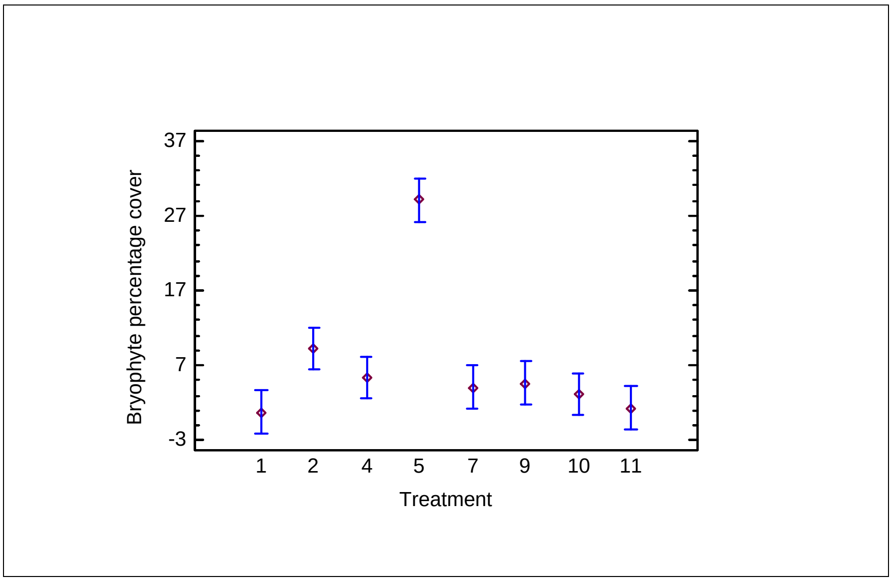


Figure 4.130 Mean bryophyte percentage cover of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Significant differences (p<0.05) were also recorded in the percentage cover of bryophytes between embankment faces and between survey months. The crest had significantly more bryophyte cover than the landward or river faces. The June survey recorded significantly less bryophyte cover than the April or August surveys. The low August figure may be explained by the much drier conditions. In terms of plant communities, Communities A and B had significantly higher (p<0.05) bryophyte cover than Communities C, D and E (Figure 4.131).

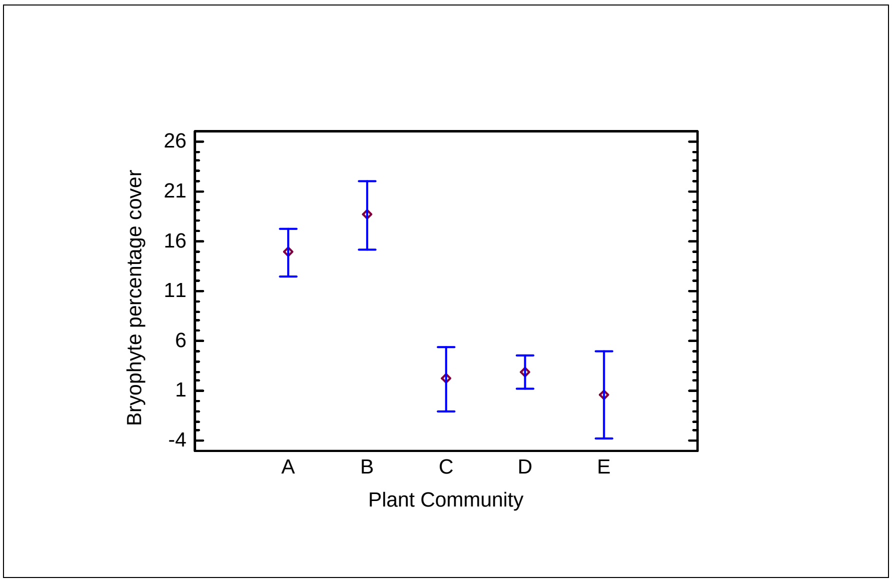


Figure 4.131 Mean bryophyte percentage cover of vegetation recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

When the change in percentage cover of bryophytes between Years 1 to 5 was analysed, significant differences were found between treatments (Figure 4.132). Treatment 5 showed the greatest increase in bryophyte cover over the five years (averaging 19 per cent), which was significantly higher than all other treatments ($p<0.05$). Treatments 2 and 7 also showed significantly higher ($p<0.05$) increases in bryophyte cover when compared to Treatments 1 and 4 (which showed the least increase in cover).

The results indicate that bryophyte abundance increased the most where arisings were collected after cutting, thus affording greater light penetration to the ground layer.

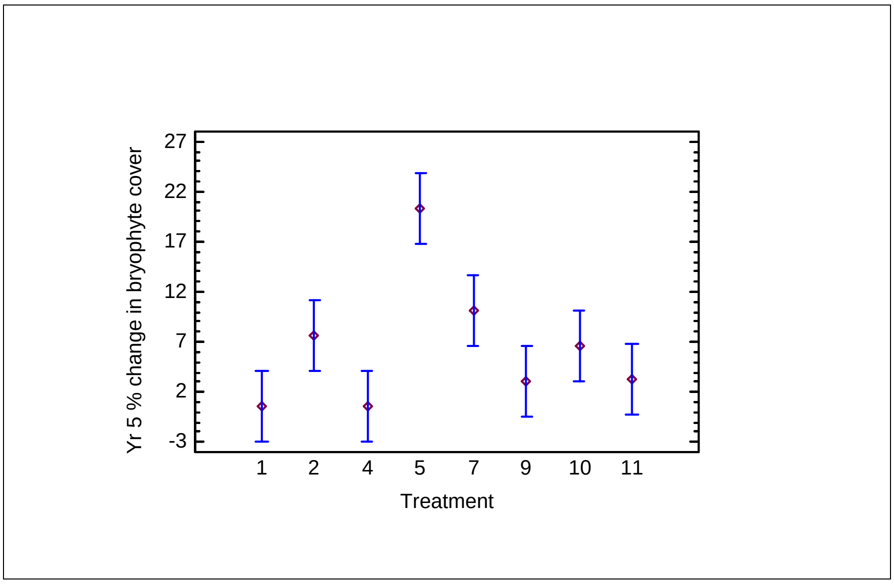


Figure 4.132 Percentage change of mean bryophyte cover between Years 1 and 5 for treatments at Reach Lode.

Bars represent least significant differences (LSD).

Mean vegetation height

Statistical analysis showed that Treatments 4, 7, 9, 10 and 11 all had significantly taller ($p<0.05$) swards than Treatments 1, 2 and 5 (Figure 4.133). This was because, by June, these treatments had already been cut at least once There was no significant difference ($p<0.05$) between the vegetation heights of treatments cut six times a year compared to those cut only three times a year.

Significant differences ($p<0.05$) were also recorded in the vegetation heights between embankment faces and between survey months. Both the river and landward faces had significantly taller vegetation than the crest, while the June survey recorded significantly taller vegetation than the April or August surveys.

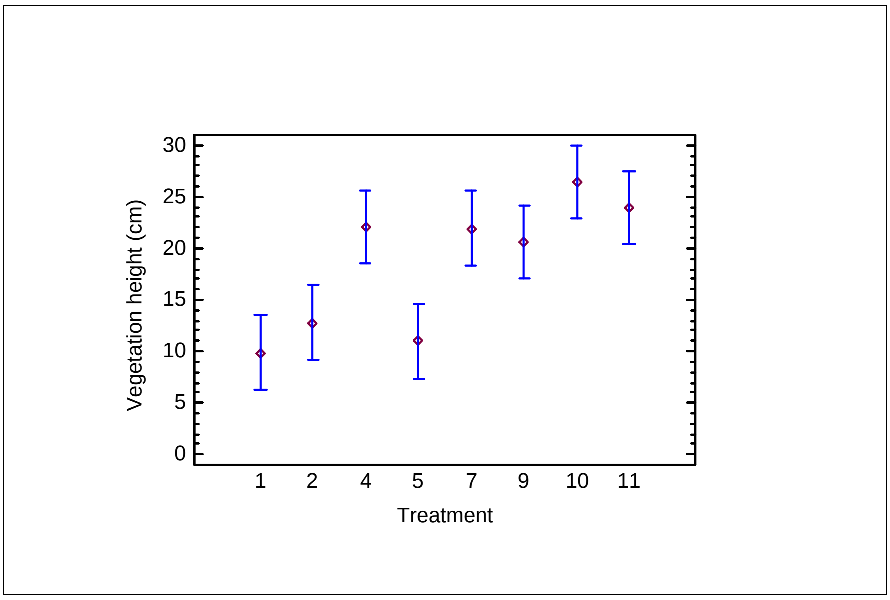


Figure 4.133 Mean vegetation height of vegetation recording plots at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

In terms of plant communities, Communities D and E had significantly higher ($p<0.05$) sward heights than occurred in all other communities (Figure 4.134). This reflected the dominance in these communities of competitive species such as *Arrhenatherum elatius* and *Elytrigia repens*.

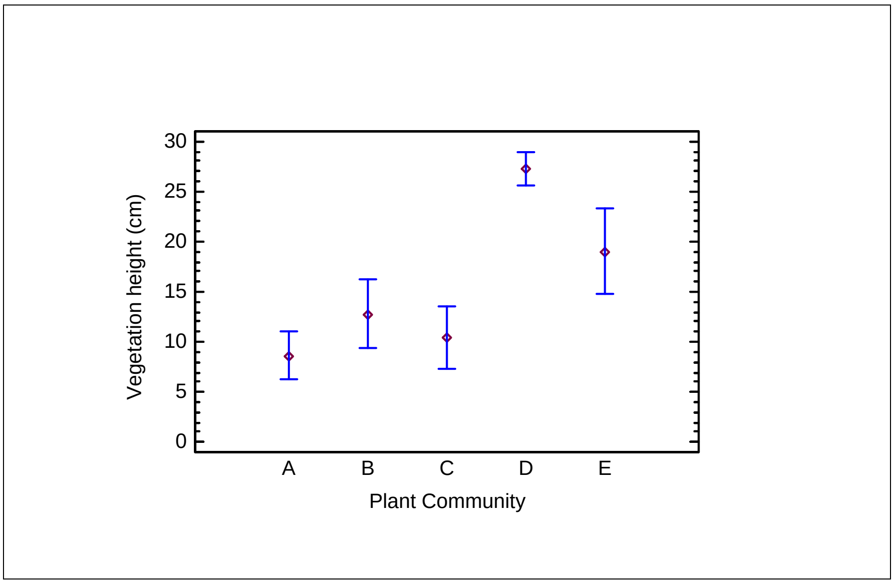


Figure 4.134 Mean vegetation height of recording plots at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Total vegetation cover

ANOVA conducted on total vegetation cover data showed only one significant difference ($p<0.05$) between treatments at Reach Lode, namely that Treatment 11 (control) had the lowest total vegetation cover (Figure 4.135).

However, more subtle differences in the data indicate that:

- where treatments involved cutting three times per year, total vegetation cover was greater when arisings were removed;
- on treatments cut once per year the reverse is true.

The river face was shown to have significantly higher total vegetation cover than the other two faces, while vegetation cover was found to be significantly lower in April than in June or August.

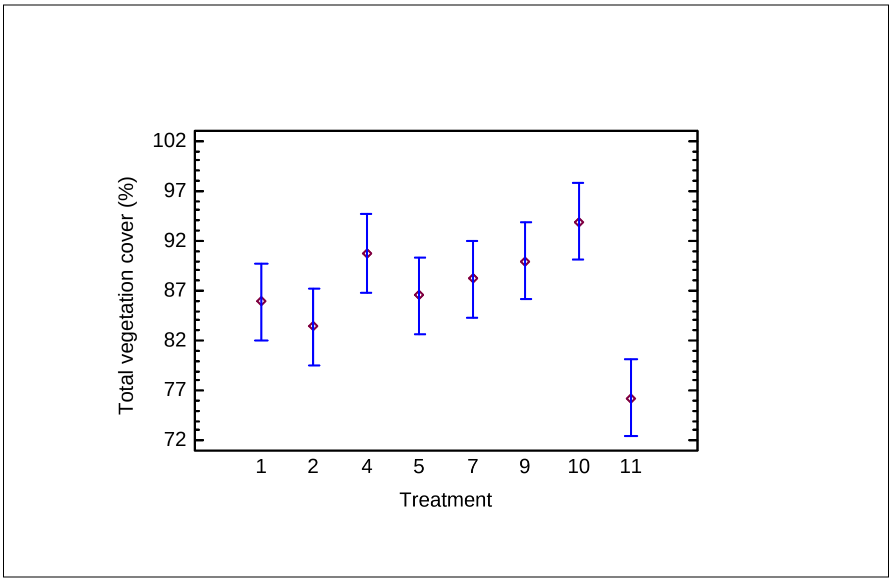


Figure 4.135 Mean total vegetation cover of vegetation recording plots for treatments at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Plant communities showed a wide range of total vegetation cover values (Figure 4.136). Communities A and C had the lowest cover, although not significantly ($p<0.05$). Community A is found on the crest of the embankment, while Community C is grazed by geese and swans as well as receiving six cuts per year.

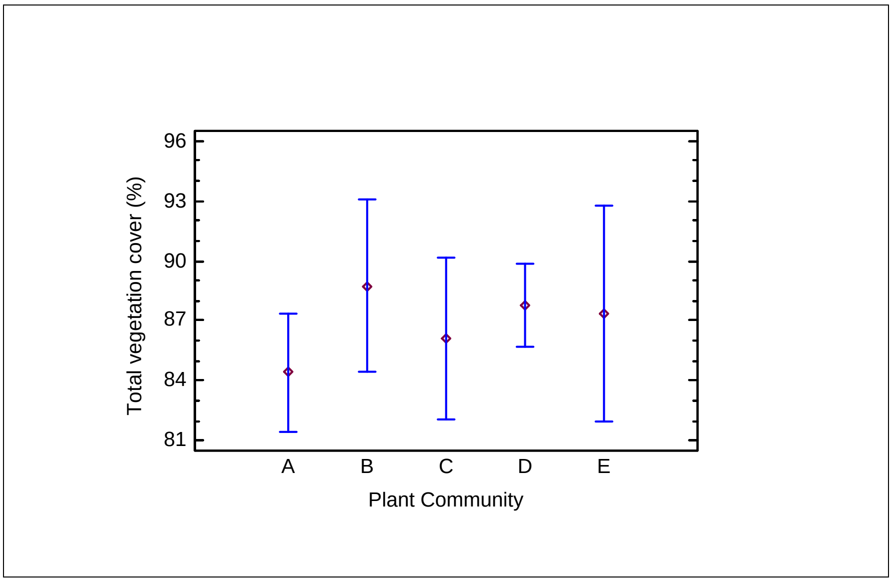


Figure 4.136 Mean total vegetation cover of recording plots for plant communities at Reach Lode, Year 5.

Bars represent least significant differences (LSD).

Dry weight of arisings

ANOVA calculations were not possible on arisings data due to the nature of the data. However, direct comparison between years showed that all treatments had experienced an increase in the dry weight of arisings collected per square metre (Figure 4.137).

Treatments 1, 2, 3 and 5 had the highest dry weight in Year 1 (at approximately 634–908 g/m^2). Treatment 6 should probably also be classed in this group as the values for both Treatments 5 and 6 are underestimates due to a missed survey month. All these treatments received 2–6 cuts per year.

By Year 3, all treatments showed an increase in the dry weight of arisings collected, particularly Treatments 7 and 8. By Year 5, Treatments 1, 2, 5 and 9 were still generating a high dry weight of arisings (>1,500 g/m^2).

Treatments cut twice per year showed the least change between Years 1 and 5, while treatments cut only once per year generally showed dramatic increases by Year 3, which continued to a lesser extent in Year 5.

Treatment 9, where weedkiller was used, showed a considerable increase in dry weight of arisings by Year 5 – more so than where growth retardant was used. This result was contrary to that found at Billingborough.

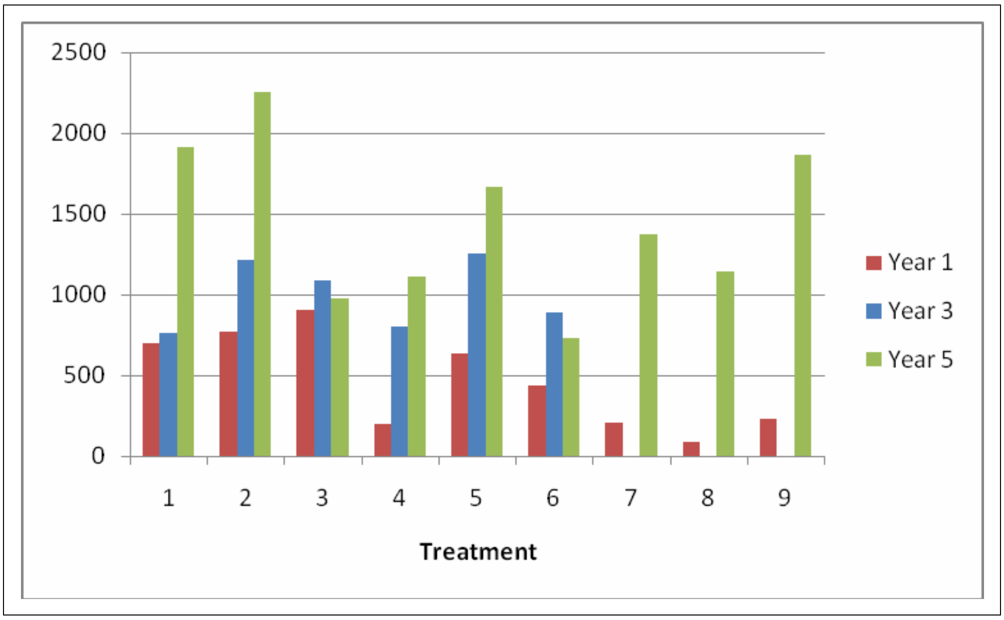


Figure 4.137 Total annual arisings (g/m^2) at Reach Lode in Years 1, 3 and 5 – river face.

Note: Treatments 5 and 6 are underestimates in Year 1 due to missing data.

The landward face showed similar patterns to those found on the river face in that Treatments 1, 2, 3 and 5 in Year 1 had the highest dry weight of arisings (c.1,200–1,800 g/m^2) (Figure 4.138). In Year 3, several treatments showed a decline in dry weight of arisings but this appears to have been temporary and may therefore be climate related. By Year 5, all treatments saw an increase in the dry weight of arisings collected, with the exception of Treatment 3 and possibly Treatment 5 (the result shown is missing one month's data on arising collection in Year 1).

Thus by Year 5, those treatments with the greatest weight of arisings were Treatments 2, 4 and 5 (all exceeding 1,500 g/m^2).

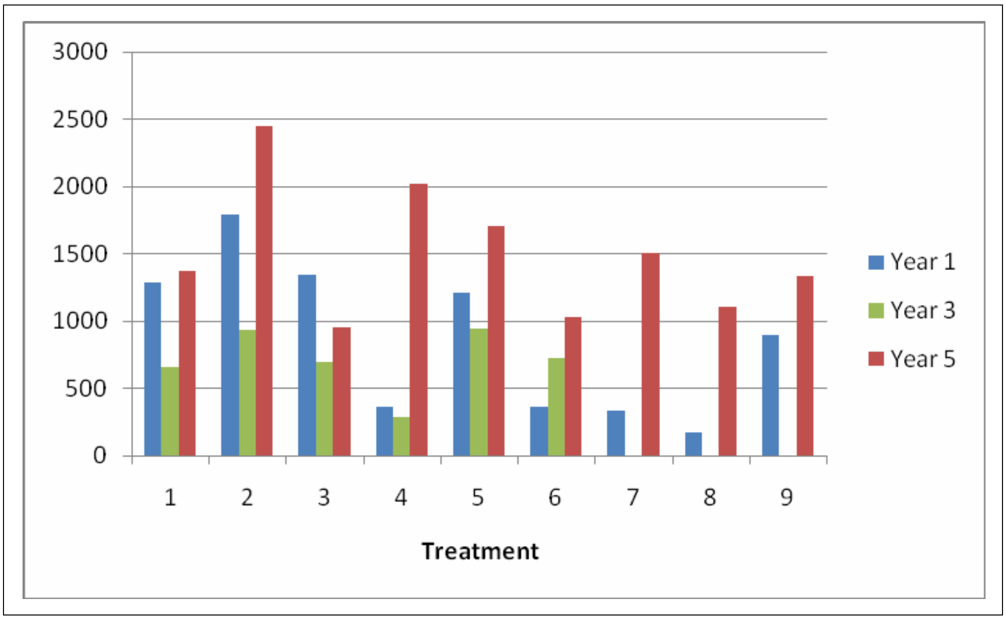


Figure 4.138 Total annual arisings (g/m^2) at Reach Lode in Years 1, 3 and 5 – landward face.

Note: Treatments 5 and 6 are underestimates in Year 1 due to missing data.

Figure 4.139 shows the overall percentage change in total annual arisings recorded in each treatment from Years 1 to 5.[13]

- Only Treatment 3 had a fall in the production of arisings on the landward face.
- Treatments 4, 7 8 and 9 showed the greatest increase in the production of arisings on both embankment faces, strongly suggesting that these treatments (i.e. cutting no more than once a year) lead to large quantities of arisings.
- On the whole, there was very little difference between the dry weight of arisings collected in treatments where the arisings were collected after cutting compared with the dry weight of arisings where they had been left on previously.

[13] With the exception of data for plots 5 and 6, which were unrecorded in Year 1.

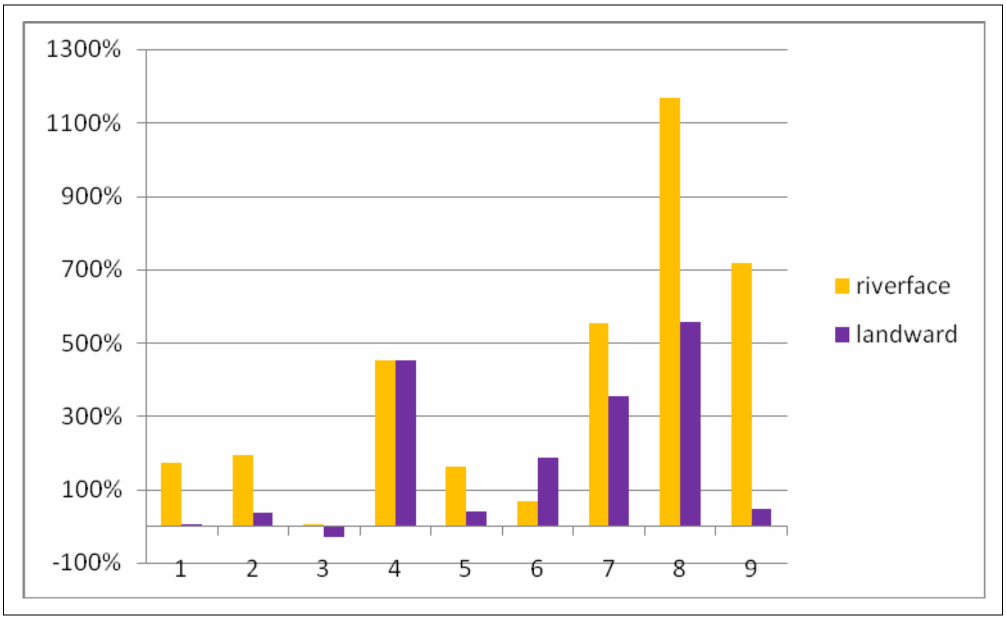


Figure 4.139 Percentage change in dry weight of arisings recorded at Reach Lode by Year 5.

Note: Treatments 5 and 6 are underestimates in Year 1 due to missing data.

Vegetation summary: Reach Lode

Reach Lode was a richer site botanically than Billingborough. Five distinctive communities were identified (A–E) of which only Communities A and B contained moderately species-rich swards dominated by finer leaved grasses. Community E was also moderately rich, but this was a local and unusual community whose 'richness' was due to ruderals growing on dredging spoil. In contrast, Communities C and D, the most extensive vegetation types, were dominated by coarse grasses and consequently species-poor. The species composition of each is presented in Table 4.29.

Treatments that had comparatively intensive cutting regimes had distinctive plant communities.

- Community C was wholly associated with mowing six times per year (Treatment 1) and was present even on the crest.
- Community E was also directly linked to treatment type, as it was associated only with localised but heavy deposition of silt from aquatic dredgings. This localised treatment overrode even mowing six times per year.
- Community B was found only where swards were mown three times per year, although there appears to be some effect of aspect as it was mostly found on the river face. The distinctive feature of this community was its high frequency of fen species, reflecting the consistently high water levels and very narrow, water-edge recording plots particularly characteristic of the Reach Lode embankment.
- Outside of these treatments, the vegetation was the species-poor and coarse Community D, which dominated the landward and river faces of all of the low-intensity treatments (0–1 cut per year).
- Community A was restricted to the crest, regardless of the treatment type.

As at Billingborough, particular variants of treatment types such as removal of arisings, application of growth retardant and herbicide made no difference to community type.

Examination of vegetation data in Years 1, 3 and 5 shows a consistent pattern across all the vegetation types. The vegetation samples within a community are quite dissimilar in Year 1 and are spread out on the PCA diagram. As the impact of management type accumulates through the years, the samples converge, forming tighter groupings on the ordination. The strongest forms of management show the greatest degree of convergence. The weakest treatments (0–1 cut per year) show least convergence, which is mostly completed by Year 3. Community E had so few vegetation recording plots that this analysis was not meaningful. Communities A, B and C, comparatively species-rich, were still moving position by Year 5, but the degree of movement was by then very small, while Community D showed no shift in position. It is concluded that the vegetation recording plots would not have changed significantly if the management experiment had been prolonged. Overall, the vegetation shift indicated a transition in all recording plots from vegetation with more frequent ruderal species to grassier more mesotrophic vegetation, reflecting the impact of stable management.

Table 4.30 summarises the main differences between treatments for vegetation metrics. Treatment type was also a significant influence on species richness and diversity, the most diverse treatments being those cut six times per year and the poorest being the unmanaged Treatment 11. This correlated with other factors; the richest Treatment 5 also had greatest percentage cover of bare ground, least percentage cover of leaf litter and the highest percentage cover of bryophytes. The richer treatments were short and more open (as indicated by Ellenberg Indicator Values for light) while species-poor treatments had a significantly taller sward. Removing arisings may not have affected community type, but it did increase species richness. All communities showed an increase in species richness over time, with those treatments cut most frequently showing a greater increase than those managed less intensively.

Table 4.30 Main differences (p<0.05) between treatments in Year 5 at Reach Lode for vegetation/sward factors.

	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Plant species-richness			-		H	-		-			L
Plant diversity			-	H	H	-		-		H	L
Leaf litter cover		H	-	L	L	-		-		H	
Bare ground cover	H		-	L	H	-		-		L	L
Bryophyte cover	L		-		H	-		-			L
Vegetation height	L	L	-	H	L	-	H	-	H	H	H
Total vegetation cover			-			-		-			L
Arisings river*	H	H	L	L	H	L			H		
Arisings land*		H	L	H	H	L					

* Not significance tested but observed differences.
H = relatively high value, L = relatively low value.

4.6.3 Ely Ouse

Floristic composition

Ely Ouse had the most extensive list of plant species of all three trial sites, facilitating the effectiveness of the TWINSPAN process. The first three divisions made by TWINSPAN resulted in eight community groups. One of the divisions had an insufficient number of vegetation recording plots to be considered a viable separation and therefore this division was amalgamated as shown.

When a PCA was performed on the Ely Ouse data set, all seven communities were found to occupy different areas on the PCA diagram (Figure 4.140). Thus no further amalgamation was necessary. Very few 'marginal' recording plots were found within the Ely Ouse data, confirming the strength of the divisions.

A synoptic table was constructed for the Ely Ouse data (Table 4.31). Brief descriptions of each community are provided below.

<u>Community A</u>

This was a species-rich sward, where no single species was dominant but instead mixtures of *Festuca rubra*, *Holcus lanatus*, *Lolium perenne*, *Poa trivialis*, *P. pratensis* and *Trisetum flavescens* were abundant. Equally as abundant were herbs of *Centaurea nigra*, *Achillea millefolium*, *Tragopogon pratensis*, *Ranunculus bulbosus* and *Trifolium pratense*. The flora was supplemented by distinctive occasionals of *Vicia cracca*, *Carex hirta*, *Lotus corniculatus* and *Prunella vulgaris*. Bryophytes were present in small amounts (with a mean cover of 6 per cent), and this community had the lowest mean total vegetation cover recorded for the site (85 per cent). See Figure 4.141.

<u>Community B</u>

Community B continued to contain *Festuca rubra* and *Lolium perenne* as key sward components, but with a slightly increased coarse grass element of *Arrhenatherum elatius* and *Bromus hordeaceus*. The vegetation was still species-rich with *Centaurea nigra*, *Plantago lanceolata*, *Achillea millefolium*, *Geranium molle* and *Vicia sativa* constant, but was marked by the frequency of *Convolvulus arvensis*, *Crepis vesicaria*, *Crepis capillaris*, *Trifolium campestre* and *Ranunculus repens*. Occasionals of *Lapsana communis*, *Hordeum secalinum*, *Leucanthemum vulgare* and *Papaver rhoeus* were also distinctive of the sward. The community contained moderate bryophyte cover (9 per cent) and had a relatively high mean bare ground cover of 17 per cent. See Figure 4.142.

<u>Community C</u>

This moderately species-rich sward was similar to Community B in that there was a constant presence of small herbs and grasses such as *Lolium perenne*, *Taraxacum officinale*, *Plantago lanceolata*, *Tragopogon pratensis*, *Crepis vesicaria*, *Achillea millefolium* and *Geranium dissectum*, but differed with the strong dominance of *Arrhenatherum elatius* at the expense of fine-leaved grasses such as *Festuca rubra*. Community C was marked by a greater frequency of ruderal species such as *Lactuca serriola* and *Picris echioides*, as well as occasionals of *Phleum bertolonii*, *Trifolium repens*, *Artemisia vulgaris*, *Malva sylvestris* and *Rumex acetosa.* This community recorded the highest mean bare ground cover for Ely Ouse (18 per cent) but also the highest bryophyte cover of 28 per cent. See Figure 4.143.

<u>Community D</u>

This species-poor sward was heavily dominated by *Arrhenatherum elatius*, with abundant *Elytrigia repens* and *Dactylis glomerata*. Fine grasses and small herbs such as *Lolium* *perenne*, *Achillea millefolium*, *Poa trivialis* and *Geranium molle* were still present in the sward but at much lower frequency than occurred in Communities A–C. Ruderals of *Picris echioides* and *Lactuca serriola* were very frequent, as was *Anisantha sterilis* and *Galium aparine* (though at low abundance). Total vegetation cover was particularly high in this community (100 per cent), with no bryophytes recorded and high bare ground cover values averaging 18 per cent. See Figure 4.144.

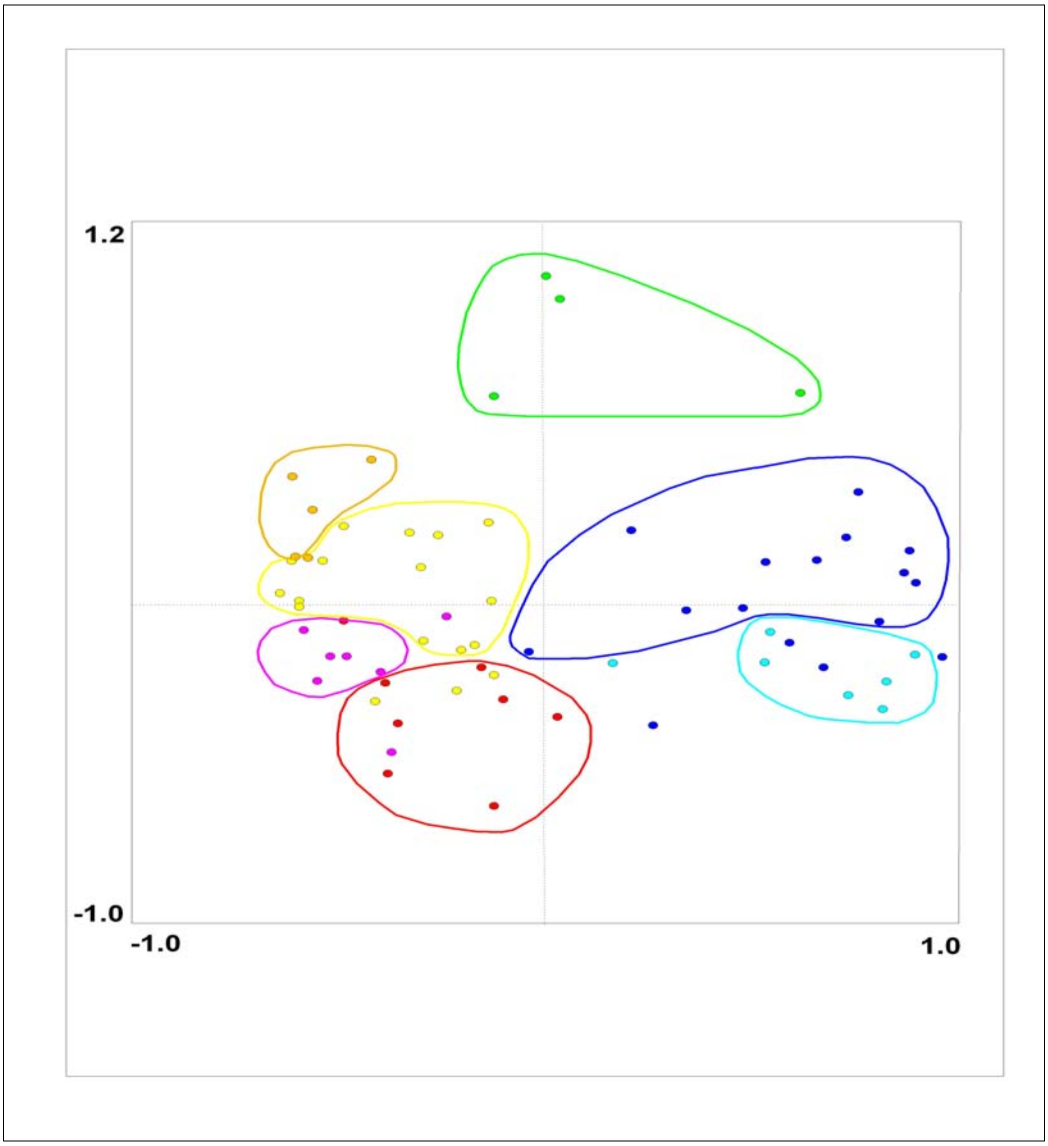


Figure 4.140 PCA diagram of vegetation recording plots for Ely Ouse using June data from Year 5 (showing axes 1 and 2).

Samples are represented by dots (Community A = pale blue, B = dark blue, C = green, D = yellow, E = orange, F = pink and G = red).
Coloured lines represent the core zone occupied by that community.

Table 4.31 Synoptic table for plant communities recorded at Ely Ouse[1].

	Plant community						
	A	B	C	D	E	F	G
Bare ground cover	10%	17%	18%	18%	8%	6%	11%
Bryophyte cover	6%	9%	28%	0%	0%	0%	0%

	Plant community						
	A	B	C	D	E	F	G
Leaf litter cover	65%	47%	15%	57%	70%	80%	75%
Aquatic litter cover	0%	0%	0%	0%	0%	0%	0%
Total vegetation cover	85%	93%	91%	100%	96%	99%	97%
Plant species-richness	25	24	19	15.1	11	16	0.17
Ellenberg Indicator Value for light	6.64	7.06	6.10	7.05	7.05	6.88	6.86
Ellenberg Indicator Value for moisture	4.67	4.80	4.24	5.04	5.09	5.36	5.17
Ellenberg Indicator Value for reaction	6.10	6.56	5.55	6.76	7.04	6.70	6.66
Ellenberg Indicator Value for nitrogen	4.88	5.39	4.97	6.22	6.24	6.31	6.12
Arrhenatherum elatius	V (3–5)	V (4–9)	**V (8–9)**	**V (7–10)**	**V (8–10)**	**V (8–10)**	**V (8–9)**
Potentilla repens	V (3–5)	V (2–5)	V (3–7)	V (2–5)	IV (2–7)	V (3–6)	IV (2–5)
Dactylis glomerata	V (3–5)	V (3–5)	III (2–4)	V (1–5)	V (3–4)	V (4–5)	V (3–5)
Heracleum sphondylium	IV (1–3)	V (2–5)	V (2–4)	V (2–5)	II (3–3)	V (3–4)	V (2–4)
Lolium perenne	**V (2–7)**	**V (2–7)**	**V (4–6)**	III (3–6)	–	I (5–5)	II (4–4)
Plantago lanceolata	**V (2–3)**	**V (1–5)**	**V (3–5)**	I (1–1)	I (2–2)	II (2–2)	I (1–1)
Tragopogon pratensis	**V (1–4)**	**V (1–3)**	**V (3–5)**	III (1–2)	I (3–3)	–	I (1–1)
Festuca rubra	**V (5–7)**	**V (4–6)**	II (3–3)	I (3–3)	–	V (2–4)	**V (3–5)**
Centaurea nigra	**V (2–4)**	**IV (2–5)**	III (2–3)	II (2–3)	–	I (3–3)	II (2–2)
Achillea millefolium	**V (1–3)**	**V (1–4)**	**IV (4–7)**	III (1–2)	–	I (3–3)	III (2–3)
Poa trivialis	**V (4–5)**	IV (3–6)	III (3–4)	III (2–4)	I (3–3)	**V (3–5)**	IV (4–5)
Glechoma hederacea	**V (1–4)**	III (1–3)	–	I (3–3)	I (4–4)	II (3–3)	III (3–4)
Poa pratensis	**V (3–4)**	–	III (3–3)	–	–	–	–
Trisetum flavescens	**V (3–6)**	**IV (4–5)**	–	–	–	–	III (2–4)
Holcus lanatus	**IV (5–7)**	**IV (3–5)**	II (2–2)	–	–	–	III (2–4)
Ranunculus bulbosus	**IV (1–3)**	**III (2–2)**	–	I (1–1)	–	–	–
Trifolium pratense	**IV (3–5)**	**IV (2–4)**	II (4–4)	I (2–2)	–	–	–
Senecio jacobaea	**III (1–1)**	**II (1–3)**	II (3–3)	–	–	–	–
Senecio erucifolius	**III (2–2)**	**II (1–3)**	–	–	–	–	–
Sonchus asper	**III (1–1)**	**II (1–3)**	–	–	–	–	I (1–1)
Vicia cracca	**III (1–2)**	–	–	–	–	–	I (3–3)
Carex hirta	**II (3–4)**	–	–	–	–	–	–
Lotus corniculatus	**II (3–3)**	–	–	–	–	–	–
Prunella vulgaris	**II (3–4)**	–	–	–	–	–	–
Dipsacus fullonum	**I (1–1)**	–	–	–	–	–	–
Medicago lupulina	**I (3–3)**	I (2–2)	–	–	–	–	–
Myosotis sp	**I (1–1)**	–	–	–	–	–	–
Vicia sativa	**IV (2–3)**	**V (2–4)**	III (1–2)	I (1–1)	I (1–1)	I (1–1)	III (2–3)

	Plant community						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Geranium molle	**IV (2–3)**	**V (1–3)**	–	III (1–3)	–	II (1–2)	–
Bromus hordeaceus	IV (2–2)	**V (3–5)**	**V (3–4)**	III (1–4)	**IV (3–5)**	I (3–3)	I (3–3)
Convolvulus arvensis	I (3–3)	**IV (1–3)**	–	I (1–3)	–	–	**IV (2–4)**
Crepis capillaris	I (1–1)	**III (1–3)**	–	–	–	–	–
Trifolium campestre	I (1–1)	**III (2–4)**	II (3–3)	–	–	–	–
Ranunculus repens	I (1–1)	**III (1–4)**	II (5–5)	I (1–1)	–	–	I (1–1)
Lapsana communis	–	**II (1–2)**	–	–	–	–	–
Hordeum secalinum	–	**I (4–4)**	–	–	–	–	–
Leucanthemum vulgare	–	**I (3–3)**	–	–	–	–	–
Papaver dubium	–	**I (1–1)**	–	–	–	–	–
Agrostis capillaris	–	**I (1–2)**	–	–	–	–	–
Crepis vesicaria	–	**IV (3–6)**	**V (4–5)**	I (1–4)	–	–	–
Taraxacum officinale	**III (1–2)**	**III (1–3)**	**IV (2–3)**	I (1–1)	–	I (1–1)	I (1–1)
Picris echioides	V (1–2)	III (1–2)	**IV (3–4)**	**IV (1–6)**	**IV (3–3)**	–	–
Lactuca serriola	I (1–1)	II (1–3)	**IV (1–3)**	**IV (1–4)**	I (1–1)	I (1–1)	–
Geranium dissectum	–	II (1–4)	**IV (3–3)**	III (1–5)	II (1–4)	**V (2–5)**	III (1–3)
Sonchus oleraceus	III (1–2)	I (1–1)	**III (1–3)**	III (1–2)	III (1–3)	I (1–1)	I (1–1)
Rumex acetosa	–	I (3–3)	**III (3–3)**	I (1–3)	–	III (1–4)	I (2–2)
Barbarea vulgaris	–	–	**II (3–3)**	I (4–4)	–	–	–
Malva sylvestris	I (1–1)	–	**II (2–2)**	–	II (1–3)	I (2–2)	–
Trifolium repens	I (2–2)	–	**II (1–1)**	–	–	II (3–3)	–
Phleum bertolonii	–	II (2–4)	**II (1–1)**	–	–	–	–
Artemisia vulgaris	–	–	**II (2–2)**	–	–	–	–
Elytrigia repens	III (4–5)	IV (3–4)	–	**V (3–6)**	–	II (5–5)	**V (3–5)**
Anisantha sterilis	–	I (3–4)	–	**III (1–4)**	III (3–5)	III (4–4)	II (3–5)
Lamium album	–	I (3–3)	–	**II (1–1)**	–	I (2–2)	–
Persicaria maculosa	–	–	–	**I (4–4)**	–	–	–
Crataegus monogyna	–	–	–	**I (1–1)**	–	–	–
Ranunculus ficaria	–	–	–	**I (1–1)**	–	–	–
Rubus fruticosus	–	–	–	**I (3–3)**	–	–	–
Sinapis arvensis	–	–	–	**I (1–4)**	–	–	–
Sonchus arvensis	–	–	–	**I (5–5)**	–	–	–
Agrostis stolonifera	–	II (2–3)	–	I (2–2)	**IV (4–5)**	III (3–4)	–
Calystegia sepium	–	–	III (3–3)	–	**III (3–4)**	I (3–3)	II (1–2)
Rumex crispus	–	I (1–1)	–	I (1–1)	**II (1–2)**	–	–
Anthriscus sylvestris	IV (2–2)	III (1–3)	II (1–1)	III (1–3)	IV (1–3)	**V (2–6)**	**V (1–3)**

	Plant community						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Galium aparine	–	I (1–1)	–	**V (2–3)**	II (2–2)	**V (2–7)**	**V (1–3)**
Cirsium arvense	II (1–1)	II (1–2)	II (1–1)	I (2–4)	–	**V (1–3)**	II (2–2)
Urtica dioica	–	I (2–2)	–	–	–	**III (1–3)**	**III (1–2)**
Phragmites australis	–	–	–	–	–	**III (2–3)**	–
Ranunculus acris	–	–	–	–	–	**II (1–2)**	–
Equisetum arvense	–	–	–	–	–	I (1–1)	**V (3–4)**
Lathyrus pratensis	I (2–2)	I (2–2)	–	–	–	II (3–3)	**III (2–3)**
Alopecurus pratensis	–	–	–	–	–	–	**II (1–2)**
Rosa canina	I (1–1)	I (1–1)	–	–	–	–	**II (2–4)**
Barbarea verna	–	–	–	–	–	–	**I (3–3)**
Filipendula ulmaria	–	–	–	–	–	–	**I (3–3)**
Knautia arvensis	–	–	–	–	–	–	**I (3–3)**
Rumex obtusifolius	–	I (2–2)	–	I (1–2)	–	–	I (1–1)
Rumex sanguineus	I (1–1)	–	–	I (2–2)	–	–	–

Notes [1] Bold text denotes characteristic species of the community.

Community E

Community E was also heavily dominated by *Arrhenatherum elatius*, with associates of *Bromus hordeaceus*, *Anisantha sterilis*, *Picris echioides* and *Agrostis stolonifera*. The vegetation was particularly species-poor, with a virtual absence of fine grasses and small herbs. The sward was also distinctive for the frequency of *Calystegia sepium* and *Rumex crispus*. Total vegetation cover was high and bare ground cover low (8 per cent), but no bryophytes were recorded. See Figure 4.145.

Community F

This was a moderately species-poor community, heavily dominated by *Arrhenatherum elatius*, with associates of *Dactylis glomerata* but also *Festuca rubra*, *Poa trivialis* and some herbs of *Geranium dissectum*, *Rumex acetosa*, *Ranunculus acris* and *Lathyrus pratensis*. More pronounced was the abundance and frequency of tall herbs such as *Anthriscus sylvestris*, *Cirsium arvense*, *Urtica dioica* and *Galium aparine*. There was also the suggestion of more moist conditions with the presence of *Phragmites australis* and *Agrostis stolonifera*. The sward hads a high total vegetation cover (99 per cent) and low bare ground cover (6 per cent), but no bryophytes were recorded. See Figure 4.146.

Community G

This community was similar to Community F in the dominance of *Arrhenatherum elatius* and associates of *Festuca rubra* and *Poa trivialis*, as well as the frequency of tall herb such as *Anthriscus sylvestris, Galium aparine* and *Urtica dioica*. However such tall herbs were at lower abundances here, and consequently species such as *Achillea millefolium, Glechoma hederacea, Trisetum flavescens, Holcus lanatus* and *Vicia sativa* were once again present. The sward was also distinctive for the frequency of *Convolvulus arvensis* and *Equisetum arvense*, as well as occasionals of *Lathyrus pratensis, Alopecurus pratensis, Filipendula ulmaria* and *Knautia arvensis*. The sward had a high total vegetation cover, with no bryophytes recorded. See Figure 4.147.

Figure 4.141 Ely Ouse Community A photographed on the landward face of Treatment 1 in June 2007.

Figure 4.142 Ely Ouse Community B photographed on the river face of Treatment 5 in June 2007.

Figure 4.143 Ely Ouse Community C photographed on the landward face of Treatment 5 in June 2007.

Figure 4.144 Ely Ouse Community D photographed on the landward face of Treatment 4 in June 2007.

Figure 4.145 Ely Ouse Community E photographed on the landward face of Treatment 9 in June 2007.

Figure 4.146 Ely Ouse Community F photographed on the river face of Treatment 4 in June 2007.

Figure 4.147 Ely Ouse Community G photographed on the landward face of Treatment 11 in June 2007.

Figure 4.148 shows the distribution of these plant communities across the embankment. The primary influence is treatment type. Community A was restricted to, and dominated, nearly all recording plots cut six times per year. Community B was strongly associated with, and dominated, areas cut three times per year, while Community G was wholly associated with unmanaged Treatment 11.

As at the other trial sites, where treatments were cut only once a year, the embankment face became the primary influence defining the community. Community F occurred principally on the river face and Community E on the landward face.

The association between community type and embankment face in low frequency cuts was perhaps weaker at this site than the other two, and the crest had very weak association with a particular community. The crest vegetation recording plots for this site consisted not of the central part of the bank, but of two strips on the outer side of the wheel ruts. Therefore ‘crest’ recording plots were more akin to river face and landward face vegetation here than was recorded at either of the other two trial sites.

Once again, Ely Ouse data suggest there was little difference between the vegetation found on treatments cut once a year in relation to whether arisings were collected or left *in situ*. The treatment where weedkiller was used generally contained species-poor plant communities, but with the odd vegetation recording plot showing a more diverse flora. Of those treatments receiving three cuts per year, there were some differences in plant communities recorded on the landward face (i.e. the more species-rich Community C was recorded in the treatment where arisings were collected), but generally there were no difference on the crest or river faces regardless of arising collection.

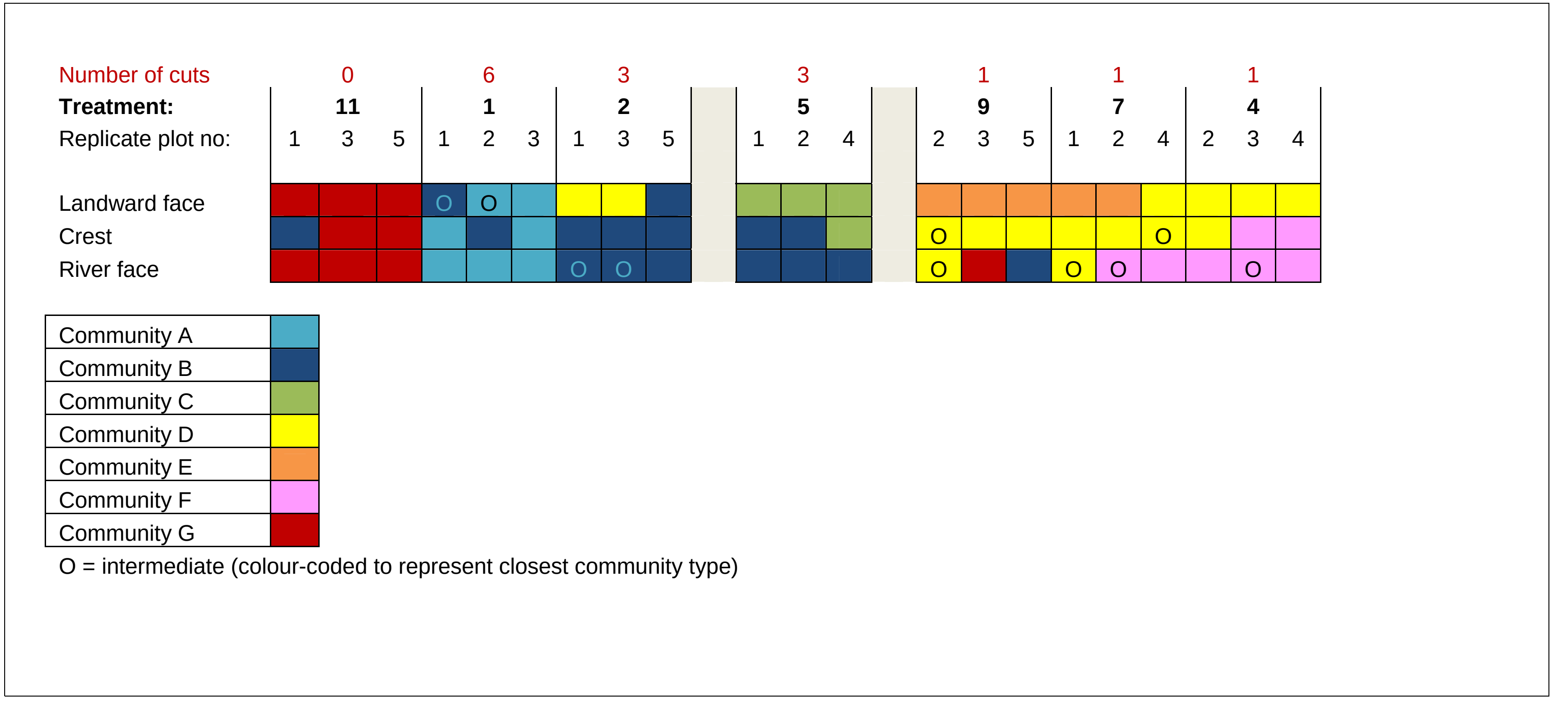


Figure 4.148 Distributions of plant communities at Ely Ouse.

Changes over time

To eliminate the possibility that these plant community differences were present in Year 1 of the trials, it was necessary to establish whether there has been a change in the floristic compositions over the five years. As with the other two sites, the April survey data were used to conduct comparisons between the floristic composition of vegetation recording plots in Years 1 and 5.

If rainfall was the only determining factor in a shift in vegetation composition between Years 1 and 5, it can be expected that all recording plots would move in the same direction on the PCA diagram. As this is not the case, it is reasonable to assume that another factor (i.e. management) was affecting composition.

The PCA diagram of species and environmental variables for Ely Ouse shown in Figure 4.149 can be used to interpret shifts in the following PCA diagrams of vegetation recording plot data. For this site:

- vegetation recording plots with a greater proportion of *Festuca rubra, Holcus lanatus* and *Crepis biennis* occur in the top right corner;
- vegetation recording plots with a greater proportion of *Anthriscus sylvestris, Urtica dioica* and *Arrhenatherum elatius* occur in the top left corner;
- vegetation recording plots dominated by *Lactuca serriola* and *Phragmites australis* occur towards the bottom left corner;
- vegetation recording plots with a greater proportion of *Poa trivialis, Ranunculus bulbosus* and *Lolium perenne* occur in the bottom right corner.

Overlaying the values of other measured variables (e.g. bare ground percentage cover) and estimated variables (e.g. Ellenberg Indicator Values for moisture) shows that those vegetation recording plots with a high Ellenberg Indicator Value for nitrogen occur on the left of the diagram, while the right of the diagram is consistent with vegetation recording plots with high species-richness. The diagram also displays those recording plots with high percentage cover of leaf litter at the bottom of the diagram, while recording plots with a greater Ellenberg Indicator Value for moisture and higher percentage cover of bryophytes occur towards the top of the diagram.

Community A

Figure 4.150 shows the shift in vegetation of recording plots from Community A in Years 1, 3 and 5. It illustrates that, in Year 1, vegetation that would later become one community generally occurred in one main cluster in the centre of the diagram. By Year 5, all vegetation recording plots were located over the far right-hand side of the diagram, showing a shift towards a more species-rich sward.

Community A is felt to represent a meaningful shift in vegetation composition because of the trend over the five-year period and because not all communities move across the diagram in the same direction (so that rainfall cannot be the only influencing factor).

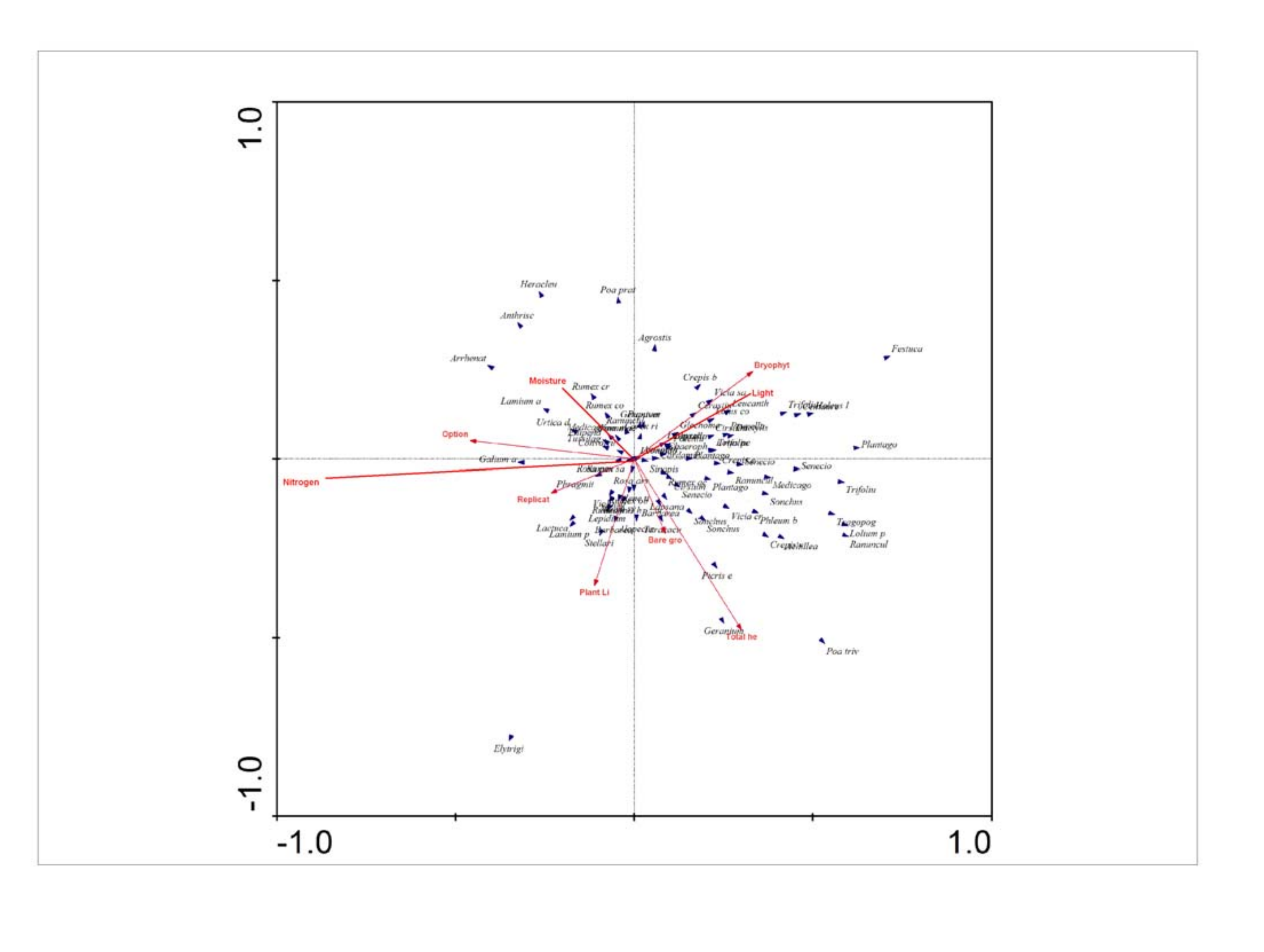


Figure 4.149 PCA diagram of vegetation data from April, Years 1, 3 and 5 at Ely Ouse – showing species and variables.

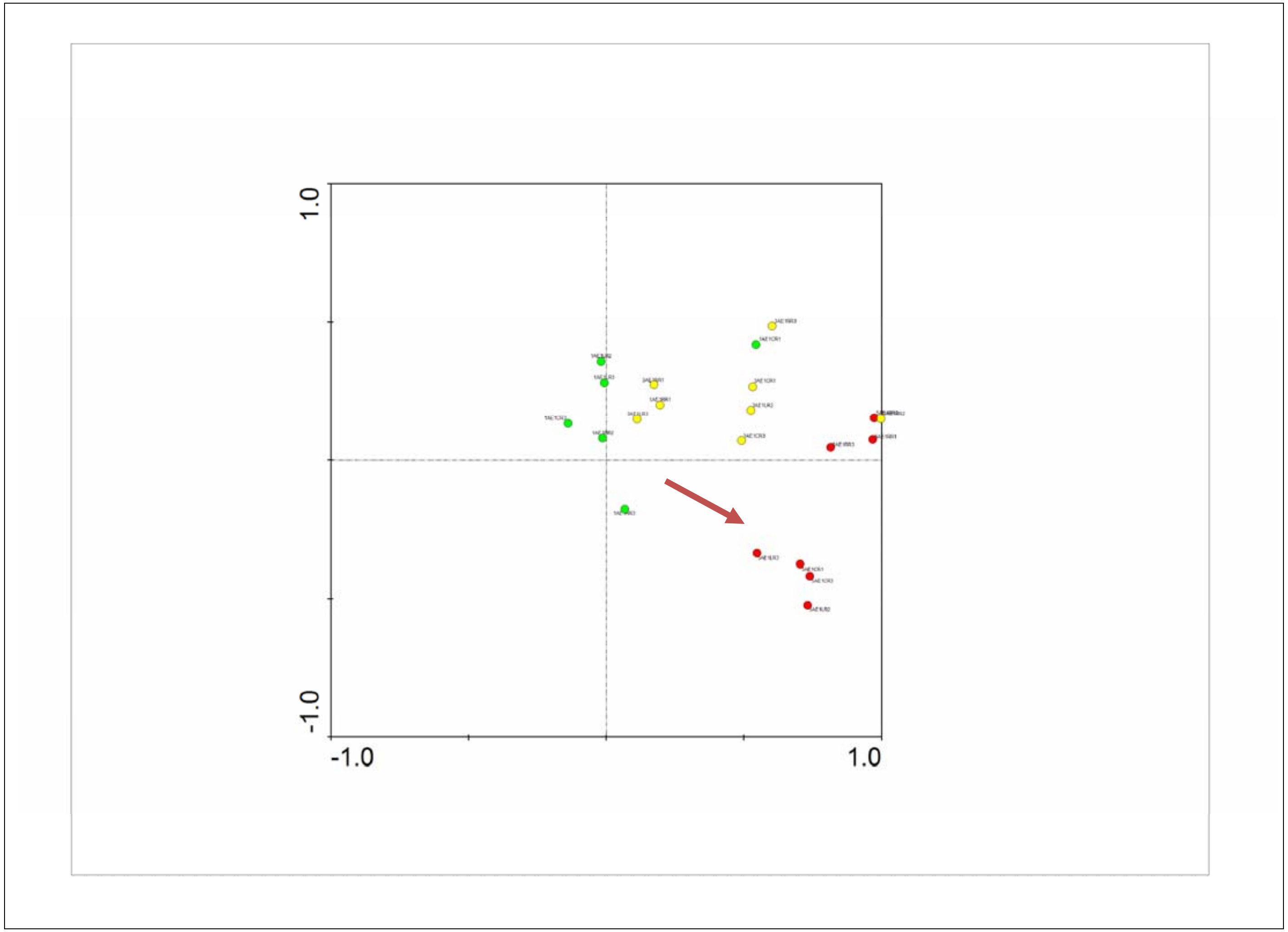


Figure 4.150 PCA diagram of April vegetation data at Ely Ouse for Community A in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

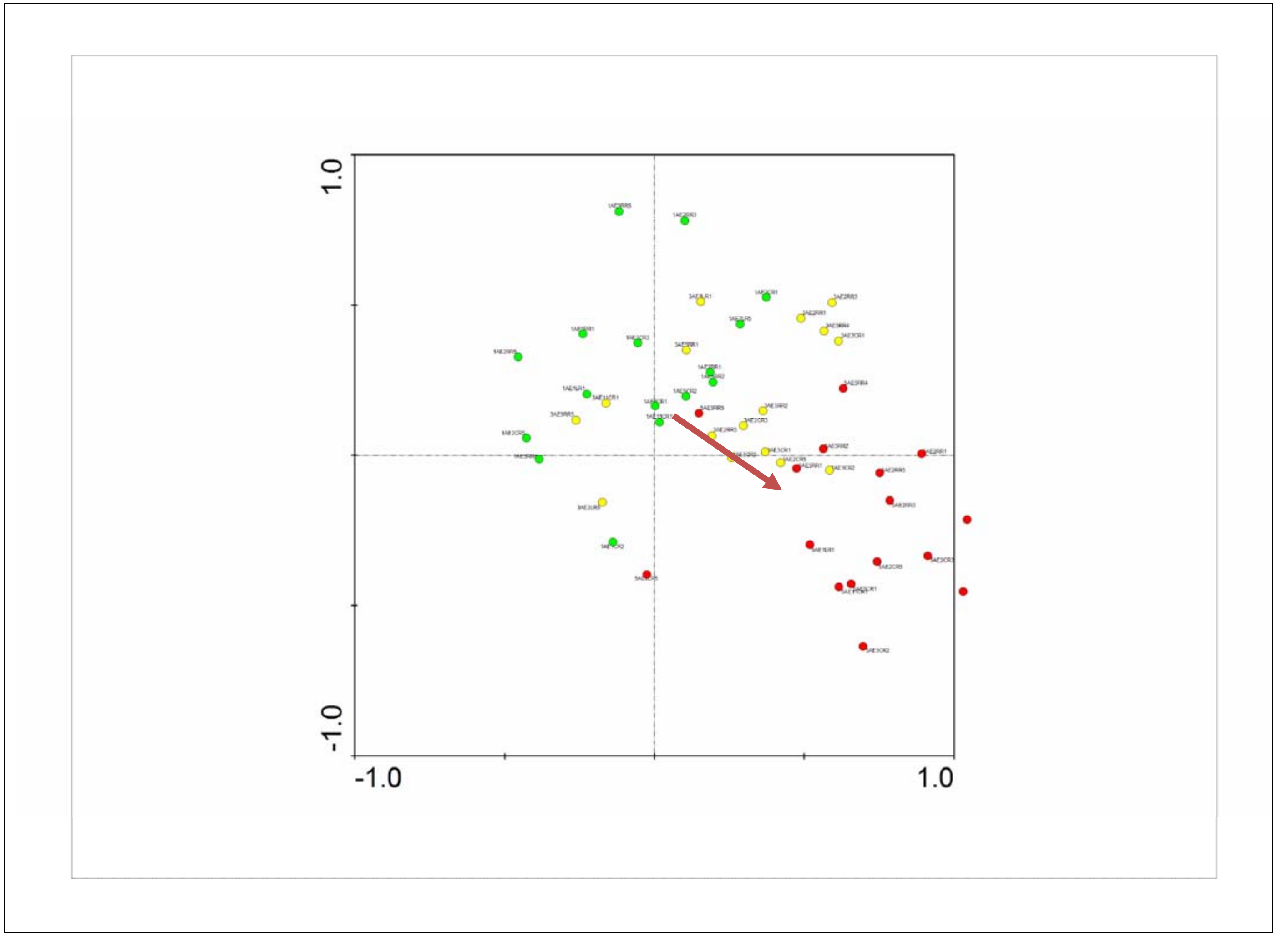


Figure 4.151 PCA diagram of April vegetation data at Ely Ouse for Community B in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Community B

Figure 4.151 shows the shift in Community B vegetation recording plots during the trials. Here recording plots in Year 1 are mainly located in a broad spread across the top half of the diagram. By Year 3, a shift has occurred towards the right, followed by a further shift towards the bottom right of the diagram. Thus vegetation recording plots of this community have also experienced a move towards a more species-rich sward.

Community B is also felt to represent a meaningful shift in vegetation composition.

Community C

As Figure 4.152 shows, vegetation recording plots classified as Community C (in Year 5) follow a similar trend towards increased species-richness to those observed in Communities A and B over the five-year period. Year 5 vegetation recording plots are located closer to the bottom of the diagram than the previous two communities, suggesting Community C recording plots in April of Year 5 contained a higher percentage cover of leaf litter and total vegetation.

Community C is felt to represent a meaningful shift in vegetation composition.

Community D

Figure 4.153 shows a broad shift in vegetation composition of Community D recording plots in Years 1, 3 and 5. Over the five-year period, the majority of recording plots remained over the left side of the PCA diagram, indicating this community continued to reflect vegetation with high Ellenberg Indicator Values for nitrogen and species-poor vegetation. By Year 5, recording plots were located in a cluster at the bottom left of the diagram, which suggests an increase in leaf litter percentage cover since Year 1 may have occurred. Some of the vegetation recording plots of Community D had already reached this part of the PCA diagram by Year 3, while others had only begun the transition.

Community D is felt to represent a meaningful shift in vegetation composition.

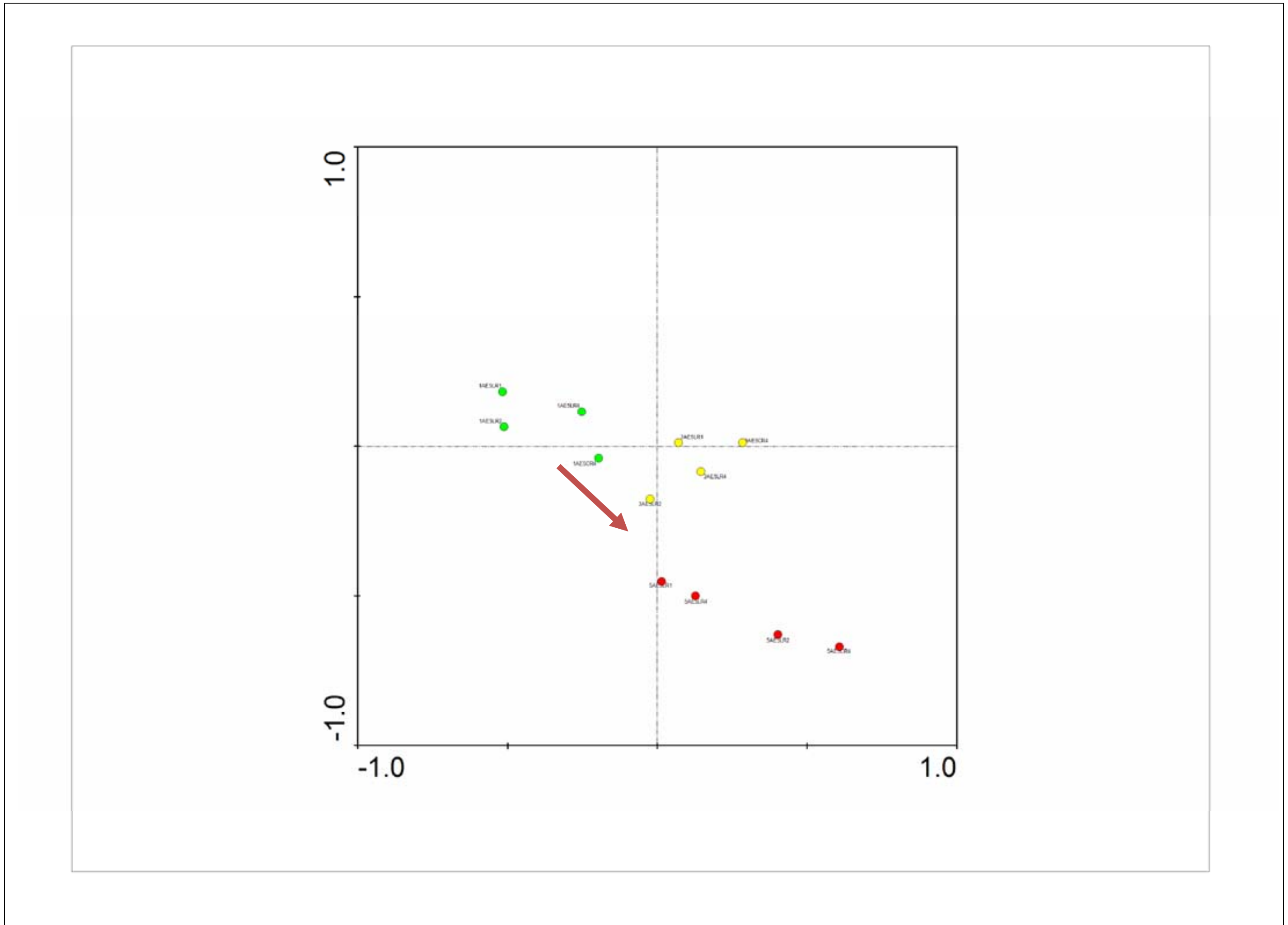


Figure 4.152 PCA diagram of April vegetation data at Ely Ouse for Community C in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

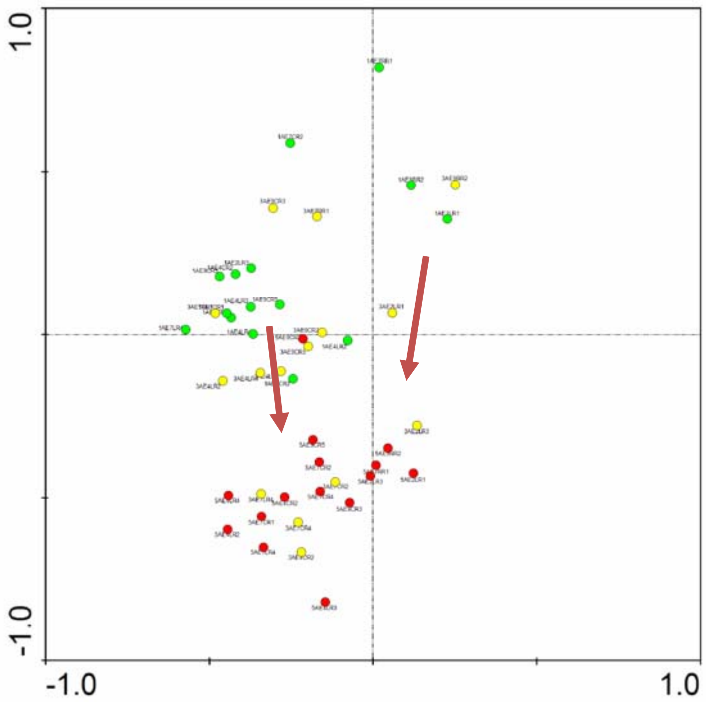


Figure 4.153 PCA diagram of April vegetation data at Ely Ouse for Community D in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Community E

The shift in the vegetation of recording plots from Community E in Years 1, 3 and 5 shown in Figure 4.154 is very similar to the shift described for Community D. However, in this case, Year 3 data appear to show the vegetation was still in transition in a direction consistent with records of high percentage cover of leaf litter.

Community E is also felt to represent a meaningful shift in vegetation composition.

Community F

In Figure 4.155, the trend towards the bottom left of the diagram continues in Community F as it did in Communities D and E. Once again, some of the vegetation recording plots (namely those which in Year 1 were on the horizontal axis line) had reached the bottom of the diagram in Year 3, while others had barely begun the transition.

Community F is felt to represent a meaningful shift in vegetation composition.

Community G

Figure 4.156 shows the moderate shift in vegetation composition between recording plots in Years 1, 3 and 5 for Community G (representing the vegetation of the control Treatment 11). Here there is still some movement of vegetation recording plots within the PCA diagram over the five-year period, but it is generally less dramatic and there is less convergence than was indicated in the other communities. It is therefore possible that the different PCA locations of vegetation recording plots in each year are principally the result of different climatic conditions in the month prior to the April survey. Alternatively the slight shift towards the bottom of the diagram in Year 5 data could indicate that there was a very gradual change in the sward composition. For this reason, it was felt unlikely that Community G exhibited a meaningful shift in vegetation composition.

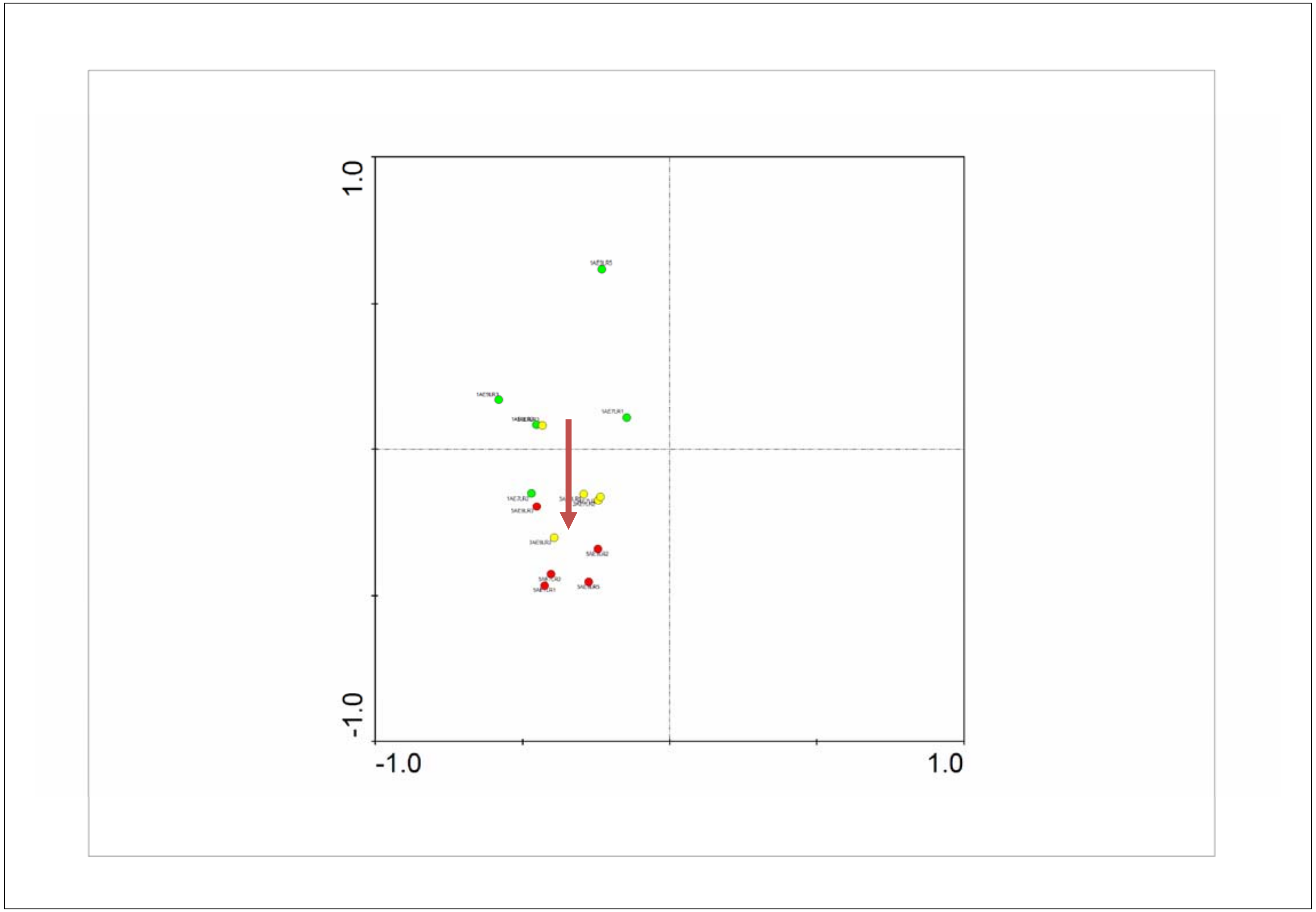


Figure 4.154 PCA diagram of April vegetation data at Ely Ouse for Community E in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

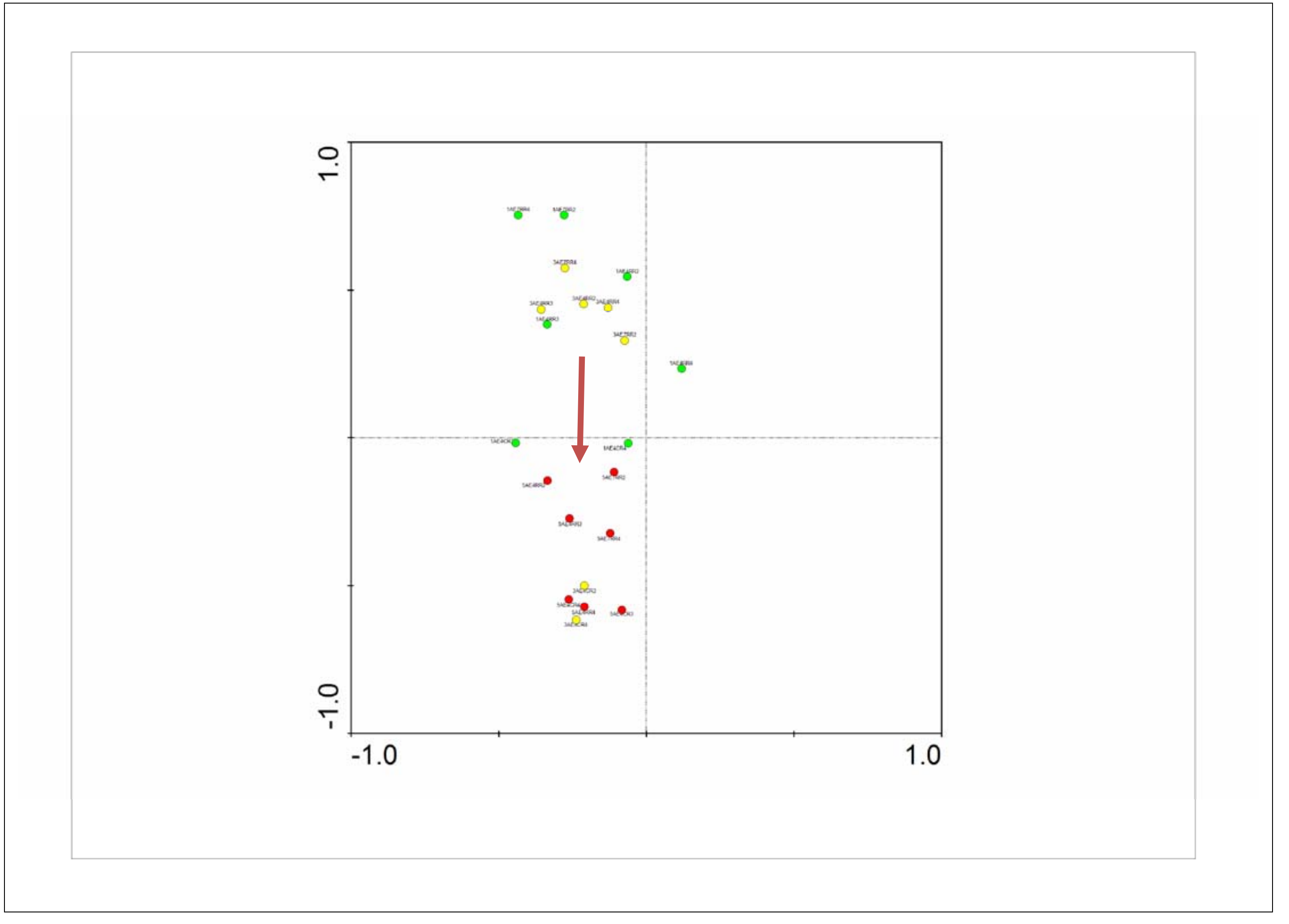


Figure 4.155 PCA diagram of April vegetation data at Ely Ouse for Community F in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time**.**

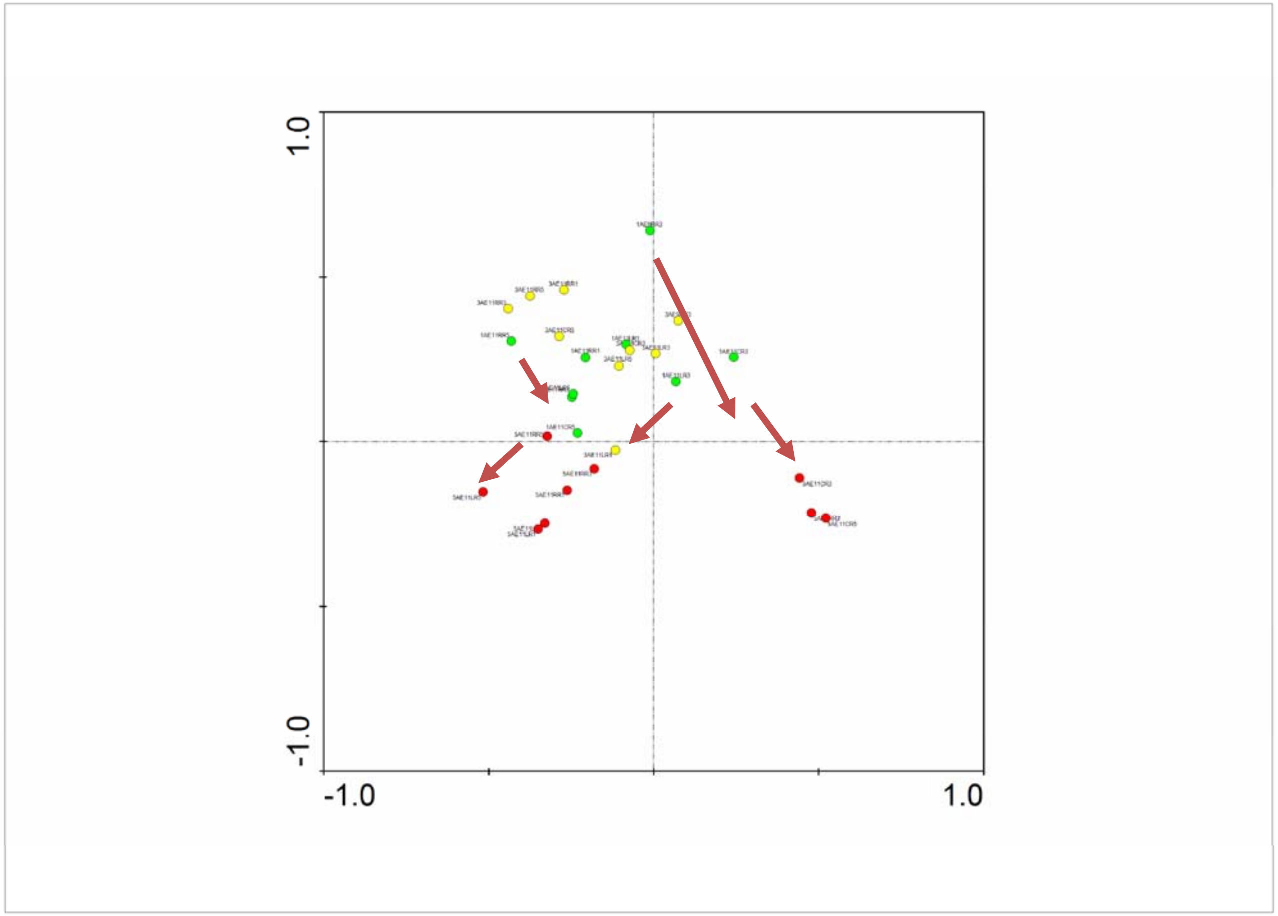


Figure 4.156 PCA diagram of April vegetation data at Ely Ouse for Community G in Years 1, 3 and 5.

Green dots = Year 1, Yellow dots = Year 3, Red dots = Year 5, Red arrow = direction of shift over time.

Plant species-richness

A significant difference ($p<0.05$) was found in the species-richness recorded at Ely Ouse in relation to management treatment.

There was a significant difference in the species-richness of Treatments 1, 2 and 5 (those cut three times a year or more) compared with Treatments 4, 7, 9 and 11 (cut once a year or less). Treatment 9, which received weedkiller treatment twice a year, showed slightly higher species richness than Treatments 4, 7 and 11, but this was not found to be significant. These differences are illustrated in Figure 4.157.

Significant differences ($p<0.05$) were also recorded in the plant species-richness between embankment faces and between survey months, so that both the crest and river faces were significantly more species-richness than the landward face. The August survey recorded significantly lower species-richness than the April or June surveys.

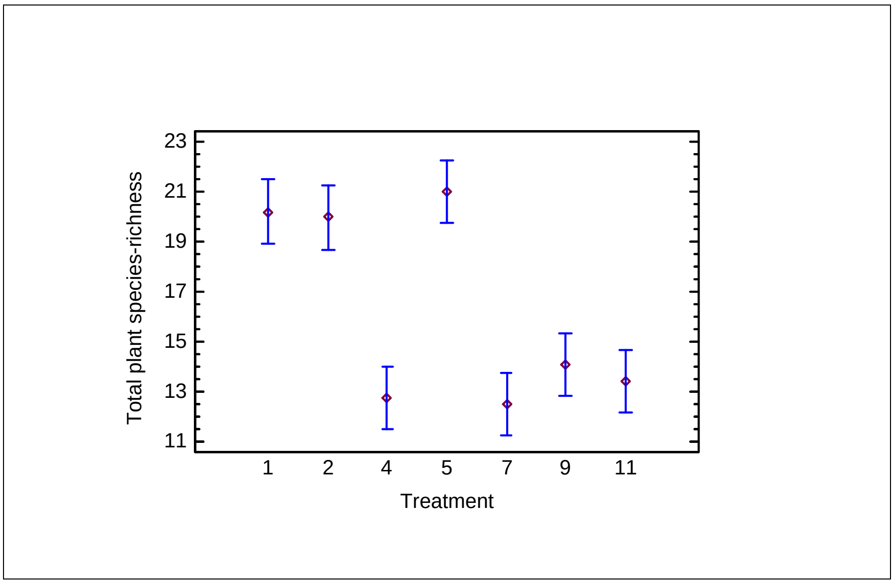


Figure 4.157 Mean plant species-richness of vegetation recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

When analysed in terms of plant community type, Communities A and B were found to have significantly higher ($p<0.05$) species-richness values than all other communities. Community C held an intermediate position (showing significant difference from all other communities at $p<0.05$), while Communities D, E, F and G were all relatively species-poor (Figure 4.158).

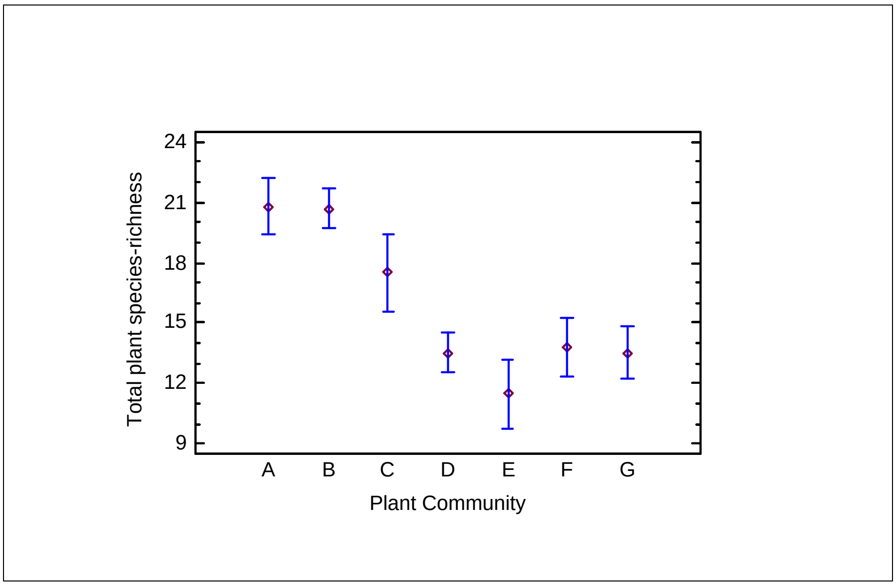


Figure 4.158 Mean plant species-richness of vegetation recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

When the percentage change of each vegetation recording plot from Years 1 to 5 was analysed, several differences were recorded between the percentage increases of plant species depending on the treatment, some of which were significant to p<0.05[14] (Figure 4.159; pairs of treatments are significantly different where LSD bars do not overlap).

Treatment 5 had the highest percentage increase in plant species, Treatments 1, 2, 7 and 9 showed moderate percentage increases, and Treatments 4 and 11 exhibited very low increases in species-richness by Year 5.

The data therefore show that there are meaningful differences in plant species-richness between the treatments in Year 5 that were not established in Year 1 and were the result of the experimental treatments. It suggests that arisings removal in treatments receiving 1–3 cuts per year where arisings were removed (Treatments 5 and 7) resulted in higher increases in species-richness than where they were not removed (Treatments 2 and 4).

[14] Significant difference at p<0.05 is indicated where the blue range lines do not overlap.

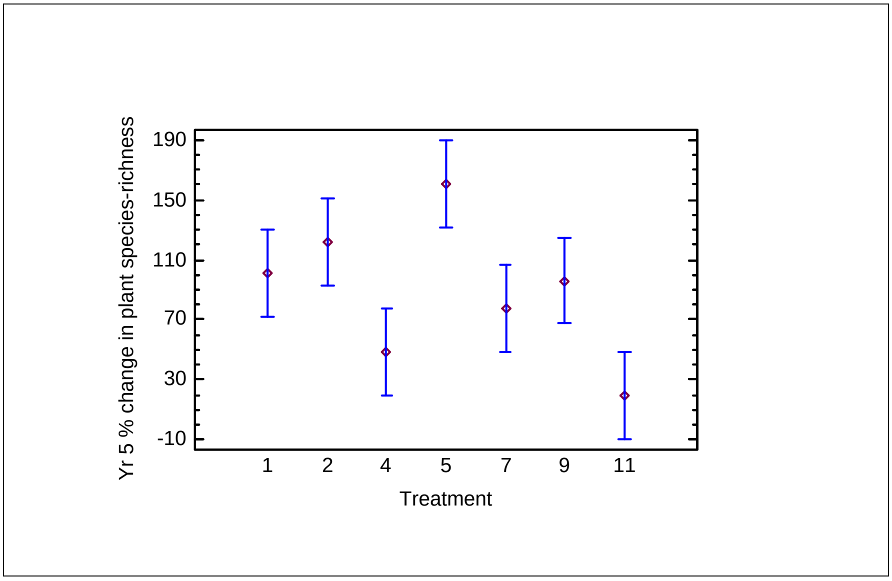


Figure 4.159 Percentage change of mean plant species-richness between Years 1 and 5 for treatments at Ely Ouse.

Bars represent least significant differences (LSD).

Plant species diversity

Analysis of the treatments in terms of plant species diversity at Ely Ouse showed similar results to those of species-richness, namely that Treatments 1, 2 and 5 had significantly higher ($p<0.05$) plant diversity than Treatments 4, 7, 9 and 11. However, in diversity terms, Treatment 9 (treated with weedkiller) showed significantly higher plant diversity than those treatments cut once a year without chemical treatment (Figure 4.160).

Like the findings for plant species-richness, the landward face of the embankment was found to be significantly lower ($p<0.05$) in terms of species diversity than either the crest or river faces. Similarly, August received the lowest diversity scores (at significance of $p<0.05$). However, June showed significantly higher diversity scores than both of the other survey months – confirming that, where possible, this is the optimal month in which to analyse differences in the plant composition of the vegetation recording plots.

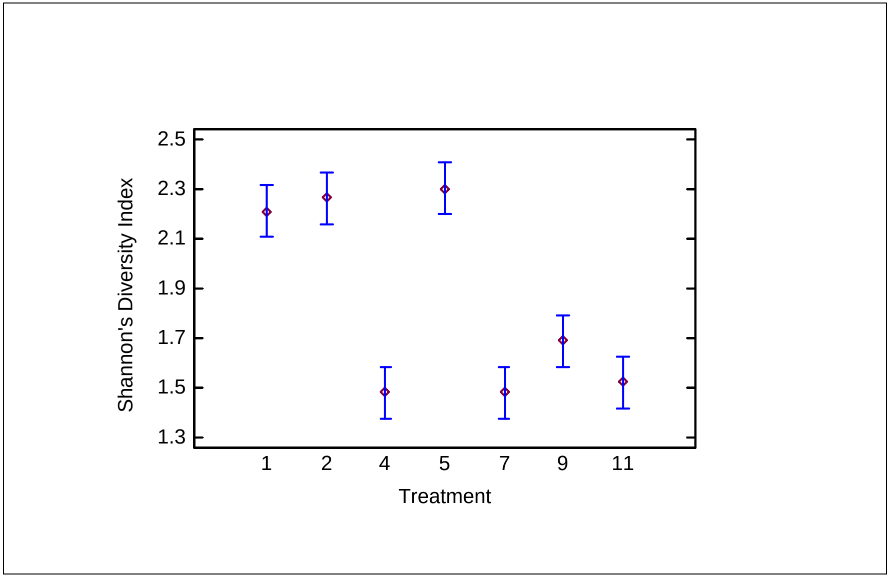


Figure 4.160 Mean plant diversity values (using Shannon's Diversity Index) of vegetation recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Figure 4.161 shows the analysis of plant diversity within the different plant communities. That in Communities A, B and C was significantly higher ($p<0.05$) than in Communities D, E, F, and G, with that in Community E significantly lower than almost all other communities.

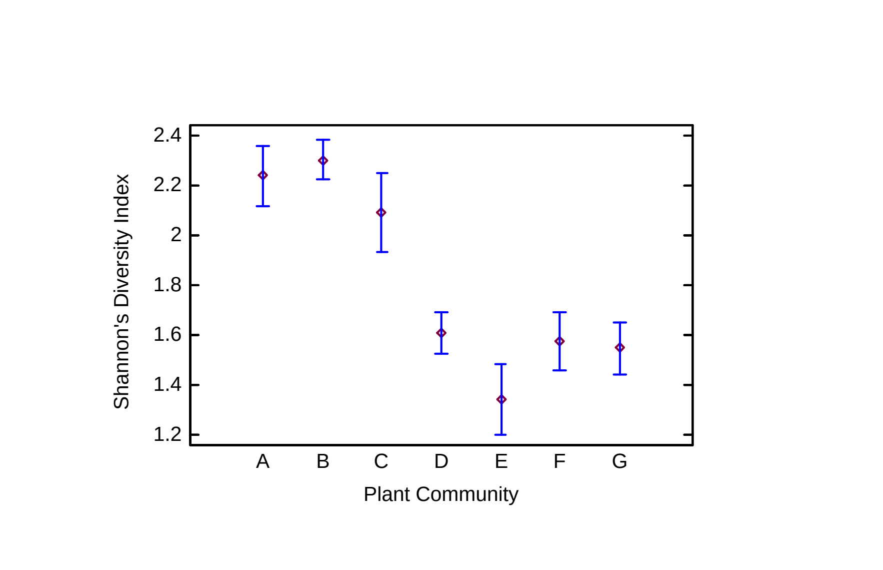


Figure 4.161 Mean plant diversity values (using Shannon's Diversity Index) of vegetation recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Leaf litter cover

ANOVA calculations showed that there were several significant differences ($p<0.05$) between the various treatments regarding percentage leaf litter cover. Treatments 4, 7, 9 and 11 showed the highest overall leaf litter cover. They were significantly higher than Treatments 1, 2 and 5. Treatment 5 showed by far the lowest leaf litter cover, as expected given that the arisings were collected after cutting (Figure 4.162).

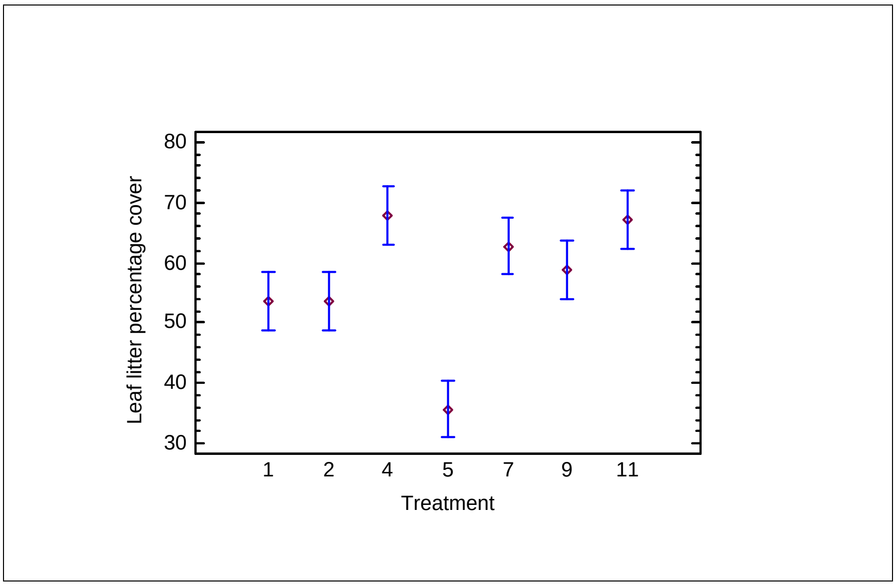


Figure 4.162 Mean plant leaf litter percentage cover of vegetation recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Leaf litter percentage cover was found to be significantly higher ($p<0.05$) on the crest than on the river face, with the landward face in an intermediate position between the other two faces. As expected, leaf litter cover was found to be highest in August, although this was statistically significant only for the April results ($p<0.05$) and not the June results.

Analysis showed that Community C had significantly lower levels of leaf litter cover than all other communities ($p<0.05$). Community B also had significantly lower leaf litter cover than Communities D, E, F and G, with Communities F and G in particular receiving the highest leaf litter cover values (Figure 4.163).

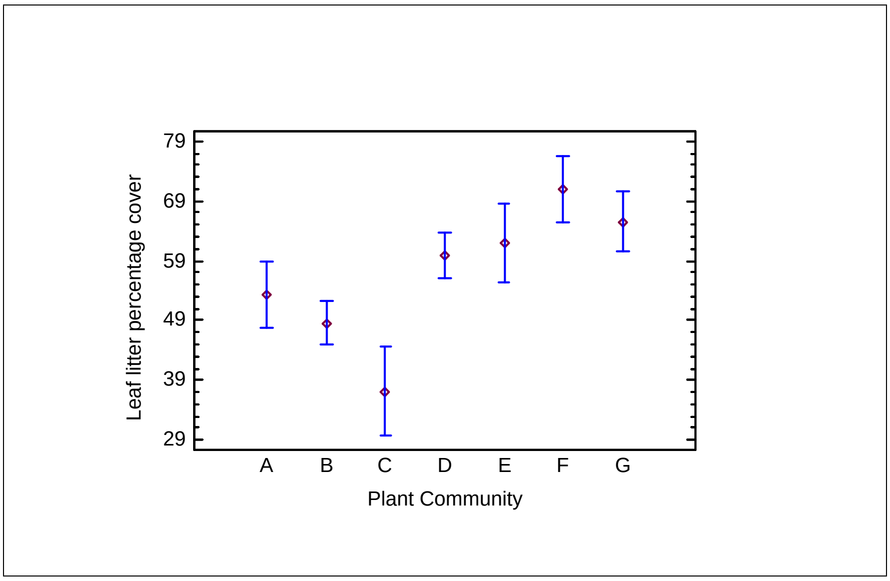


Figure 4.163 Mean plant leaf litter percentage cover of vegetation recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

ANOVA calculations of the percentage change in April leaf litter cover of each vegetation recording plot from Years 1 to 5 showed the majority of treatments had increased by 25–50 per cent by Year 5. The exceptions were Treatment 5, which showed the lowest leaf litter cover increases (5–25 per cent) and Treatment 11, which showed the highest increases (40–65 per cent).

However, the differences between treatments increase during the course of the year as the effects of different treatments take place. The data show that there were a few clear differences in leaf litter percentage cover in April between some of the treatments in Year 5, which were not established in Year 1.

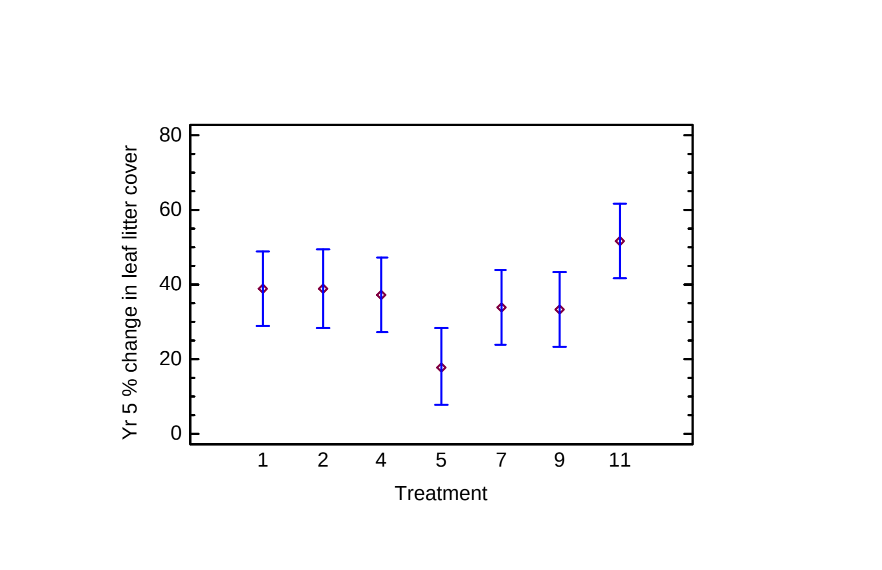


Figure 4.164 Percentage change of plant leaf litter percentage cover between Years 1 and 5 for treatment at Ely Ouse.

Bars represent least significant differences (LSD).

Bare ground cover

Analysis showed that the only significant difference ($p<0.05$) in terms of percentage bare ground cover was between Treatments 9 and 11, with Treatment 9 (treated with weedkiller) being the higher of the two. Those treatments receiving three cuts per year had noticeably higher percentage cover of bare ground than those cut only once a year, though this was not significant at $p<0.05$ (Figure 4.165).

A significant difference ($p<0.05$) was found between bare ground cover on the landward face and the much lower cover on the crest and river face. This may well be the result of increased risk of fire incidents on the landward embankment face.

Percentage bare ground cover was highest in April. June was next highest and August lowest, a result which was statistically significant ($p<0.05$).

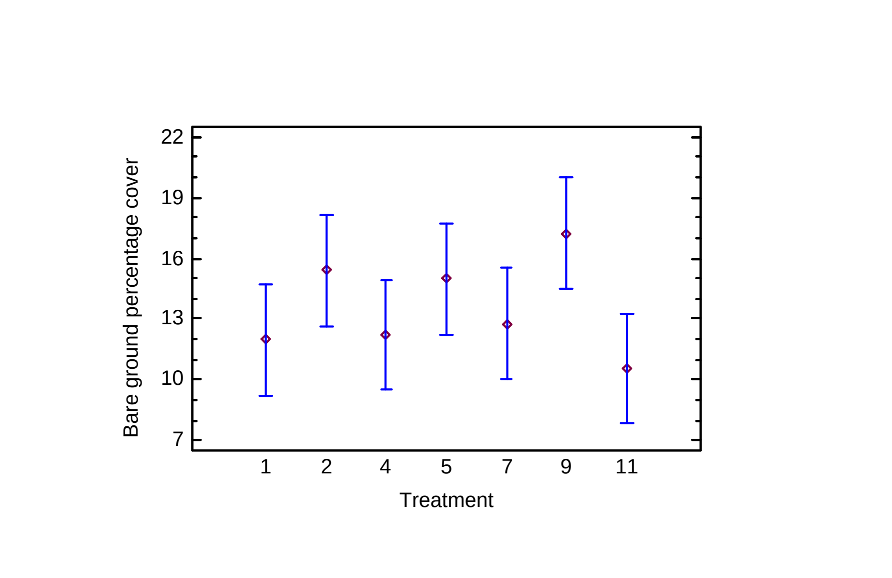


Figure 4.165 Mean bare ground percentage cover of vegetation recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Only subtle differences were found with regard to the percentage cover of bare ground of the Ely Ouse plant communities (Figure 4.166), though Community F had significantly lower ($p<0.05$) bare ground cover than Communities B, C, D and E. Communities A and G also had relatively low cover of bare ground compared with Communities C, D and E.

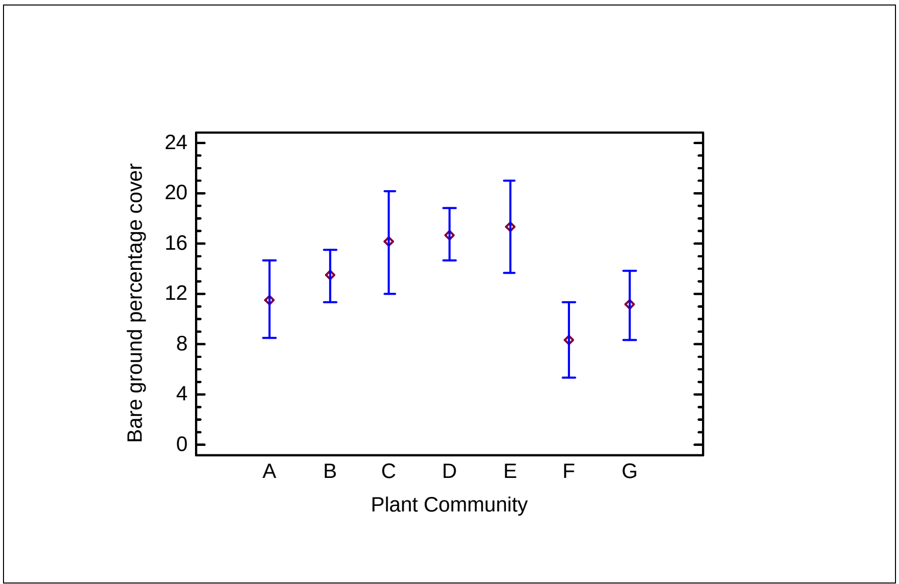


Figure 4.166 Mean bare ground percentage cover of vegetation recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Changes over time

Analysis of the percentage change of April bare ground cover for each vegetation recording plot in Years 1 to 5 showed that Treatments 9 and 11 had significantly higher ($p<0.05$) increases in cover than Treatments 4, 5 or 7, with Treatments 1 and 2 in an intermediate position (Figure 4.167).

The data therefore show that there are differences in bare ground percentage cover in April between some of the treatments in Year 5 which were not established in Year 1. This suggests that, although Treatment 5 had some of the highest cover of bare ground in Year 5, this was not due to an increase in bare ground cover over the five-year period but instead reflects the large amounts of bare ground present in Year 1.

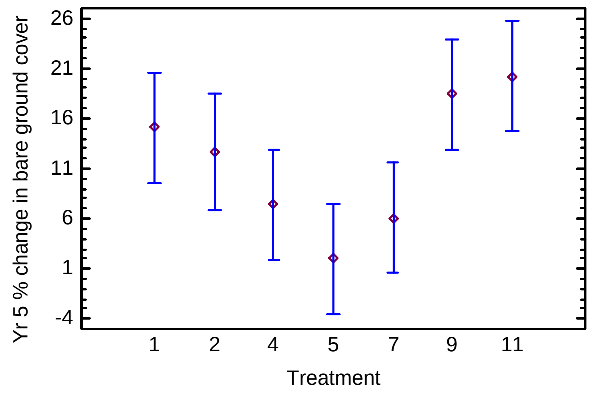


Figure 4.167 Percentage change of bare ground cover between Years 1 and 5 for treatments at Ely Ouse.

Bars represent least significant differences (LSD).

Bryophyte (moss and liverwort) cover

Treatment 5 was found to have significantly higher ($p<0.05$) bryophyte cover than all other treatments at Ely Ouse (Figure 4.168). Treatments 1 and 2 also showed moderate bryophyte cover, at significantly higher values than those recorded in Treatments 4, 7, 9 and 11.

The river face was found to be significantly higher ($p<0.05$) in terms of bryophyte percentage cover than the crest or landward faces, presumably due to the greater levels of soil moisture found on this face. However, although June survey results showed slightly lower bryophyte cover than June or August, this was not found to be significant ($p<0.05$).

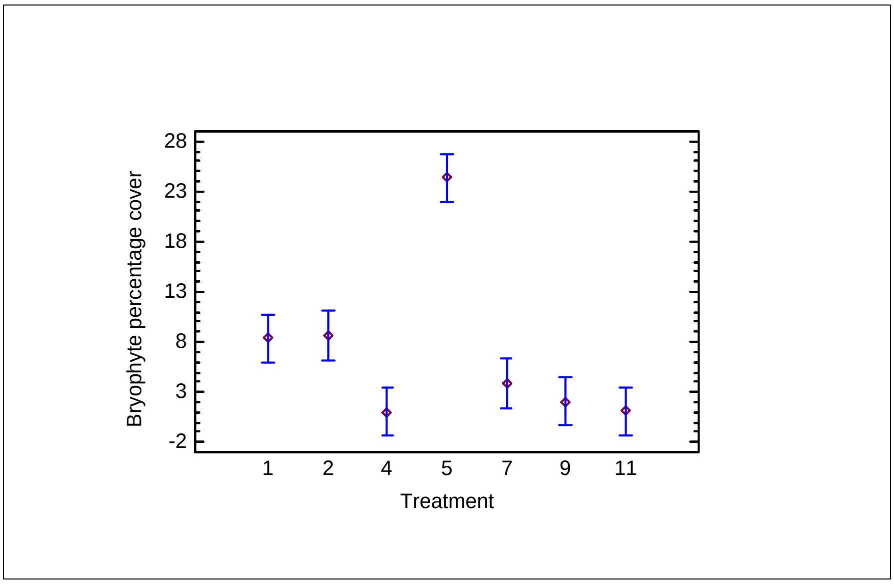


Figure 4.168 Mean bryophyte percentage cover of vegetation recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

ANOVA calculations (results illustrated in Figure 4.169) showed that Community C had significantly higher bryophyte coverage than all other communities at Ely Ouse (at $p<0.05$). Communities D, E, F and G all had virtually no bryophyte coverage, which was significantly lower than Communities A, B and C where only limited coverage of bryophytes was recorded.

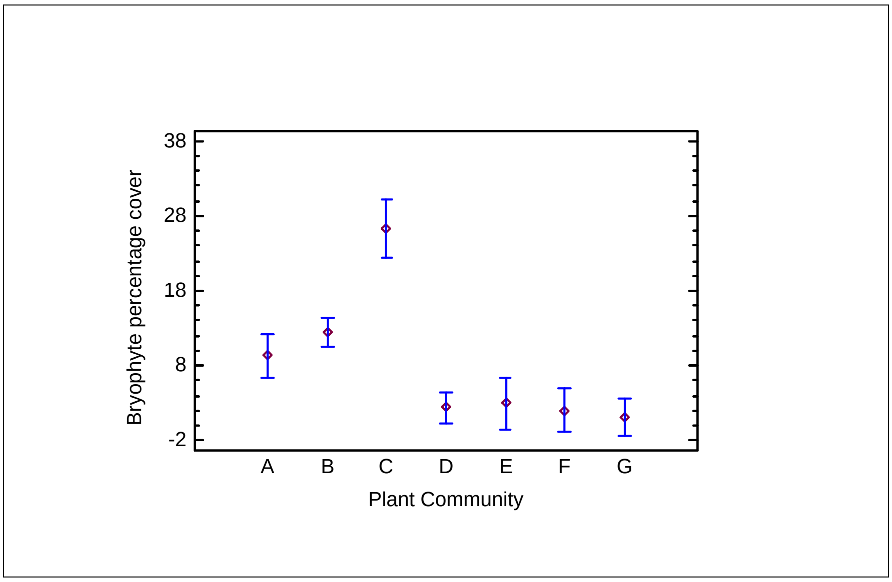


Figure 4.169 Mean bryophyte percentage cover of vegetation recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Changes over time

Analysis of the percentage change of April bryophyte cover in Years 1 to 5 showed that Treatments 1, 2, 5 and 7 all increased in coverage (by approximately 3–12 per cent) while Treatments 4, 9 and 11 showed no change or a slight decline in bryophyte coverage (Figure 4.170). These differences were largely significant (p<0.05), with the exception of Treatments 4 and 5 where there was a slight overlap on ranges.

The data therefore indicate that those treatments cut at least three times a year, or cut once but with arisings removed, are likely to improve in terms of bryophyte coverage over time, presumably due to the increased light levels and availability of bare ground in these treatments.

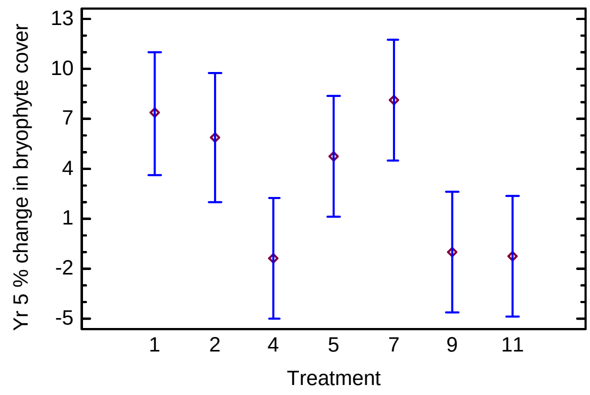


Figure 4.170 Percentage change of bryophyte cover between Years 1 and 5 for treatments at Ely Ouse.

Bars represent least significant differences (LSD).

Mean vegetation height

Analysis showed that, consistent with the other two trial sites, there are significant differences (p<0.05) in the vegetation height of recording plots between treatments (Figure 4.171). Treatments cut three times a year or more had significantly shorter swards than those cut no more than once (even where chemical treatment was applied).

The crest was found to have significantly lower (p<0.05) mean vegetation heights than either the river or landward faces at Ely Ouse. The most likely explanation for this is the increased trampling and machinery access on this face. However, it is also likely to reflect the additional cuts that took place on the crest at Ely Ouse by mistake.

Like Billingborough, the peak vegetation height was reached here in June (with results in this month significantly higher, p<0.05, than both April and August).

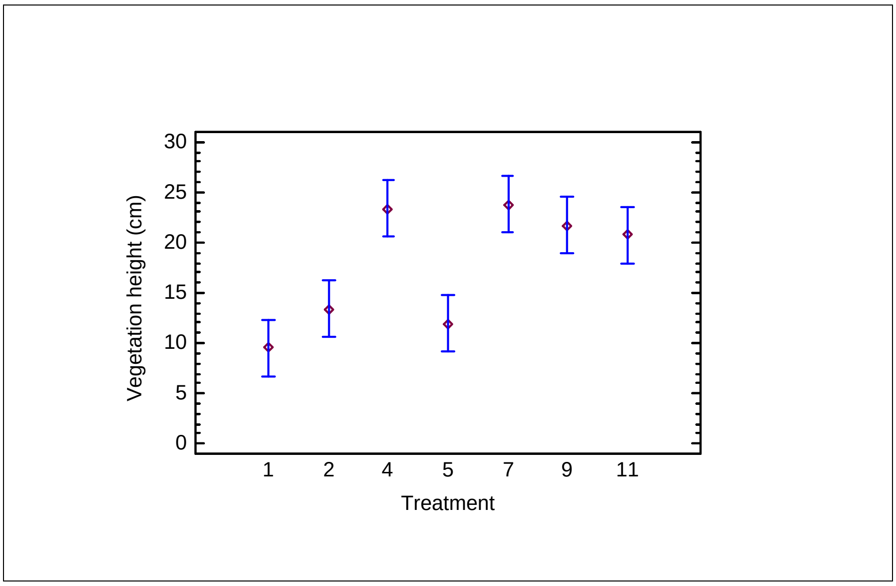


Figure 4.171 Mean total vegetation height of recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Total vegetation height was greatest in Communities D, E, F and G at significance p<0.05 (Figure 4.172). These communities are all dominated by coarse grasses such as *Arrhenatherum elatius* and tall herbs such as *Anthriscus sylvestris*.

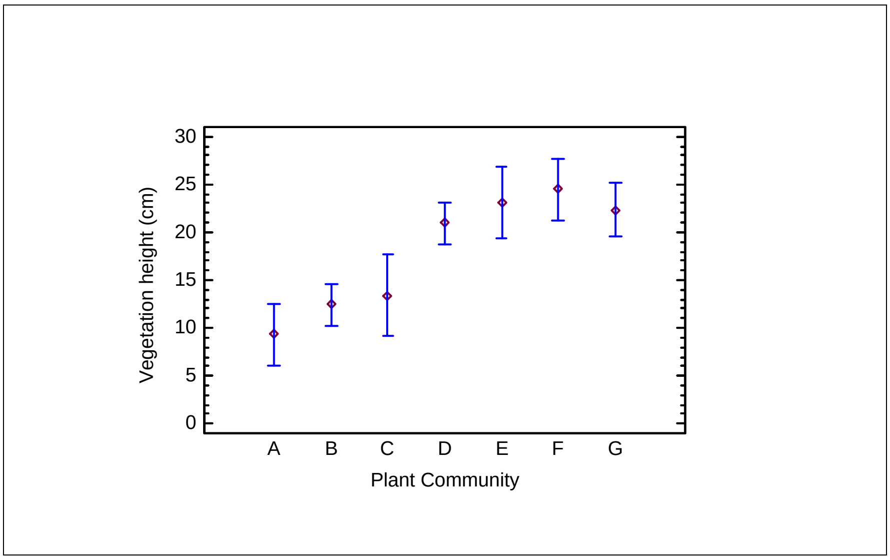


Figure 4.172 Mean total vegetation height of recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Total vegetation cover

Analysis showed no significant differences (p<0.05) between the total vegetation cover of treatments at Ely Ouse (Figure 4.173), although Treatment 2 achieved the highest total cover.

However, the landward face was found to be significantly lower (p<0.05) in terms of total vegetation cover than the crest or river face recording plots. Once again, this is likely to be due to the frequency of summer fires on this face at Ely Ouse. August was also found to have a higher total vegetation cover than April or June survey months.

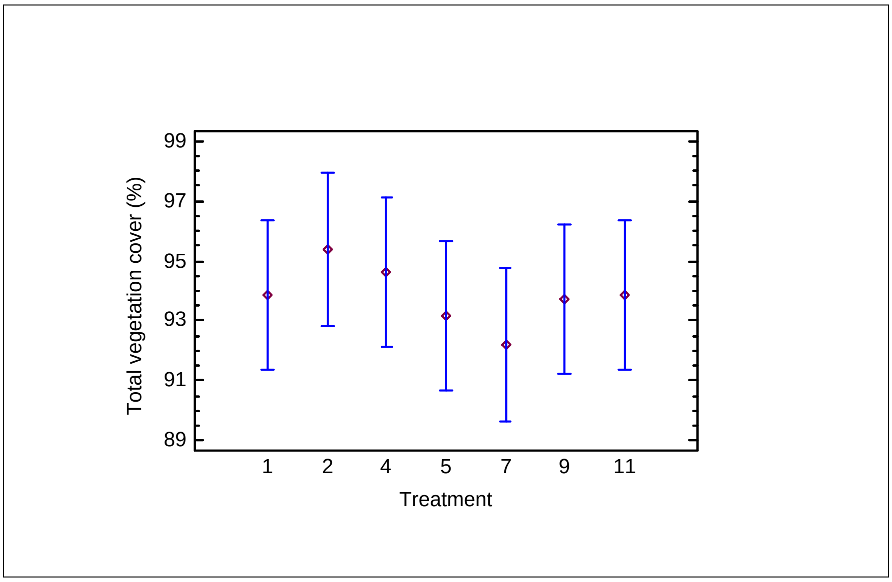


Figure 4.173 Mean total vegetation cover of recording plots for treatments at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

Mean total vegetation cover was generally not found to differ significantly (p<0.05) between plant communities (Figure 4.174).

Community B had the highest total vegetation cover values, closely followed by Communities A, D, F and G.

Community C had the lowest total vegetation cover (significantly lower than A, B, D and G; p<0.05), principally because it occurred mainly on the landward face where summer fires were more prevalent.

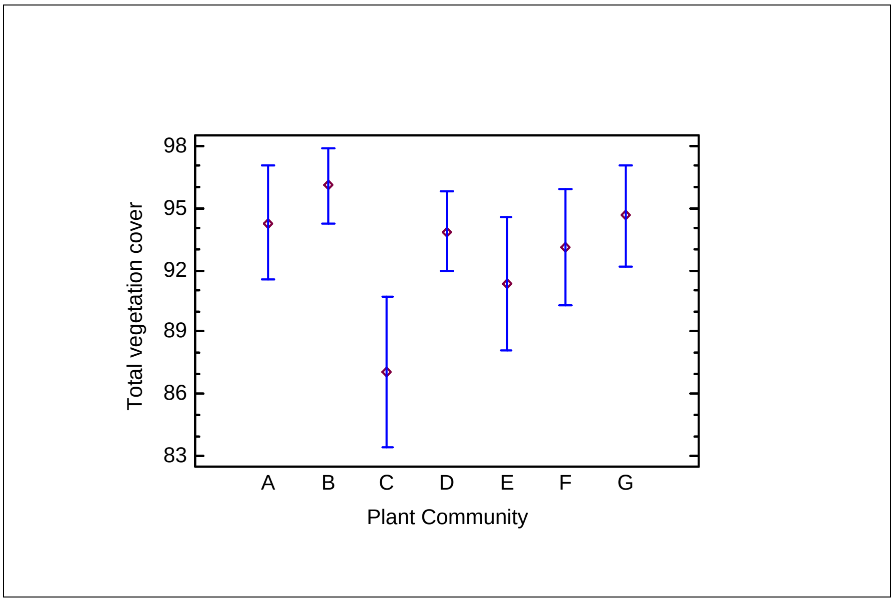


Figure 4.174 Mean total vegetation cover of recording plots for plant communities at Ely Ouse, Year 5.

Bars represent least significant differences (LSD).

<u>Changes over time</u>

Comparisons between the total vegetation cover of Years 1 and 5 could not be made due to this variable only being adopted after the baseline survey.

Dry weight of arisings

ANOVA calculations were not possible on arisings data due to the nature of the data. However, direct comparison between years showed that all treatments had experienced an increase in the dry weight of arisings collected per square metre (Figure 4.175).

Treatments 1, 2, 3 and 5 had the highest dry weight of arisings in Year 1 (at c.630–900 g/m^2). Treatment 6 should probably also be classed in this group as the values for both Treatments 5 and 6 are underestimates due to a missed survey month in these treatments. All these treatments were cut between two and six times a year.

In Year 3, all treatments showed a considerably higher dry weight of collected arisings, particularly in treatments cut only once per year.

By Year 5, Treatments 1, 2 and 5 were still generating a high dry weight of arisings. Treatments cut twice per year (i.e. Treatments 3 and 6) showed the least change in dry weight of arisings between Years 1 and 5, while treatments receiving only one cut per year had also shown some increase by Year 5, though not to the same extent as Treatments 1, 2 and 5. Treatment 9, where weedkiller was used, showed a considerable increase in dry weight of arisings by Year 5 – more so than where growth retardant was used. This result is in keeping with that found at Reach Lode.

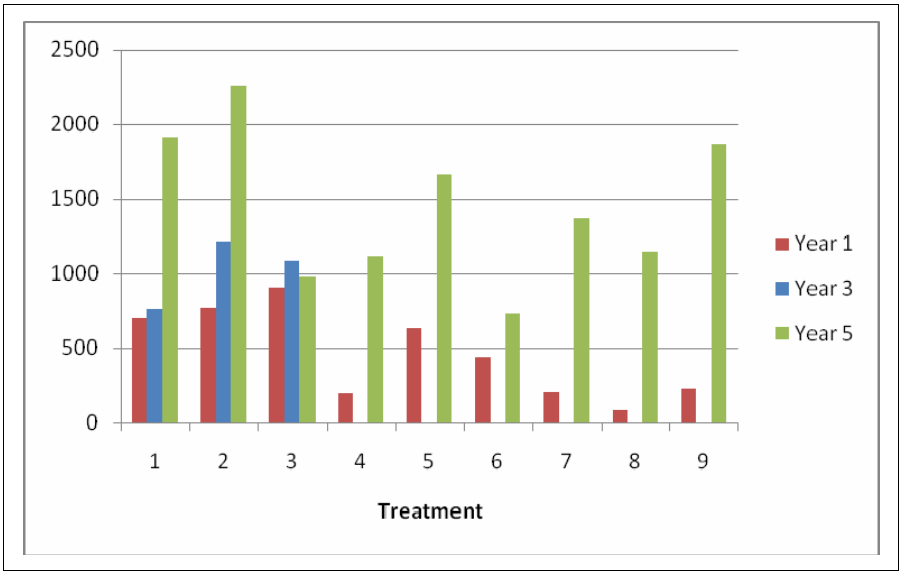


Figure 4.175 Total annual arisings (g/m^2) at Ely Ouse in Years 1, 3 and 5 – river face.

Note: Treatments 5 and 6 are underestimates in Year 1 due to missing data.

The landward face showed similar patterns to those found on the river face in that Treatments 1, 2, 3 and 5 had the highest dry weight of arisings in Year 1 (c.1,200–1,800 g/m^2), albeit in much greater quantities generally. Year 3 on the landward face showed a decrease in dry weight of arisings in the majority of treatments, which coincided with the occurrence of summer fires on this face. By Year 5, all treatments saw an increase in the dry weight of arisings collected, with the exception of Treatment 3 and possibly Treatment 5 (the result shown is missing one month's data on arising collection). Thus by Year 5, those treatments with the greatest dry weight of arisings were Treatments 2, 4 and 5 (all >1,500 g/m^2). Once again treatments cut no more than once a year did show some increase in dry weight of arisings, but had not reached those levels found in treatments cut three times per year.

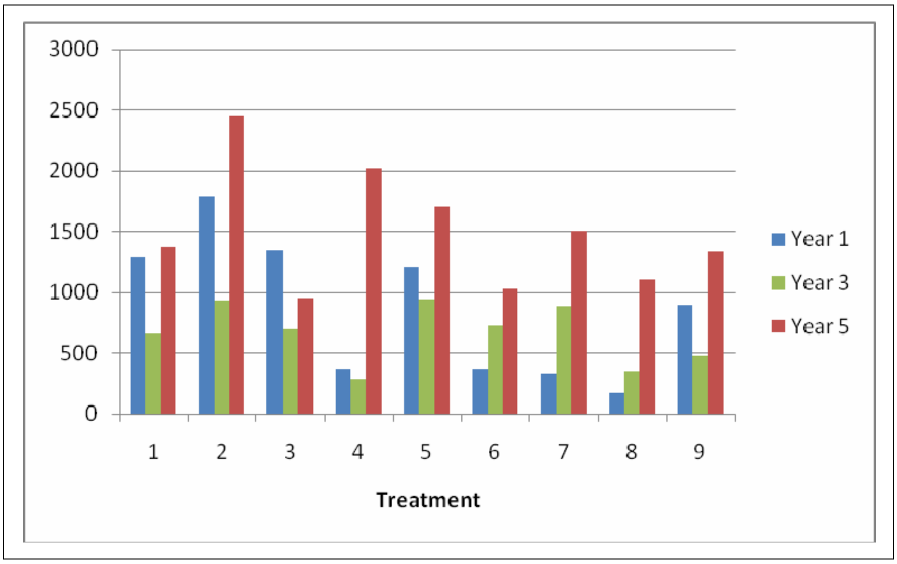


Figure 4.176 Total annual arisings (g/m^2) at Ely Ouse in Years 1, 3 and 5 – landward face.

Note: Treatments 5 and 6 are underestimates in Year 1 due to missing data.

Figure 4.177 shows the overall percentage change in total annual arisings recorded in each treatment from Years 1 to 5.[15] The greatest increases in dry weight arisings were recorded from the river faces of Treatments 4, 7, 8 and 9, and the landward face of Treatments 4 and 8. All of these treatments were cut only once per year. Treatments cut three times a year on the river face appeared to show a modest increase in dry weight of arisings, while on the landward face (where conditions were more harsh due to fire incidents and exposure), there was very little change in the dry weight of arisings.

[15] With the exception of data for plots 5 and 6, which were under-recorded in Year 1.

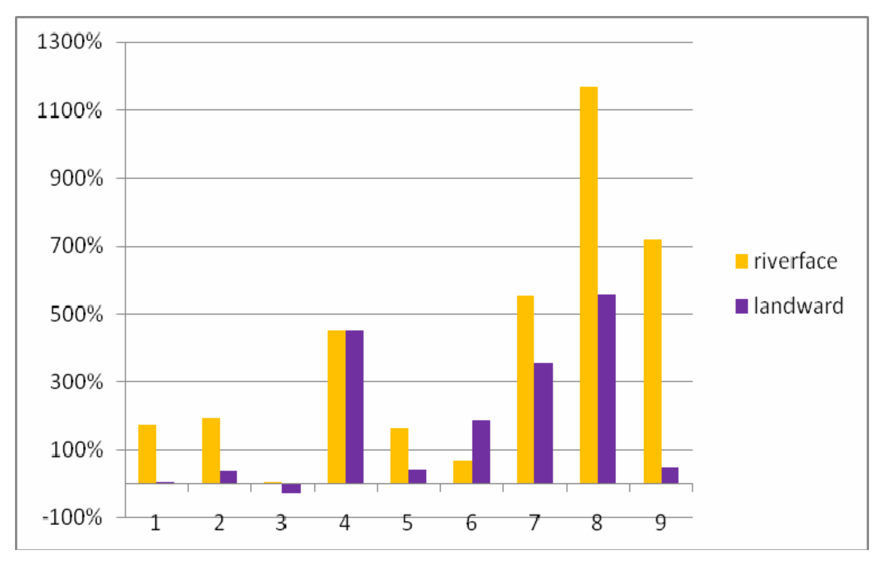


Figure 4.177 Percentage change in arisings collected in Years 1 and 5 at Ely Ouse.

Vegetation summary: Ely Ouse

Ely Ouse had the most extensive list of plant species of all three trial sites. Seven communities were identified (A–G), the majority of which showed strong separation in terms of plant composition. Communities A and B were the only species-rich ones, with diverse swards dominated by fine grasses. Community C was also moderately rich in species, but dominated by coarse grasses. The remaining communities were all relatively species-poor and strongly dominated by coarse grasses. The species composition of each community is presented in Table 4.31.

The primary community divisions correspond closely with treatment, although the crest vegetation recording plots were not distinguished as a separate community here because the recording plots were rather atypical of the crest. Community A was restricted to Treatment 1, cut six times per year, with Community B almost entirely restricted to Treatments 2 and 5, both cut three times per year. Community C, the other species-rich community was restricted to Treatment 5. The species-poor Community G was restricted to and dominated Treatment 11 (control).

The remaining communities (D, E and F) were all species poor and were restricted to treatments involving one cut per year. Within this overall grouping, embankment face separated the three communities, with Community F characterising the river face, Community D the crest and Community E the landward face, although there were exceptions. As at Reach Lode, additional management work such as clearing or leaving arisings or use of weed wipes did not determine communities. This was solely by cutting frequency and, to a lesser extent, embankment face.

The PCA analysis of treatments over the five years of the experiment showed a significant shift in the composition of the communities as management continued. Treatment 11 (control) was the only exception showing at best a very minor change. The form of the change was quite different here than at Reach Lode. At Ely Ouse, the species-rich communities cut frequently did not show convergence of the samples by the end of the five years. In addition, the size of the shift in composition did not diminish from Years 1 to 5 suggesting that they had not stabilised by the end of the experiment. The species-poor communities cut once per year showed significant shift and convergence by the end of the five years, generally toward an area of the PCA diagram characterised by species poverty and high Ellenberg Indicator Values for nitrogen and increasing leaf litter percentage cover. Again, the size of shift did not diminish over time.

Regarding species richness and diversity, analysis showed that the communities associated with the most frequent mowing had higher diversity than those mown 0–1 times per year. Community A, mown six times per year had the highest species-richness. The crest and river faces were richer than the landward face (regardless of community) and all communities and treatment types showed an increase in diversity over time. Although removing arisings did not change community types, it did result in a significant increase in species-richness over the five years. Data indicate that removing arisings also results in lower leaf litter cover and higher bare ground.

Table 4.32 summarises the variation in vegetation factors with treatment, again showing correlations with the conclusions above. The richest communities, mown most frequently, had lowest leaf litter cover, greater bryophyte cover and overall lower total vegetation height. Leaf litter percentage cover was lowest of all in Treatment 5, where mowing was frequent and the arisings collected. Bare ground was not significantly different between treatments and community types, except the uncut control which had very low bare ground cover.

Table 4.32 Main differences ($p<0.05$) between treatments in Year 5 at Ely Ouse for vegetation/sward factors.

	Treatment										
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Plant species-richness	H	H	-	L	H	-	L	-	L	-	L
Plant diversity	H	H	-	L	H	-	L	-		-	L
Leaf litter cover			-	H	L	-	H	-		-	H
Bare ground cover			-			-		-	H	-	L
Bryophyte cover			-	L	H	-	L	-	L	-	L
Vegetation height	L	L	-	H	L	-	H	-	H	-	H
Total vegetation cover			-			-		-		-	

Arisings river*	H	H	L		H	L			H	-	-
Arisings land*		H	L	H	H	L				-	-

* Not significance tested but observed differences.
H = relatively high value, L = relatively low value.

4.7 Statistical analysis of habitat utilisation data

4.7.1 Billingborough

Invertebrates

It was not possible to perform ANOVA calculations on the invertebrate data due to the nature of the data. Direct comparison was also complicated by the baseline only consisting of a September survey which took place immediately after the majority of vegetation had been cut and was consequently limited in terms of numbers recorded. Furthermore, invertebrate survey results are highly dependent on the weather conditions on the day of survey, with the consequence that some variation between years is inevitable.

Figure 4.178 shows the number of invertebrates recorded in June in Years 2, 3 and 5 at Billingborough.

Year 2 showed the highest number of invertebrates recorded in all treatments, 391 on average, probably due to more suitable weather conditions in this year than experienced in previous years. There was little difference in numbers of individuals between the treatments, although Treatments 4, 9 and 10 had the lowest counts at around 365–380 individuals.

In Year 3, invertebrate numbers were more variable between treatments, with Treatments 7 and 9 having particularly high counts and Treatments 1 and 2 having the lowest counts.

By Year 5 (which was a particularly wet year and therefore would not have been conducive to high numbers of invertebrates), Treatments 4, 9 and 11 fair badly, with 65 individuals or less. Treatments 5 and 7 recorded the highest numbers of individuals (95–109).

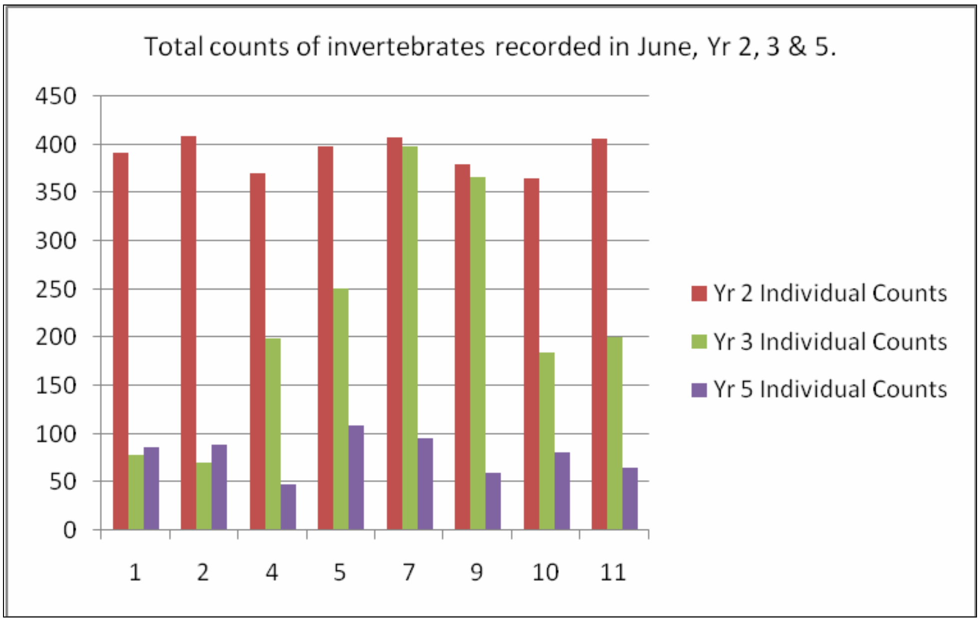


Figure 4.178 Total numbers of invertebrates recorded at Billingborough, in June, in Years 2, 3 and 5.

The limited data available for TWINSPAN analysis showed that each site had its own distinctive assemblage of invertebrate species, which overrode any differences due to treatment. The PCA diagram shown in Figure 4.179 of each treatment's data illustrates that Billingborough was distinctive for its abundance of *Tipula paludosa* (crane fly) and occurrence of hoverflies such as *Eupeodes corolla* and *Syritta pipiens*.

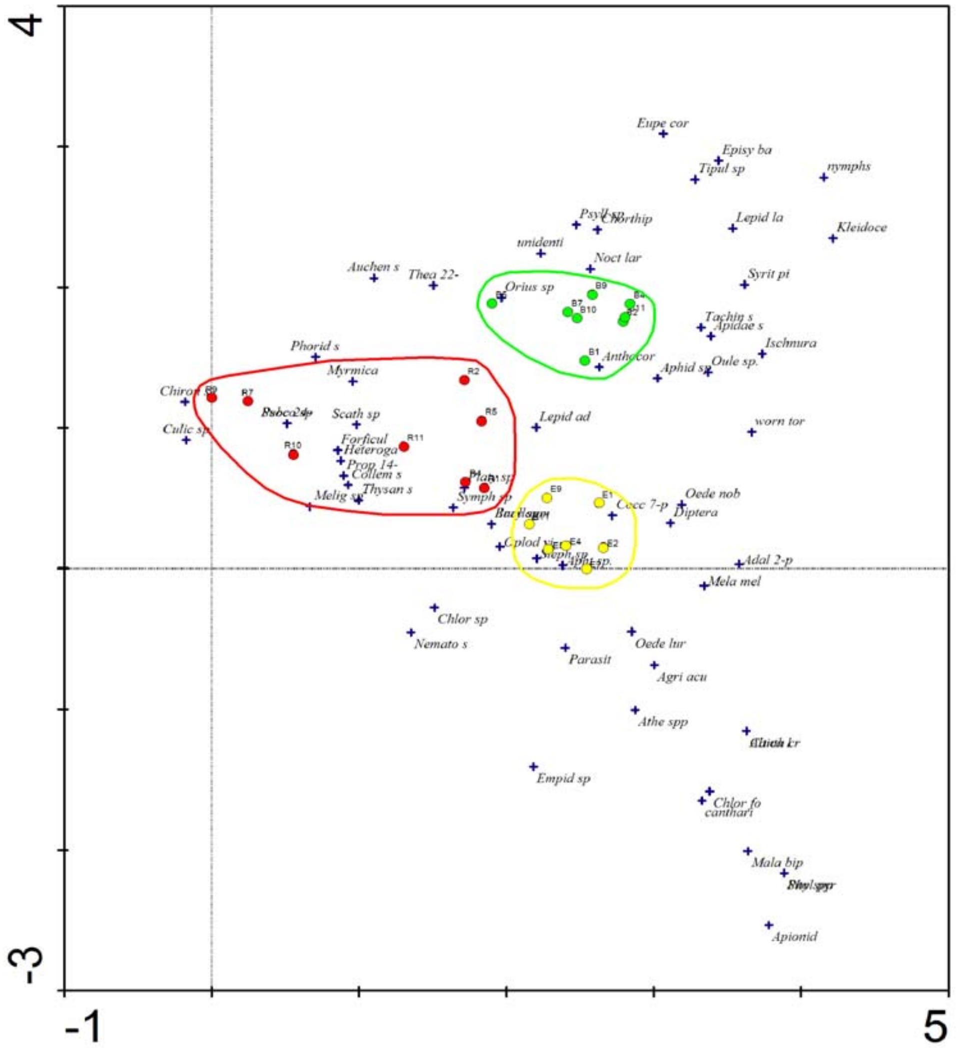


Figure 4.179 DCA diagram of invertebrate samples from all sites in Year 5 (using June and September records).

Red = Reach Lode, green = Billingborough, yellow = Ely Ouse

Analysis of the taxonomic groups (Figure 4.180) shows that, at Billingborough, Year 2 had a greater count of groups (average of 11), as well as number of individuals than Years 3 and 5 (average of six and seven respectively). Treatments 2, 4, 5 and 7 had consistently higher numbers of invertebrate groups compared with the other treatments.

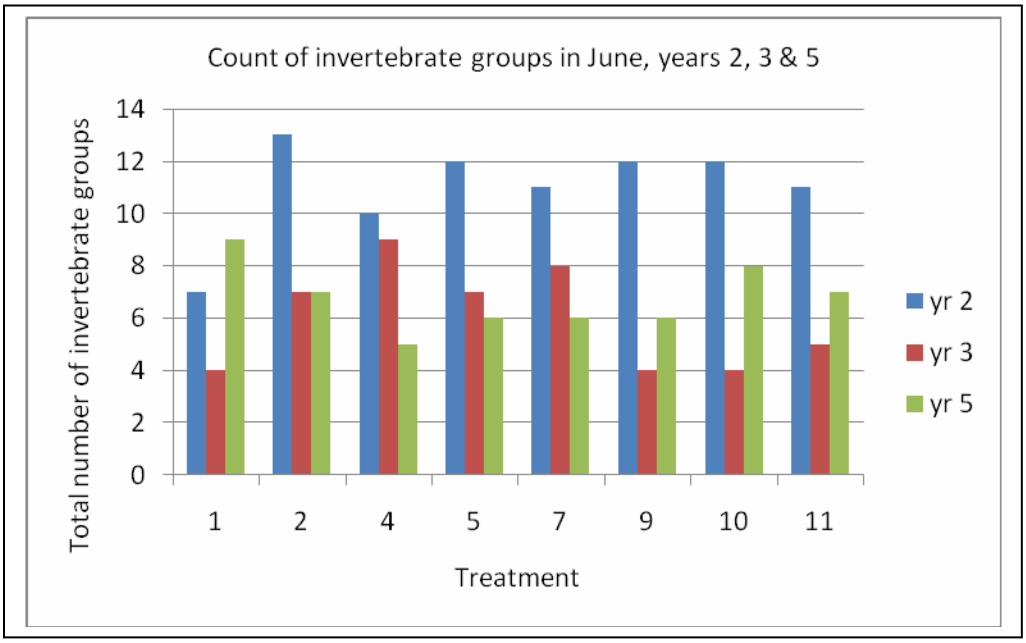


Figure 4.180 Total numbers of invertebrate groups recorded at Billingborough, in June, in Years 2, 3 and 5.

For Year 5 data, the invertebrate diversity of each treatment was estimated using Shannon's Diversity Index. The figures can only be approximate as not all groups of invertebrates were identified down to species level. However, all treatments were recorded in the same way and the results are therefore comparable.

The treatments are remarkably similar in terms of species diversity (Figure 4.181). However, Treatments 1 and 2 were consistently the highest throughout the year, with the unmanaged Treatment 11 also fairing well. Treatment 5, where arisings were removed (unlike Treatment 2), diversity was particularly low in June. This suggests that collection of arisings is not beneficial to invertebrate diversity. However, there was no such difference between treatments cut only once a year, whether arisings were left or removed (Treatments 4 and 7 respectively).

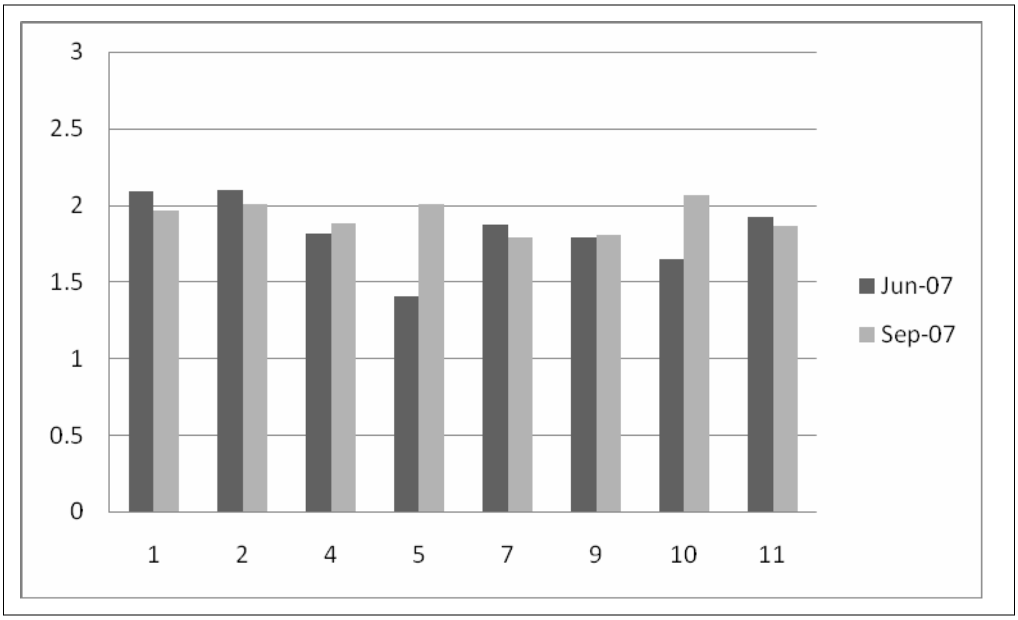


Figure 4.181 Diversity of invertebrates recorded at Billingborough in Year 5 (using Shannon's Diversity Index)

The following provides a breakdown of changes in the number of individuals recorded within their taxonomic groups. Bar charts of the number of individuals recorded in each group can be found on the accompanying CD 1.

- ***Odonata* (dragonflies/damselflies).** Very few *Odonata* were recorded at Billingborough. Because of the low numbers, the aquatic larval stage and the mobility of the group, there is a greater element of chance as to whether these species would be recorded in a treatment. However it is clear that Treatment 2 consistently has some *Odonata* presence in all three years, with Treatments 5, 7, 10 and 11 recording some presence in at least two of the three years. Particularly low numbers of this group were found with Treatments 1 and 9.

- ***Orthoptera* (grasshoppers and crickets).** This group of invertebrates showed its highest numbers in Treatments 1 and 2 (typically recording five or more individuals in each June survey). Year 3 appears to have been a particularly poor year for *Orthoptera* across the whole embankment. The treatments with the overall lowest count of this group of insect are Treatments 5 and 10. The species found at Billingborough are herbivorous and are typically associated with the kind of dry grassland found here.

- ***Dermaptera* (earwigs).** This group was very poorly represented at Billingborough, with individuals generally only recorded in treatments cut once a year where there was considerable leaf litter build up (with the exception of Treatment 1 in Year 5). *Dermaptera* are omnivorous and live primarily on a diet of plant matter (both living and decayed material). Because they prefer dark, sheltered environments and are mainly nocturnal, it is to be expected that numbers of this group would be low.

- ***Heteroptera* (true bugs).** The *Heteroptera* recorded at Billingborough were mainly *Miridae* (plant, leaf and grass bugs). General comparison shows that Treatments 9, 10 and 11 had consistently high counts of *Heteroptera*, with Treatment 7 also showing substantial numbers in September. Their feeding requirements are variable and they may be both herbivorous and predatory, adapting to their food sources. They are abundant on annual and perennial plants, and sweep netting (the collection technique used here) can often fail to collect the full suite of the *Miridae* present.

- ***Homoptera* (aphids).** This group was recorded in nearly all treatments in all three years. As with the other groups of insects recorded, Year 2 showed the highest number of individuals in the majority of treatments, with Treatment 5 showing consistently high numbers. Treatment 7 also showed a dramatic peak in Year 3, which had declined again by Year 5. Those treatments with the lowest counts by Year 5 included Treatments 1, 4, 7 and 11. However, when June data were combined with September data, the greatest numbers were found in Treatments 1, 2, 5, 9 and 11, suggesting this group do not favour treatments cut only once a year unless they are also treated with weed wipes.

- ***Diptera* (flies and midges).** This group was well represented at Billingborough in Years 2 and 3, but showed a notable decline in numbers across all treatments in Year 5. By which time, the lowest counts occurred in Treatments 4 and 9 (despite this treatment containing high numbers in previous years). Those treatments with the greatest consistency over the five years for high numbers of *Diptera* included Treatments 5 and 7. *Nematocera* (primitive flies) occurred only at Billingborough in Treatments 1 and 2.

- ***Hymenoptera: Aculeata*** (wasps, bees and ants). As in previous groups, Year 2 showed the highest counts for *Aculeata*, with more than 40 individuals recorded in Treatment 7. Year 5 data indicate that Treatments 10 and 11 were the preferred areas for this group, possibly in response to the abundance of *Sinapis arvensis* flowers in these treatments in June.

- ***Hymenoptera: Parasitica* (parasitic solitary wasps).** This group showed their greatest occurrence in Year 3, where Treatments 4, 7 and 9 did particularly well (approximately 30–60 individuals counted). By Year 5, no individuals were recorded in any of the treatments, probably due to wet weather conditions.

- ***Hymenoptera: Symphyta* (sawflies).** Very few individuals of this group were recorded during the June surveys of the five year trials. Treatments that failed to record any individuals during that time included Treatments 1, 7 and 11.

- ***Lepidoptera* (butterflies and moths).** This group was poorly represented at Billingborough, with only one or two adult individuals recorded during each survey from the majority of treatments in Year 2. No individuals were recorded in Treatment 1. Year 3 data show a complete absence of *Lepidoptera* records in June, but by Year 5, Treatments 2 and 10 had recorded a single adult individual each. Larvae were only recorded in the Year 2 June survey from Treatments 2, 5, 9 and 11, although *Noctuidae* larvae were present at this site in several treatments during the September survey in Year 5. *Noctuidae* larvae (owlet moths) were most abundant in Treatments 2, 4 and 7 (using combined June and September data). The larvae of some *Noctuidae* feed on brassicas and may therefore be more abundant here than at the other trial sites due to the abundance of *Sinapis arvensis*.

- ***Coleoptera* (beetles).** Year 2 showed little variation between treatments for this group of insects. However, by Year 3, Treatment 9 had considerably higher counts of *Coleoptera* than all other treatments, with Treatments 1 and 2 performing particularly poorly. Numbers of *Coleoptera* were lowest in all treatments in June, Year 5, for which only Treatments 4, 7, 10 and 11 had counts of five individuals or more. However, when June and September data were combined, *Phyllotreta* sp. (a kind of leaf beetle) were recorded in their highest nummbers in Treatments 2, 5 and 9.

- **Other**. Other invertebrate taxonomic groups found in very low abundances at Billingborough included *Plecoptera* (stoneflies), *Psocoptera* (book louse), *Thysanoptera* (thrips), *Neuroptera* (lacewings) and *Mecoptera* (scorpion flies).

Summary

The invertebrate fauna at Billingborough was in general very poor and found to be very variable between years. Of all the three sites, it appeared to contain a greater occurrence of invertebrates that are regarded as pest species to crops.

No strong patterns emerged regarding the influence of management and it appears that annual fluctuations, probably due to weather, override any other variable. However some broad comments can be made.

- Year 2 showed the highest number of invertebrates recorded and the highest count of invertebrate groups. In Year 3, invertebrate numbers were more variable between treatments, with Treatments 7 and 9 having particularly high counts and Treatments 1 and 2 having the lowest counts. By Year 5, the treatments had the least numbers of invertebrates present.
- Adding the total invertebrate counts together for each year reveals that Treatments 1 and 2 (cut regularly) had low counts (<600) and Treatments 5, 7, 9 and 11 had most invertebrates (>650).
- On average, Treatment 1 had the poorest count of invertebrate groups and Treatment 2 had the highest count. This indicates that, although more than one cut is beneficial to a diversity of invertebrate groups, high frequencies of mowing (i.e. six cuts) may cause too much damage and reduce diversity.
- The dominant groups at Billingborough were *Heteroptera*, *Homoptera*, *Diptera, Hymenoptera aculeata* and *Coleoptera*.

Mammals, fish, reptiles and birds

Although no concentrated surveys were conducted on the mammal, fish, reptile and bird interest of the treatments, data from the walkover surveys and the number of vole holes recorded during the crack survey do allow some interpretation, although no statistical analysis was possible.

Billingborough was the only site where evidence of badgers using the site was recorded. However, as these signs were present in Year 1, this cannot be assigned to changes in management.

Evidence of rabbits (in the short sward of Treatment 5) and foxes (in various treatments) were also recorded.

Molehills were recorded by Year 5 only in those treatments cut three times a year.

Vole holes were also recorded regularly at this site. Using these holes as an indication of the vole population across the various plant community types, Community C was least used by voles while Community D was most used (Table 4.33). Holes were absent from the crest of the bank, but showed a slightly higher average on the landward face than the river face (an average of 4.75 holes per replicate compared with 3.5 holes per replicate on the river face).

Table 4.33 Number of vole holes recorded at Billingborough in Year 5.

Plant community	Range of hole records per replicate	Mean number of holes per replicate
A	0–10	2.67
B	0–4	2.33
C	0–2	0.4
D	0–12	5.5
E	0–5	2

No birds were observed nesting in any of the treatments over the five-year period of the trials. Similarly no reptiles were observed using the embankment. However a single frog and toad were observed within treatments cut three times a year or more (Treatments 1 and 5).

4.7.2 Reach Lode

Invertebrates

Figure 4.182 shows the number of invertebrates recorded in June in Years 2, 3 and 5 at Reach Lode. As at Billingborough, Year 2 showed the highest number of invertebrates recorded in all treatments (328 on average), probably due to more suitable weather conditions in this year than experienced in other years. At this time there was little difference in numbers of individuals between the treatments, although Treatment 9 had the lowest counts at 243 individuals. In Year 3, invertebrate numbers were low across all treatments, with Treatments 7 and 5 having particularly low counts. By Year 5 (which was a particularly wet year and therefore would not have been conducive to high numbers of invertebrates), invertebrate were found in only three of the treatments (9, 10 and 11), with counts all less than 50 individuals.

TWINSPAN analysis showed that Reach Lode was distinctive for its occurrence of *Collembola* (springtails, which are detritivores), *Barypeithes* sp. (a kind of true weevil) and large numbers of *Chironimidae* and *Culicidae* (both classified as mosquitoes), particularly in treatments receiving only one cut per year.

Treatments 7, 9, 10 and 11 (all of which receive no more than one cut a year) were split into a separate TWINSPAN division because of the presence of *Staphylinidae* (rove beetles). These consist of predatory species and may therefore prefer the structural heterogeneity provided by taller vegetation with considerable leaf litter cover.

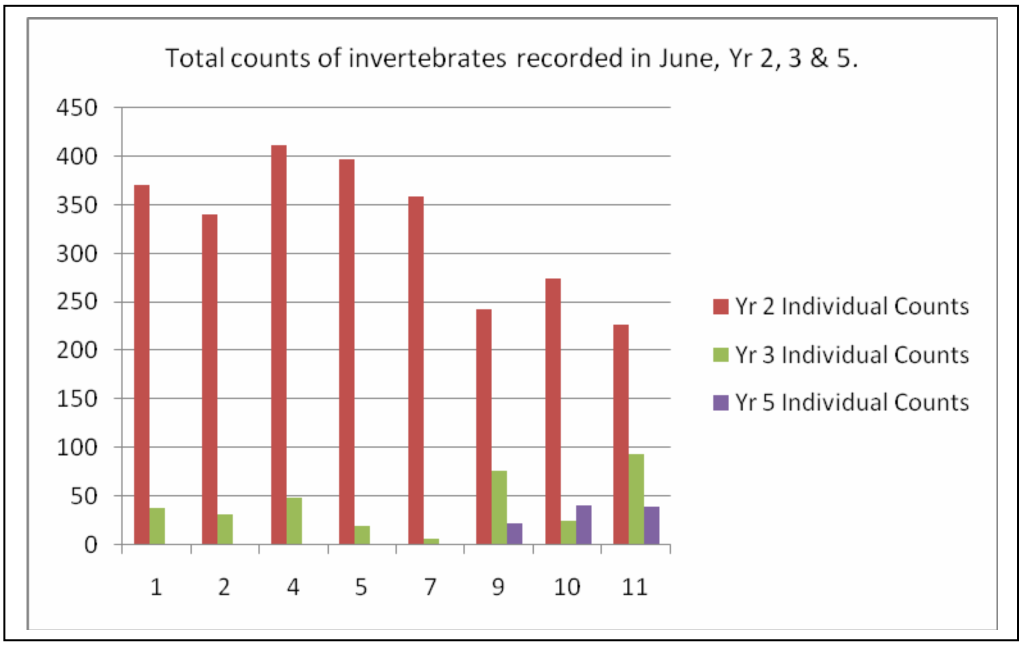


Figure 4.182 Total numbers of invertebrates recorded at Reach Lode, in June, in Years 2, 3 and 5.

Analysis of the taxonomic groups (Figure 4.183) showed that, at Reach Lode in June, Year 2 had a greater variety of groups (average of 12), as well as number of individuals than Years 3 and 5 (average of four and two respectively). In Year 2, Treatments 2, 9 and 11 had the highest number of invertebrate groups. Despite the low count of individuals in Year 5, the variety of groups recorded was greater than in Year 3.

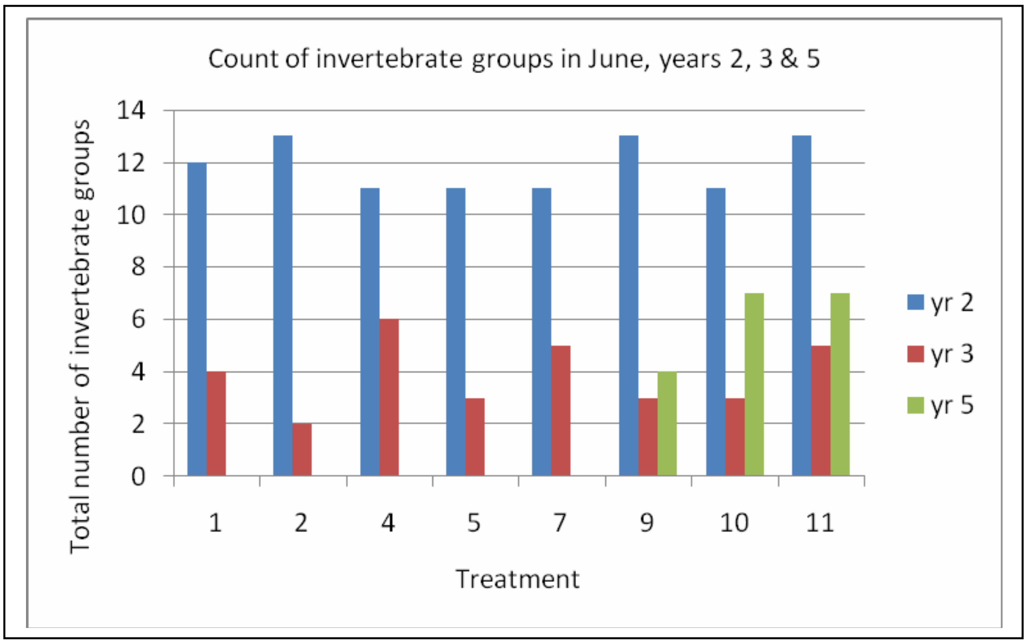


Figure 4.183 Total numbers of invertebrate groups recorded at Reach Lode, in June, in Years 2, 3 and 5.

For Year 5 data, the invertebrate diversity of each treatment was estimated using Shannon's Diversity Index. The figures can only be approximate as not all groups of invertebrates were identified down to species level. However, all treatments were recorded in the same way and the results are therefore comparable.

Reach Lode recorded more variation between treatments than was recorded at Billingborough (Figure 4.184). Treatments 5 and 11 showed the highest diversity throughout the year, with Treatments 1, 2 and 4 also moderately high. Treatments 7, 9 and 10 (all receiving only one cut a year) showed the lowest diversity. Year 5 data showed no consistent pattern between arising collection and invertebrate diversity, with collection of arisings showing higher diversity where three cuts were taken, but the reverse being the case where one cut was taken.

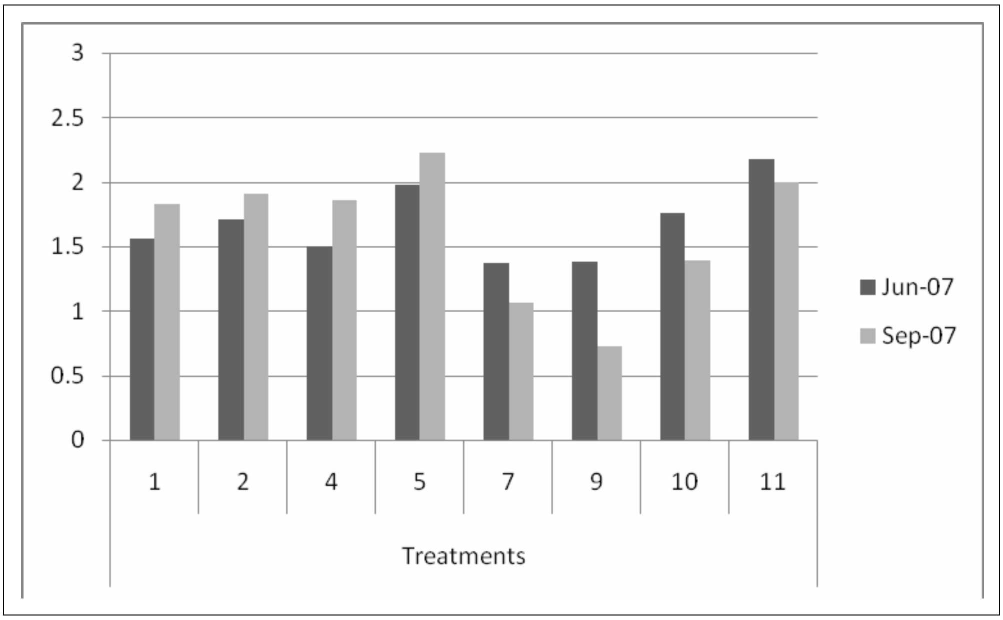


Figure 4.184 Diversity of invertebrates recorded at Reach Lode in Year 5 (using Shannon's Diversity Index).

The following section provides a breakdown of changes in the number of individuals recorded within their taxonomic groups. Bar charts of the number of individuals recorded in each group can be found in on the accompanying CD 1.

- ***Odonata* (dragonflies and damselflies**). As at Billingborough, very few *Odonata* were recorded at Reach Lode. Because of the low numbers, the aquatic larval stage and the mobility of the group, there is a greater element of chance as to whether these species will be recorded in a treatment. However it is clear that Treatments 1, 7 and 9 consistently had some *Odonata* presence in all three years (up to two individuals), with Treatments 5, 10 and 11 recording no presence in any of the three years. There was no year in which numbers were better or poorer than other years.

- ***Orthoptera* (grasshoppers and crickets).** This group of invertebrates showed its highest numbers in Year 2, with only one recording in other years. Treatment 2 had the highest recording (nine individuals), while Treatments 1, 5, 10 and 11 also had relatively large populations.

- ***Dermaptera* (earwigs).** This group had one of the lowest populations of the invertebrate groups found at Reach Lode, with individuals recorded only in Treatments 5 and 9. *Dermaptera* are omnivorous and live primarily on a diet of plant matter, both living and decayed. Because they prefer dark sheltered environments and are mainly nocturnal, it is to be expected that numbers of this group would be low.

- ***Heteroptera* (true bugs).** Most of the *Heteroptera* recorded at Reach Lode were found during the Year 2 survey. The *Heteroptera* found were mainly *Miridae* (plant, leaf and grass bugs). Treatments 2, 7 and 10 had the highest counts of *Heteroptera*, although Treatment 11 was the only treatment to have *Heteroptera* populations present in all years of the survey. *Anthocoris* spp. (flower bugs) were rather poorly represented at Reach Lode, though it is not clear why.

- ***Homoptera* (aphids).** Unlike the abundant populations at Billingborough, this group was mainly recorded in one year of trials (Year 2). Treatment 1, 4, 5, 9 and 11 had the highest counts of individuals within the *Homoptera* group. Treatments 10 and 11 were the only treatments where populations were detected in all three years of survey.

- ***Diptera* (flies and midges).** This group was the most abundant of the invertebrates, with the highest populations of up to 160 individuals in Year 2. The largest populations were found in Treatments 4 and 5 of Year 2. Treatment 7 was the only treatment to have a population of *Diptera* found in only one of the three survey years. Treatments 9, 10 and 11 appeared to have stable populations, with *Diptera* present in all three years (although Year 5 had lower populations). *Tipula paludosa* (crane fly) were recorded in large numbers, mainly in Treatments 1, 2, 4 and 5.

- ***Hymenoptera: Aculeata* (wasps, bees and ants).** As in previous groups, Year 2 showed the highest counts for *Aculeata*, with more than 30 individuals recorded in Treatment 1 and 10. Small populations (less than five) were found for *Aculeata* in Year 5 in Treatments 4, 5 and 7.

- ***Hymenoptera: Parasitica* (parasitic solitary wasps)**. Populations of this group were recorded in Years 2 and 3, with no recordings in Year 5. The highest count of 13 individuals was found in Treatment 1 in Year 3. High populations were also found in the other frequently cut treatments (Treatments 2 and 5) as well as the unmanaged Treatment 11, as many species require sunny, disturbed habitats as well as unmanaged habitats such as brambles and dead wood.

- ***Hymenoptera: Symphyta* (sawflies).** Very few individuals of this group were recorded, although this was the only trial site at which they occurred. In Year 5 Treatments 1, 2, 4 and 5 all recorded *Symphyta*.

- ***Lepidoptera* (butterflies and moths)**. This group was predominantly found in Year 2 at Reach Lode. Treatment 7 was the only treatment in this year with no *Lepidoptera* present. Treatment 11 had the highest counts of *Lepidopterawith* up to five individuals. Larvae of *Lepidoptera* were also found in Year 2 surveys, but at lower populations than the adults. In Year 5, Nocturidae were only recorded in the unmanaged treatment.

- ***Coleoptera* (beetles).** *Coleoptera* occurred at high densities in Year 2, with the highest populations in Treatments 1, 2, 4, 5 and 7 (over 100 individuals). The lowest numbers found were in Treatments 9, 10 and 11. Results from Years 3 and 5 were low and sporadic. Treatment 11 was the only treatment where *Coleoptera* were found in all survey years. Very few *Oedemera nobilis* (a flower beetle) were recorded at Reach Lode, possibility because the adults feed on flowers such as *Leucanthemum vulgare*.

- **Other**. Other invertebrate taxonomic groups found in low abundances included *Collembola* (springtails), *Ephemeroptera* (upwinged flies), *Plecoptera*

(Stoneflies), *Psocoptera* (book louse), *Thysanoptera* (thrips), *Neuroptera* (lacewings) and *Mecoptera* (scorpion flies).

<u>Summary</u>

Reach Lode was less diverse in terms of invertebrate species than Billingborough, but appeared to contain greater numbers of semi-aquatic species (particularly at the larval stage) presumably due to the proximity of the Lode.

Invertebrate populations in Year 2 were approximately four times those found in Years 3 and 5. By Year 5 (which was a particularly wet year and therefore will not have been conducive to high numbers of invertebrates) invertebrates were found in only three of the treatments (9, 10 and 11) in June but numbers had picked up again by September.

On average, Treatment 5 had the poorest variety of invertebrate groups but the greatest diversity of species. Treatment 11 had both high variety and high diversity of invertebrates.

The dominant groups at Reach Lode were *Heteroptera*, *Homoptera*, *Diptera, Hymenoptera aculeata* and *Coleoptera*.

As at Billingborough, the invertebrate fauna at Reach Lode was poor, showing both low abundance of individuals and low species-richness. No uncommon species were recorded. The year of sampling, and weather conditions on the day, were the most influential factors.

Mammals, fish, reptiles and birds

Although no concentrated surveys were conducted on the mammal, fish, reptile and bird interest of the treatments at Reach Lode, data from the walkover surveys and the number of vole holes recorded during the crack survey do allow some interpretation, though no statistical analysis was possible.

A number of small birds were recorded using the marginal vegetation on the edge of the river face at Reach Lode including yellow hammer, gold finch, reed bunting and reed warbler. These species were generally only observed where wetland vegetation persisted (such as *Phragmites australis* and *Carex acutiformis*). As a consequence, they were not present where the vegetation was very short and the river face was very narrow, such as in Treatment 1. In contrast, swans and geese tended to prefer the shorter vegetation of Treatments 1 and 5, for feeding and resting. A single sighting of a green woodpecker within the tall vegetation on the landward face of Treatment 7 was recorded in Year 3.

Vole holes were also recorded regularly at this site. Using these holes as an indication of the vole population across the various plant community types, Community B was most used by voles (Table 4.34). This plant community occurred only on the river face in treatments cut three times a year. Holes were generally absent from the crest of the bank, but were equally as frequent on the landward as on the river face.

Table 4.34 Number of vole holes recorded at Reach Lode in Year 5.

Plant community	Range of hole records per replicate	Mean number of holes per replicate
A	0–1	0.17
B	4–7	5.5
C	0–5	1.7
D	0–7	2.5
E	7	7

4.7.3 Ely Ouse

Invertebrates

Figure 4.185 shows the number of invertebrates recorded in June in Years 2, 3 and 5 at Ely Ouse. Unlike Billingborough and Reach Lode, the highest number of invertebrates recorded was in Year 3 (Treatments 2, 4 and 5 had more than 300 individuals), although when examining all of the treatments, Year 2 had the greatest count in total. Similarly to Year 3, the greatest counts were found in Treatments 4, 5 and 7 in Year 2. By June of Year 5 (which was a particularly wet year and therefore will not have been conducive to high numbers of invertebrates), invertebrates were found in smaller numbers with counts all less than 150 individuals. This was still three times the number at Reach Lode.

TWINSPAN analysis showed that Ely Ouse was distinctive for the abundance of *Diptera* spp. and the diversity of species not found at the other two sites. These included:

- *Apionidae* (seed weevils);
- *Cantharidae* (soldier beetles);
- *Pyllobius pyri* (common leaf weevil);
- *Sitonia* spp. (sitonia weevil);
- *Malachius bipustulatus* (common malachite beetle);
- *Oedemera lurida* (a flower beetle);
- *Atheta* spp. (rove beetles).

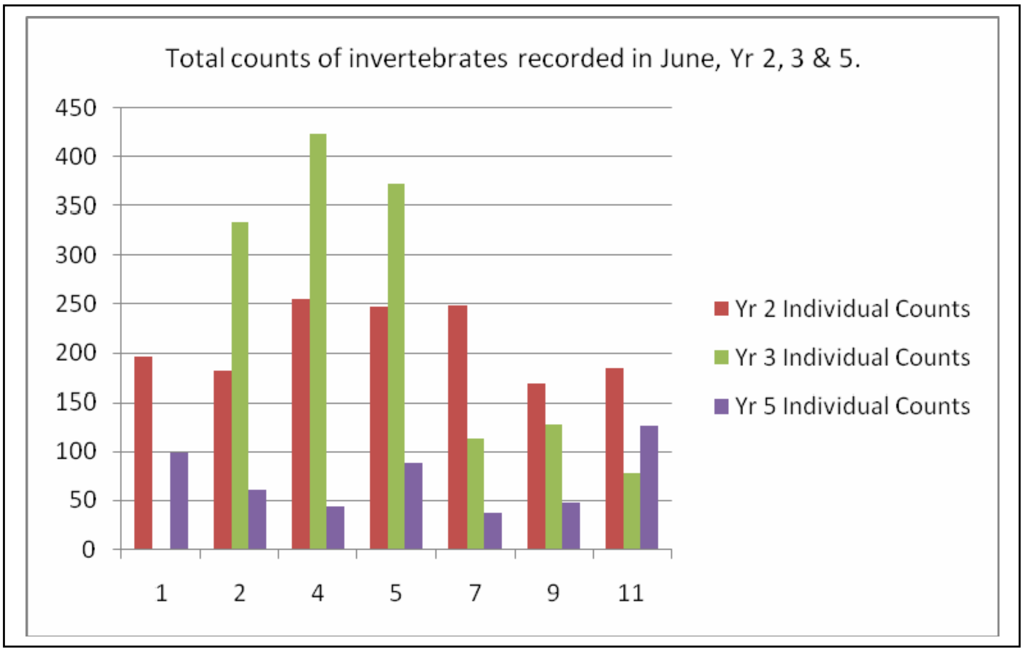


Figure 4.185 Total numbers of invertebrates recorded at Ely Ouse, in June, in Years 2, 3 and 5.

Analysis of the taxonomic groups (Figure 4.186) shows that, at Ely Ouse, Year 2 had a greater diversity of groups (average of 11) and number of individuals than Years 3 and 5 (average of six and six respectively). In Year 2, Treatments 2 and 4 had the lowest number of invertebrate groups (<10) and Treatment 1 had the greatest (14). Considering Years 3 and 5, Treatment 5 had the lowest number of invertebrate groups.

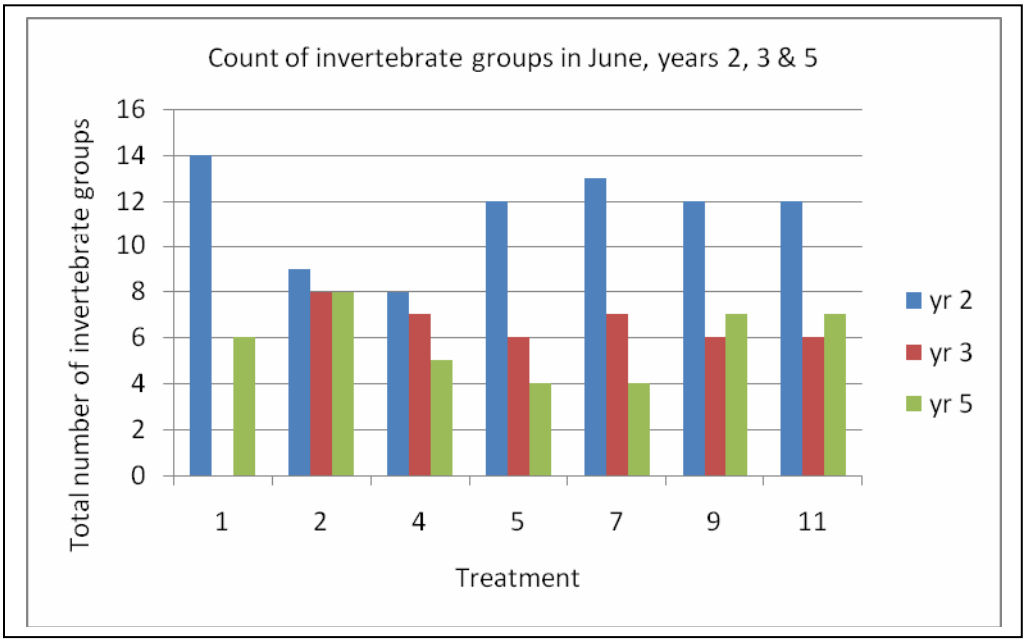


Figure 4.186 Total number of invertebrate groups recorded at Reach Lode, in June, in Years 2, 3 and 5.

For Year 5 data, the invertebrate diversity of each treatment was estimated using Shannon's Diversity Index. Ely Ouse recorded more variation during the course of the year than either Billingborough or Reach Lode Treatments 2, 9 and 11 showed the highest overall diversity for the year, with Treatment 5 showing particularly low scores for June (Figure 4.187). By

September, those treatments receiving one cut a year showed the highest invertebrate diversity.

Year 5 data suggest that, although collection of arisings results in lower invertebrate diversity where three cuts were taken, no significant difference in diversity was recorded where only one cut took place.

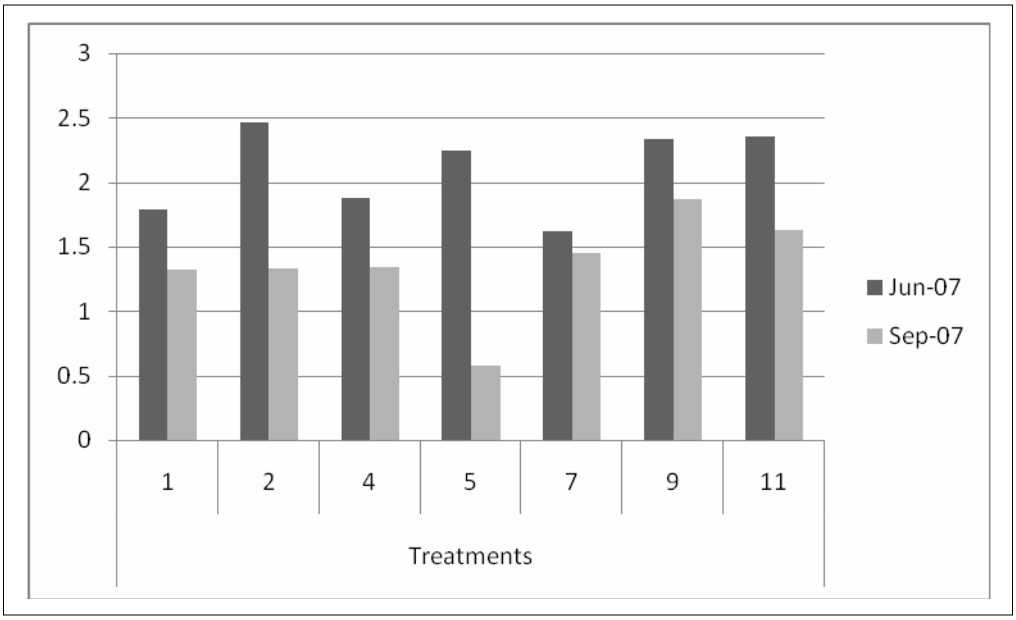


Figure 4.187 Diversity of invertebrates recorded at Ely Ouse in Year 5 (using Shannon's Diversity Index).

The following section provides a breakdown of changes in the number of individuals recorded within their taxonomic groups. Bar charts of the number of individuals recorded in each group can be found in on the accompanying CD 1.

- ***Odonata* (dragonflies and damselflies).** As at Billingborough and Reach Lode, very few *Odonata* were recorded at Ely Ouse, no more than one individual per treatment on any survey occasion. Therefore, there are no trends to show a preference for years or treatments.

- ***Orthoptera* (grasshoppers and crickets).** All counts for *Orthoptera* (with the exception of one in Year 5) were from Year 2 surveys. The greatest populations were found in Treatments 1, 5 and 11 (4–6 individuals). No *Orthoptera* were found in Treatment 4.

- ***Dermaptera* (earwigs).** As was the case at the other sites, this group had one of the lowest populations of the invertebrate groups found. Individuals were recorded in two of the survey years in Treatments 1 and 7 and only in one year in Treatments 2 and 4. As discussed above, the feeding habits and preferred habitat of the *Dermaptera* may explain its low capture.

- ***Heteroptera* (true bugs).** There were relatively high numbers of *Heteroptera* found in all years at Ely Ouse, with Year 2 having the greatest counts (in particular Treatments 2 and 4). Treatments 9 and 5 had the most consistently high populations of *Heteroptera* in all three years.

- ***Homoptera* (aphids).** This group were abundant with large populations in Treatments 2, 5 and 7 of more than 60 in both Years 2 and 3. Year 5 counts of

Homoptera were all low compared with previous years (<20), but were greatest in Treatments 1, 2, 5 and 11.

- ***Diptera* (flies and midges).** Once again, this group was the most abundant of the invertebrates, with the highest populations of up to 140 individuals in Year 2. The largest populations were found in Treatments 2 and 4 in Years 2 and 3. Like many other of the invertebrate groups, counts of *Diptera* were much lower in the wettest of the survey years (Year 5), with populations below 60 in all treatments. *Chironomidae* (mosquitoes) were only found in Treatment 11. *Melanostoma mellinum* (a hoverfly) was mainly recorded from this site.

- ***Hymenoptera: Aculeata* (wasps, bees and ants).** Unlike previous invertebrate groups and trial sites, Year 3 showed the highest counts for *Aculeata*, with more than 200 individuals recorded in Treatments 4 and 5. Populations in other treatments were sporadic.

- ***Hymenoptera: Parasitica* (parasitic solitary wasps).** Five of the treatments (1, 5, 7, 9 and 11) had a population of *Parasitica* in Year 5. However, the highest counts were found in Treatments 2 and 11 of Year 5 (nine and 33 individuals respectively). Treatment 4 was the only treatment to have no individuals of *Parasitica* recorded.

- ***Hymenoptera: Symphyta* (sawflies).** Low counts (1–2) of this group were only recorded in Year 2 of the surveys. Treatment 7 was the only treatment to have no *Symphyta* present.

- ***Lepidoptera* (butterflies and moths).** This group was found at low levels in all years at Ely Ouse (although Year 2 had a slightly greater occurrence). Treatments 1, 5 and 9 had the greatest number of adult *Lepidoptera* found, while Treatment 11 (control) was the only treatment to have *Lepidoptera* present every year. Larvae of *Lepidoptera* were also found in Year 2 surveys, but at lower populations than the adults.

- ***Coleoptera* (beetles).** *Coleoptera* occurred at high densities, in particular in Year 2 where there was little variability between the treatments. The highest population (>90 individuals) was found in Treatment 5 in Year 3. Year 5 populations were all below 20. The presence of *Cantharidae* at this site indicates that there was a sufficient food source of soft-bodied invertebrates. *Malachius bipustulatus* was recorded from Treatments 2, 5 and 7 in Year 5, a species which requires open structured flowers in its adult stage and small invertebrates in its larval stage.

- **Other.** Other invertebrate taxonomic groups found in low abundances included *Collembola* (springtails), *Psocoptera* (book louse), *Thysanoptera* (thrips), *Neuroptera* (lacewings) and *Mecoptera* (scorpion flies).

Summary

Ely Ouse had the greatest variety of invertebrate groups, representing a range of life strategies and food requirements. Several of the species recorded mainly at this site require open flowered plants, which were abundant at this site in treatments cut more than once a year.

Invertebrate populations had the highest peaks in Year 2 (greatest in Treatments 2, 4 and 5), but were highest across all the treatments in Year 3. In Year 5, invertebrate populations were low. Populations were most stable across all the years in Treatment 11.

The dominant groups at Ely Ouse were *Heteroptera*, *Homoptera*, *Diptera*, *Hymenoptera aculeata* and *Coleoptera*.

Unlike the two previous sites, the invertebrate fauna was somewhat richer here, with some groups showing preferences for certain management treatments. However, no strong trends were visible due to climatic factors affecting the invertebrate communities in particular sampling years.

Mammals, fish, reptiles and birds

As at Reach Lode, occasional sightings were made of small birds such as reed bunting using the marginal vegetation on the berm below the river face recording plots at Ely Ouse. This marginal vegetation was present across the entire trial embankment and was not affected by the vegetation management.

A single sighting of a weasel was recorded on the river face of Treatment 9, which may have been using the bank as a foraging route, as rabbits have also occasionally been sighted in the neighbouring area and a burrow was recorded near Treatment 11 in Year 5. It is possible that Treatment 11 was chosen for the burrow location because of its undisturbed nature.

Moles and particularly vole holes were also recorded regularly at this site. Using these holes as an indication of the vole population across the various plant community types, Communities A and B (both cut frequently) were least used by voles (Table 4.35). Holes were generally absent from the crest of the bank, but were equally as frequent on the landward as on the river face.

Table 4.35 Number of vole holes recorded at Ely Ouse in Year 5.

Plant community	Range of hole records per replicate	Mean number of holes per replicate
A	1–2	1.5
B	0–3	0.8
C	4	4
D	0–11	4.15
E	2–7	4.5
F	7	7
G	1–9	5

4.8 Relationship between soil and vegetation variables

In addition to validating plant community divisions, PCA (using Canoco for Windows version 4.52) was also used to analyse how the other sward variables, recorded alongside species data (e.g. leaf litter percentage cover, species-richness or vegetation height) corresponded for each site with the PCA axes. If a good correlation was found between say leaf litter cover and Axis 1, this would suggest leaf litter cover is the principal factor (and therefore the cause) that separates the plant communities found.

As part of the PCA process, Pearson's Product-Moment Correlation Coefficients (using Canoco for Windows version 4.52) were calculated on all vegetation/sward variables for the June survey (the optimum month in terms of floristic composition). To perform correlation tests between vegetation and soil variables (e.g. soil strength and soil moisture), June data were not available so April data were used instead.

Identifying relationships using these data was limited by the smaller sample size, i.e. only one measurement of soil moisture was recorded per bank face for the whole treatment compared with three sets of floristic data per bank face per treatment. Ellenberg Indicator Values for light, nitrogen, moisture and reaction were therefore calculated for each vegetation recording plot so that a larger dataset was available for these variables.

A summary table was produced showing the average value recorded for each vegetation and soil variable within the given plant communities per site. These values are provided below.

4.8.1 Billingborough

Vegetation and invertebrate relationships

The accompanying CD 3 includes a matrix of correlation coefficients for all vegetation/sward variables and PCA axes for Billingborough. At this site, Axis 1 showed a positive correlation (at 99 per cent significance) to several variables including mean vegetation height, Ellenberg Indicator Values for nitrogen and reaction, as well as a negative correlation (at 99 per cent) with the number of cuts taken. Clearly several of these variables are interconnected (e.g. the number of cuts will affect the mean vegetation height), but the data do suggest cutting frequency (directly or indirectly) is the primary influence on how the plant communities are different. It supports previous conclusions that across the flood embankments, cutting frequency was the main driver for species composition.

Axis 2 (the secondary division used in analysing the plant data) showed a positive correlation (at 99 per cent) with Ellenberg Indicator Values for light and the total annual arisings collected.

Many significant correlations were found between vegetation variables at Billingborough, some of which reflect direct relationships between variables, while others are indirect due to a shared third variable.

Table 4.36 summarises all the relationships recorded using the June data.

The key relationships are as follows:

- More cuts correlates (at 95 per cent or more) with:
  - lower Ellenberg Indicator Values for nitrogen;
  - lower Ellenberg Indicator Values for reaction;
  - increased plant species-richness;
  - lower leaf litter cover;
  - increased bryophyte cover.

- Larger numbers of invertebrates correlates (at 99 per cent) with increased leaf litter cover.
- Applying weedkiller correlates (at 99 per cent) with lower total vegetation cover.
- More leaf litter cover correlates (at 95 per cent) with lower bryophyte cover.
- More leaf litter cover correlates (at 95 per cent) with lower total vegetation cover.
- Higher Ellenberg Indicator Values for nitrogen correlates (at 99 per cent) with taller vegetation height.
- Taller vegetation height correlates (at 95 per cent) with less bryophyte cover.
- Taller vegetation height correlates (at 99 per cent) with reduced plant species-richness.
- Taller vegetation height correlates (at 99 per cent) with increased bare ground cover.
- Higher Ellenberg Indicator Values for moisture correlates (at 99 per cent) with reduced plant species-richness.

Table 4.36 Correlation coefficients (using Pearson's Product-Moment) for vegetation and invertebrate variables recorded at Billingborough in Year 5.

	Total vegetation. cover	Ellenberg Reaction Value	Ellenberg Nitrogen Value	Ellenberg Moisture Value	Ellenberg Light Value	Use of weed wipes	Number of cuts	Total number of invertebrates	Total annual arisings	Mean vegetation height	Bryophyte cover	Leaf litter cover	Bare ground cover	Plant species-richness
Plant species-richness		-ve	-ve	-ve			+ve	-ve		-ve				
Bare ground cover		+ve	+ve							+ve		-ve		
Leaf litter cover	-ve						-ve	+ve			-ve			
Bryophyte cover							+ve		+ve	-ve				
Mean vegetation height		+ve	+ve	+ve	+ve		-ve		-ve					
Total annual arisings					-ve		+ve	+ve						
Total number of invertebrates			+ve		-ve									
Number of cuts		-ve	-ve											
Use of weed wipes	-ve													
Ellenberg Light Value														
Ellenberg Moisture Value	+ve													
Ellenberg Nitrogen Value	?													
Ellenberg Reaction Value														
Total vegetation cover														

Key: +ve = positive correlation, -ve = negative correlation
red = >99 per cent significance, orange = 99 per cent significance, yellow = 95–99 per cent significance
grey = correlations not usable due to nature of data.

Soil relationships

The accompanying CD 3 includes a matrix of correlation coefficients for soil against vegetation and invertebrate at Billingborough. Many significant correlations were found between soil and vegetation or invertebrate variables at Billingborough, reflecting both direct and indirect relationships.

Table 4.37 summarises all the relationships recorded using the April data. There may be other correlations that did not meet a significance level of ≥95 per cent but which may still be related to each other in some way. However, the relationship was not apparent, possibly due to the smaller number of samples taken of soil variables.

The key relationships are as follows:

- More cuts correlates (95 per cent significance) with:
  - greater soil strength at the surface (using a pocket penetrometer);
  - higher soil temperatures;

- greater plant species-richness.

- Use of weed wipes correlates (99 per cent significance) with lower soil pH values.
- Lower soil moisture at the surface correlates (99 per cent significance) with greater plant species-richness.
- More bare ground cover correlates (99 per cent significance) with less bryophyte cover.
- Greater phosphorus, potassium and nitrate values correlate (95–99 per cent significance) with less bare ground cover.
- Greater bryophyte cover correlates (99 per cent significance and 95 per cent significance) with higher soil moisture at the surface and at depth.
- Greater leaf litter cover correlates (95 per cent significance) with lower soil moisture at the surface.
- Taller vegetation correlates (99 per cent significance) with:
  - lower surface soil strength (using a proving ring penetrometer, pocket penetrometer and hand vane);
  - lower soil magnesium values.
- Higher soil organic matter content correlates (95 per cent significance) with:
  - a lower soil pH;
  - increased phosphorus values;
  - increased soil moisture at depth.
- Higher soil potassium, magnesium and nitrate values correlate (95–99 per cent significance) with lower surface soil strength (using a proving ring penetrometer).
- Higher soil moisture at the surface and at depth correlates (95–99 per cent significance) with lower soil strength at depth (using a pocket penetrometer and a proving ring penetrometer).
- Higher soil strength at the surface using a hand vane correlates (at 95 per cent significance) with both higher surface soil strength (using a pocket penetrometer and a proving ring penetrometer) and higher soil strength at depth (using a pocket penetrometer).

Table 4.37 Correlation coefficients (using Pearson's Product-Moment) for vegetation and soil variables recorded at Billingborough in Year 5.

	Total vegetation cover	Use of weed wipes	Number of cuts	Soil moisture at depth	Soil moisture at surface	Proving ring penetrometer	PP at depth	PP at surface	Hand vane at depth	Hand vane at surface	Nitrate	Organic matter content	Magnesium	Potassium	Phosphorus	Soil pH	Root content	Mean vegetation height	Bryophyte cover	Leaf litter cover	Bare ground	Plant species-richness
Plant species-richness			+ve		-ve	+ve	+ve			+ve												
Bare ground cover											-ve			-ve	-ve				-ve	-ve		
Leaf litter cover					-ve								-ve									
Bryophyte cover				+ve	+ve									+ve								
Mean vegetation height						-ve		-ve		-ve			-ve									
Root content																						
Soil pH		-ve										-ve										
Phosphorus				+ve							+ve	+ve										
Potassium						-ve																
Magnesium				+ve																		
Organic matter content				+ve																		
Nitrate				+ve																		
Hand vane at surface						+ve	+ve	+ve														
Hand vane at depth							+ve															
Pocket penetrometer at surface			+ve			+ve																
Pocket penetrometer at depth				-ve	-ve																	
Proving ring penetrometer					-ve																	
Soil moisture at surface				+ve																		
Soil moisture at depth																						
Number of cuts																						
Use of weed wipes																						
Total vegetation cover																						

Key: +ve = positive correlation; -ve = negative correlation
red = >99 per cent significance; orange = 99 per cent significance; yellow = 95–99 per cent significance
Degrees of freedom vary between variables due to occasional missing data.

Table 4.38 summarises some of the soil parameters in relation to each plant community. Hand vane data suggest that Communities D and E had the worst surface soil strength but that Community B had the worst soil strength at depth. Interestingly Community B also had the highest average dry weight of roots per 25 g sample.

Table 4.38 Average soil variables for plant communities at Billingborough, Year 5.

	Plant community				
	A	B	C	D	E
Hand vane 0 m (April)	99.5	104.7	102.3	86.8	36.3
Hand vane 0.25 m (April)	96.3	69	111.5	89.4	92.3
Soil pH (April)	7.85	8.1	7.5	7.9	7.9
Surface moisture (April)	20.6	15.5	21.3	26	18.5
0.3 m depth moisture (April)	23.2	15.7	18.4	24.3	19.1
Roots (April)	2.32	61.6	2.86	2.81	2.26
Organic matter (April)	6.4	6	5.8	6.6	7.3
Nitrate (April)	12.1	8.17	6.16	6.32	4.17

Analysis of the number of fissures and plant communities at Billingborough showed that in April, Year 5, the species-rich Communities A and B had fewer Class 2 category fissures than the species-poor, taller swards of Communities D and E (Figure 4.188). Very few large fissures were recorded and these occurred only in Communities A and B. In general terms Communities B and C showed the least sign of cracking. Figure 4.189 shows examples of cracking in Communities A and D.

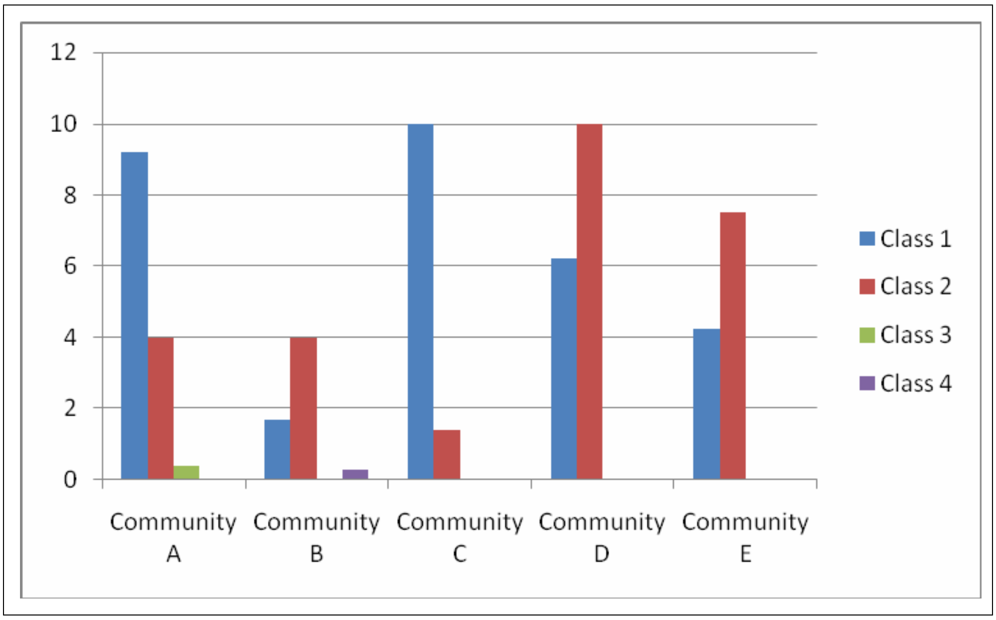


Figure 4.188 Number of fissures per size class recorded in each plant community at Billingborough in April, Year 5.

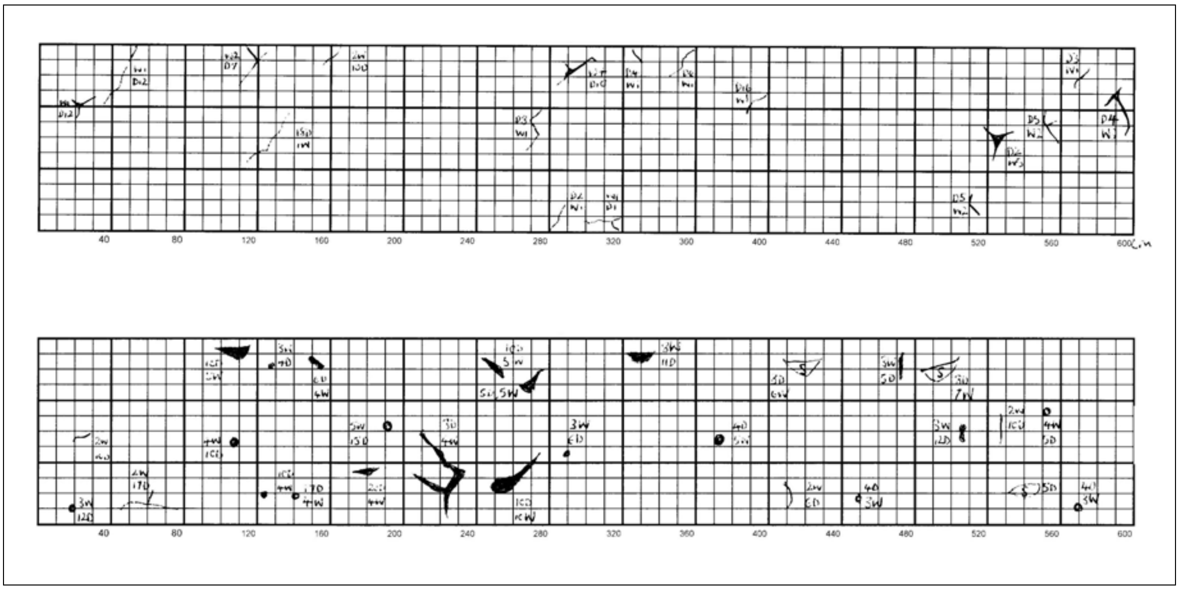


Figure 4.189 Billingborough, April Year 5. Above: example of hairline cracking on the landward face in Community A. Below: example of Class 2 cracking on the landward face in Community D.

The August survey followed a wet summer and therefore the results are likely to be somewhat obscured. However, they show that the short sward of Community A had many hairline fissures but very few moderate and no large fissures. Communities B, C and D all had several Class 2 fissures and only Community D had a large fissure (Figure 4.190).

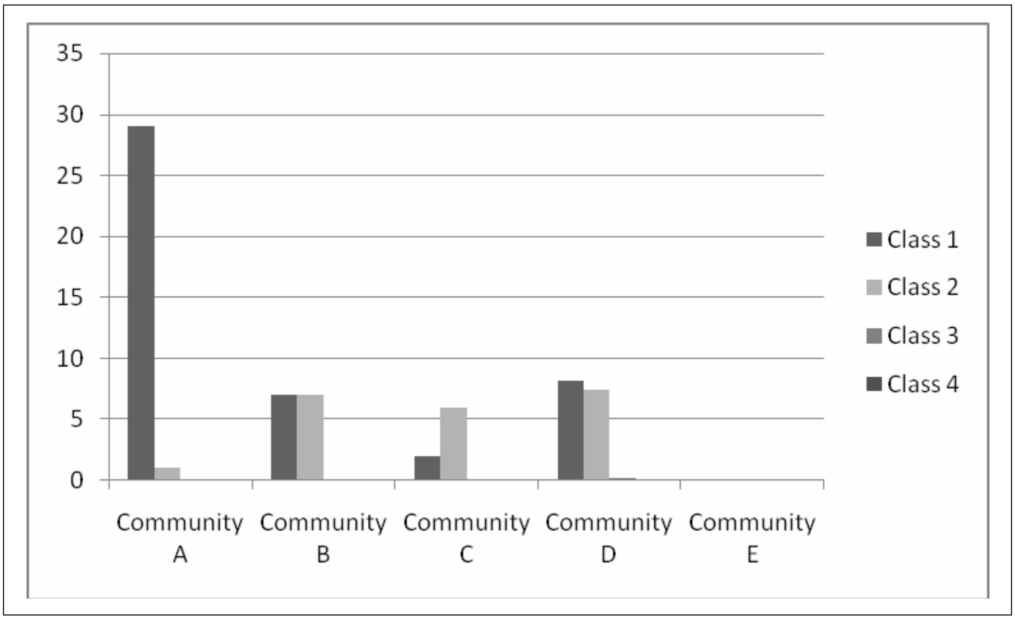


Figure 4.190 Number and size of fissures recorded in each plant community at Billingborough in August, Year 5.

4.8.2 Reach Lode

Vegetation and invertebrate relationships

The accompanying CD 3 includes a matrix of correlation coefficients for all vegetation/invertebrate variables and PCA axes for Reach Lode. Here, Axis 1 showed a negative correlation (at 99 per cent significance) to mean vegetation height, Ellenberg Indicator Values for nitrogen, Ellenberg Indicator Values for reaction and the total number of invertebrates, as well as a positive correlation (at 99 per cent significance) with Ellenberg Indicator Values for light. Thus the data indicate that cutting frequency may indirectly be the primary influence on how the plant communities are different by affecting mean vegetation height.

Axis 2 (the secondary division used in analysing the plant data) showed a negative correlation (at 99 per cent significance) with Ellenberg Indicator Values for moisture. This reflects the influential effect the embankment face has on the vegetation at this site.

Many significant correlations were found between vegetation variables at Reach Lode; some reflect direct relationships between variables, while others are indirect due to a shared third variable.

Table 4.39 summarises all the relationships recorded using the June data.

The key relationships are listed below:

- More cuts correlates (at 95 per cent significance or more) with:
  - more total annual arisings;
  - increased bare ground cover;
  - higher Ellenberg Indicator Values for light.
- Larger numbers of invertebrates correlates (at 99 per cent significance) with:
  - greater aquatic litter cover;
  - taller vegetation.
- More leaf litter cover correlates (at 95 per cent significance or more) with:
  - less bryophyte cover;
  - higher Ellenberg Indicator Values for moisture.
- More aquatic litter cover correlates (at 99 per cent significance) with:
  - higher Ellenberg Indicator Values for nitrogen;
  - lower total vegetation cover;
  - higher Ellenberg Indicator Values for reaction;
  - lower Ellenberg Indicator Values for light.
- Taller vegetation correlates (at 95 per cent significance or more) with:
  - more leaf litter cover;
  - lower Ellenberg Indicator Values for light;

- less bryophyte cover;
- higher Ellenberg Indicator Values for nitrogen.

- High plant species-richness correlates (at 95 per cent significance) with:
  - low aquatic litter cover;
  - low Ellenberg Indicator Values for nitrogen;
  - high bare ground cover.

Table 4.39 Correlation coefficients (using Pearson's Product-Moment) for vegetation/invertebrate variables recorded at Reach Lode in Year 5.

	Total vegetation cover	Ellenberg Reaction Value	Ellenberg Nitrogen Value	Ellenberg Moisture Value	Ellenberg Light Value	Use of weed wipes	Number of cuts	Total number of invertebrates	Total annual arisings	Mean vegetation height	Aquatic litter cover	Bryophyte cover	Leaf litter cover	Bare ground cover	Plant species-richness
Plant species-richness	+ve		-ve								-ve	+ve		+ve	
Bare ground cover			-ve	-ve			+ve	-ve		-ve		+ve	-ve		
Leaf litter cover	+ve			+ve						+ve	-ve	-ve			
Bryophyte cover		-ve	-ve					-ve		-ve					
Aquatic litter cover	-ve	+ve	+ve		-ve			+ve							
Mean vegetation height	+ve	+ve	+ve	+ve	-ve		-ve	+ve							
Total annual arisings		+ve	+ve				+ve	+ve							
Total number of invertebrates		+ve	+ve	+ve	-ve		-ve								
Number of cuts	-ve				+ve										
Use of weed wipes															
Ellenberg Light Value															
Ellenberg Moisture Value	+ve														
Ellenberg Nitrogen Value															
Ellenberg Reaction Value															
Total vegetation cover															

Key: +ve = positive correlation, -ve = negative correlation
red = >99 per cent significance, orange = 95–99 per cent significance, yellow = 95 per cent significance
grey = correlations not usable due to nature of data.

Soil relationships

Many significant correlations were found between soil and vegetation variables at Reach Lode, reflecting both direct and indirect relationships between variables.

Table 4.40 summarises all the relationships recorded using the April data. There may be other correlations that which did not meet a significance level of 95 per cent or more but which may still be related to each other in some way. However, the relationship was not apparent, possibly due to the smaller number of samples taken of soil variables.

The key relationships are as follows:

- Greater leaf litter cover correlates (at 95 per cent significance or more) with:
  - less soil strength at the surface (as measured by a hand vane and a proving ring penetrometer);
  - less soil strength at depth (as measured by the hand vane).
- Greater aquatic litter cover correlates (at 95 per cent significance) with less soil strength at the surface (as measured by a pocket penetrometer and a proving ring penetrometer).
- Taller vegetation correlates (at 95 per cent significance) with:
  - less soil strength both at the surface and depth (as measured by a hand vane, proving ring penetrometer and pocket penetrometer);
  - high organic matter content.
- Greater bryophyte cover correlates (at 95 per cent significance) with greater soil strength at the surface (as measured by a hand vane).
- Greater root content correlates (at 95 per cent significance) with greater total vegetation cover.
- Greater organic matter content correlates (at 95 per cent significance) with:
  - higher soil moisture content both at the surface and at depth;
  - lower soil strength at the surface (as measured by a hand vane, pocket penetrometer and proving ring penetrometer);
- More cuts correlates (at 95 per cent significance) with greater soil moisture content at depth.

The majority of nutrients measured showed positive correlations to each other at 95 per cent confidence. Positive correlations were also frequent between variables measuring strength such as the hand vane measurements at the surface and at depth. Although surface soil strength measurements show the greatest response to other variables (e.g. leaf litter cover), it is possible that there may be a secondary response to soil strength at depth which is not quite as strong. For example, there is a correlation between greater soil strength at depth (using a hand vane) and low soil moisture which is just below 95 per cent confidence limits.

The lack of correlations for variables such as plant species-richness suggests that April is not the optimum month for measuring several variables. It also indicates that the reduced number of samples available for analysis limited the likelihood of finding correlations within 95 per cent confidence limits. Furthermore, the variability recorded in the macronutrients resulted in a lack of correlations between these and vegetation variables. This is at least partly because a single sample taken over a 70 cm diameter circle of ground per 90 m treatment per embankment face is unlikely to be representative of the bank as a whole, particularly where the substrate of that bank is very variable. Therefore it was felt that the Ellenberg Indicator Values of nitrogen provided a much more representative value than spot testing of soil chemistry.

Table 4.40 Correlation coefficients (using Pearson's Product-Moment) for vegetation and soil variables recorded at Reach Lode in Year 5.

	Total vegetation cover	Use of weed wipes	Number of cuts	Soil moisture at depth	Soil moisture at surface	Proving ring penetrometer	PP at depth	PP at surface	Hand vane at depth	Hand vane at surface	Nitrate	Organic matter content	Magnesium	Potassium	Phosphorus	Soil pH	Root content	Mean vegetation height	Aquatic litter cover	Bryophyte cover	Leaf litter cover	Bare ground	Plant species-richness
Plant species-richness																		-ve					
Bare ground cover									+ve												-ve		
Leaf litter cover	+ve					-ve			-ve	-ve										-ve			
Bryophyte cover	-ve									+ve	-ve	-ve	-ve	-ve				-ve					
Aquatic litter cover	-ve					-ve		-ve															
Mean vegetation height						-ve		-ve	-ve	-ve		-ve											
Root content	+ve																						
Soil pH			-ve	-ve	-ve						-ve	-ve		-ve	-ve								
Phosphorus			+ve								+ve	+ve											
Potassium		-ve									-ve	-ve	+ve										
Magnesium																							
Organic matter content				+ve	+ve	-ve		-ve		-ve	+ve												
Nitrate					+ve	-ve		-ve		-ve													
Hand vane at surface						+ve		+ve	+ve														
Hand vane at depth						+ve		+ve															
Pocket penetrometer at surface				-ve																			
Pocket penetrometer at depth						+ve																	
Proving ring penetrometer																							
Soil moisture at surface				+ve																			
Soil moisture at depth	+ve		+ve																				
Number of cuts																							
Use of weed wipes																							
Total vegetation cover																							

Key: +ve = positive correlation, -ve = negative correlation
red = >99 per cent significance, orange = 99 per cent significance, yellow = 95 per cent significance
grey = correlations not usable due to nature of data.

Table 4.41 summarises some of the soil parameters in relation to each plant community. Soil strength at the surface was greatest in the species-rich Community A and worst in species-poor Community D and the community influenced heavily by aquatic dredgings (E). At 0.25 m depth, Community A was still found to be the strongest. However Community B showed the lowest soil strength at depth using the hand vane, presumably because of the high soil moisture readings from this community. There was little difference in the soil strength at depth of the remaining communities. Community B had the highest average dry weight of roots per 25 g sample and Community A had the lowest.

Table 4.41 Average soil variables for plant communities at Reach Lode, Year 5.

	Plant community					
	A	**B**	**C**	**D**	**E**	**F**
Hand vane 0 m (April)	120.00	76.5	76	66	56	23*
Hand vane 0.25 m (April)	100.00	20	60	53	58	62*
Proving ring	1201.00	666	761	448	308	25*
Soil pH (April)	7.9	7.9	7.7	7.9	7.9	7.8*
Surface moisture (April)	19.60	37.3	31.7	34.1	34.3	34.9*
0.30 m depth moisture (April)	22.40	27.7	28.9	26.4	26.3	27.3*
Roots (April)	0.37	12.17	2.86	5.73	2.07	4.06*
Organic matter (April)	9.8	15.2	18.5	16.6	13.1	14.8*

* Based on a single sample.

Analysis of soil variables and plant communities at Reach Lode showed that in April, Year 5, the species-rich Community A had the greatest number of hairline fissures (Figure 4.191). This was a community found solely on the crest of the bank and therefore exposed to regular trampling and vehicle access. Community B, which occurred in treatments receiving three cuts per year, showed the lowest total number of fissures on the river face. Community D, which represents the species-poor tall vegetation found on the majority of river and landward face recording plots, was found to contain many hairline fissures as well as several Class 2 fissures and occasionally larger fissures. Examples of cracking at Communities A, B and D are shown in Figure 4.192.

Insufficient data were available on the number of cracks found in the August survey because many of the plant communities recorded were not sampled for fissures in that month.

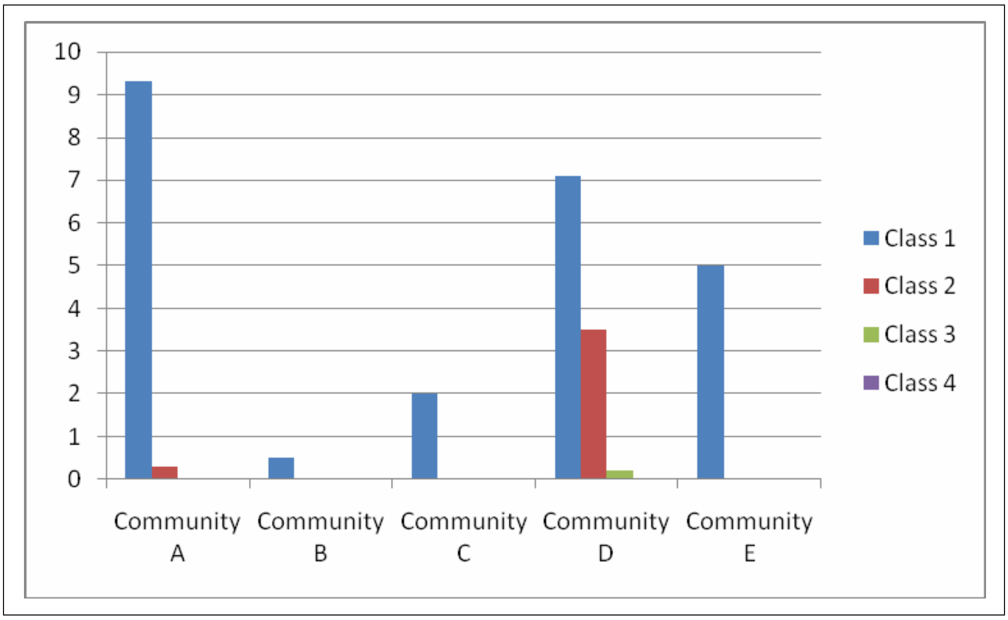


Figure 4.191 Number of size of fissures recorded in each plant community at Reach Lode in April, Year 5.

Figure 4.192 Reach Lode, April Year 5. Top: example of hairline cracking on the crest in Community A. Middle: example of occasional cracking on the river face in Community B. Bottom: example of Class 2 cracking on the landward face in Community D.

4.8.3 Ely Ouse

Vegetation and invertebrate relationships

The accompanying CD 3 includes a matrix of correlation coefficients for all vegetation and invertebrate variables and PCA axes for Ely Ouse. Here, Axis 1 showed a positive correlation (at 99 per cent significance) to plant species-richness and the number of cuts, as well as negative correlations (at 99 per cent significance) with mean vegetation height and Ellenberg Indicator Values for moisture, nitrogen and reaction. Thus the data indicate that cutting frequency is likely to be the primary influence on how the plant communities are different by affecting mean vegetation height.

Axis 2 (the secondary division used in analysing the plant data) showed a negative correlation (at 99 per cent significance) with leaf litter cover, as well as a positive correlation with bryophyte cover and Ellenberg Indicator Values for light, all of which are inter-related. The data therefore indicate the importance of light as a secondary factor in the differences between plant communities.

Many significant correlations were found between vegetation variables at Ely Ouse, some of which reflect direct relationships between variables, while others are indirect due to a shared third variable.

Table 4.42 summarises all the relationships recorded using the June data.

The key relationships are as follows:

- More cuts correlates (at 95 per cent significance or more) with:
  - less leaf litter cover;
  - greater plant species-richness;
  - less total vegetation cover.
- Use of weed wipes correlates (at 95 per cent significance or more) with:
  - lower plant species-richness;
  - higher Ellenberg Indicator Values for nitrogen.
- Greater leaf litter cover correlates (at 99 per cent significance) with:
  - lower plant species-richness;
  - less bryophyte cover;
  - lower Ellenberg Indicator Values for light;
  - higher Ellenberg Indicator Values for moisture;
  - higher Ellenberg Indicator Values for nitrogen.
- Greater plant species-richness correlates (at 99 per cent significance) with lower Ellenberg Indicator Values for nitrogen.
- Taller vegetation correlates (at 95 per cent significance or more) with:
  - higher Ellenberg Indicator Values for nitrogen;
  - greater total arisings.

- Larger numbers of invertebrates correlates (at 99 per cent significance) with greater total arisings.

Table 4.42 Correlation coefficients (using Pearson's Product-Moment) for vegetation and invertebrate variables recorded at Ely Ouse in Year 5.

	Total vegetation cover	Ellenberg Reaction Value	Ellenberg Nitrogen Value	Ellenberg Moisture Value	Ellenberg Light Value	Use of weed wipes	Number of cuts	Total number of invertebrates	Total annual arisings	Mean vegetation height	Bryophyte cover	Leaf litter cover	Bare ground cover	Plant species-richness
Plant species-richness	-ve	-ve	-ve	-ve	+ve	-ve	+ve			-ve	+ve	-ve	+ve	
Bare ground cover					+ve					-ve		-ve		
Leaf litter cover			+ve	+ve	-ve		-ve			+ve	-ve			
Bryophyte cover			-ve		+ve		+ve							
Mean vegetation height	+ve	+ve	+ve	+ve	-ve		-ve		+ve					
Total annual arisings		+ve						+ve						
Total number of invertebrates														
Number of cuts	-ve	-ve	-ve	-ve										
Use of weed wipes		+ve	+ve											
Ellenberg Light Value														
Ellenberg Moisture Value														
Ellenberg Nitrogen Value														
Ellenberg Reaction Value	+ve													
Total vegetation cover														

Key: +ve = positive correlation, -ve = negative correlation
red = >99 per cent significance, orange = 99 per cent significance, yellow = 95 per cent significance
grey = correlations not usable due to nature of data.

Soil relationships

Many significant correlations were found between soil and vegetation variables at Ely Ouse, reflecting both direct and indirect relationships between variables. Table 4.43 summarises all the relationships recorded using the April data. There may be other correlations that did not meet a significance level of 95 per cent or more but which may still be related to each other in some way. However, the relationship was not apparent, possibly due to the smaller number of samples taken of soil variables.

The key relationships are as follows:

- More cuts correlates (at 95 per cent significance or more) with:
  - greater plant species-richness;
  - greater bryophyte cover;
  - lower nitrate levels.

- Greater leaf litter cover correlates (at 95 per cent significance) with lower plant species-richness.
- Taller vegetation correlates (at 95 per cent significance or more) with:
  - greater bare ground cover;
  - less total vegetation cover;
  - lower soil strength at the surface (as measured by a proving ring penetrometer).
- Greater bryophyte cover correlates (at 95 per cent significance) with greater soil moisture both at the surface and at depth.
- Greater root content correlates (at 95 per cent significance) with:
  - greater surface soil moisture content;
  - lower soil strength at the surface (as measured by a hand vane).
- More total vegetation cover correlates (at 95 per cent significance) with greater soil strength at the surface (using a hand vane and a proving ring penetrometer).
- Greater soil moisture at the surface correlates (at 95 per cent significance) with greater soil strength at the surface.

Once again, positive correlations were also frequent between variables measuring strength such as between hand vane measurements at the surface and at depth.

Table 4.43 Correlation coefficients (using Pearson's Product-Moment) for soil and vegetation variables recorded at Ely Ouse in Year 5.

	Total vegetation cover	Use of weed wipes	Number of cuts	Soil moisture at depth	Soil moisture at surface	Proving ring penetrometer	PP at depth	PP at surface	Hand vane at depth	Hand vane at surface	Nitrate	Organic matter content	Magnesium	Potassium	Phosphorus	Soil pH	Root content	Mean vegetation. height	Bryophyte cover	Leaf litter cover	Bare ground	Plant species-richness
Plant species-richness			+ve								-ve			-ve	-ve			-ve	+ve	-ve		
Bare ground cover																		+ve		-ve		
Leaf litter cover					-ve									+ve								
Bryophyte cover			+ve	+ve	+ve									-ve								
Mean vegetation height	-ve		-ve			-ve					+ve											
Root content					+ve					-ve												
Soil pH												-ve										
Phosphorus											+ve	+ve										
Potassium													+ve									
Magnesium		-ve																				
Organic matter content											+ve											
Nitrate			-ve																			
Hand vane at surface	+ve					+ve		+ve														
Hand vane at depth					+ve	+ve		+ve														
Pocket penetrometer at surface						+ve																
Pocket penetrometer at depth				-ve	-ve																	
Proving ring penetrometer	+ve																					
Soil moisture at surface																						
Soil moisture at depth																						
Number of cuts																						
Use of weed wipes																						
Total vegetation cover																						

Key: +ve = positive correlation, -ve = negative correlation
red = >99 per cent significance, orange = 99 per cent significance, yellow = 95 per cent significance
grey = correlations not usable due to nature of data.

Table 4.44 summarises of some soil parameters in relation to each plant community. The majority of communities had high soil strength at the surface as measured by the hand vane. Values were lowest in the species-poor Community F and the unmanaged Community G. Data from the proving ring penetrometer showed more variation than the hand vane, with the species-rich and frequently cut Communities A and B showing much stronger surface soil strength than the less frequently managed communities. Interestingly organic matter was also low in Communities A and B.

At 0.25 m depth, soil strength was again consistently high in Communities A and B and lowest in the unmanaged vegetation of Community G. The data appear to show that the average dry weight of roots was marginally higher in the species-poor communities but it is not clear if this was due to the variability of the root distribution or a meaningful result.

Table 4.44 Average soil variables for plant communities at Ely Ouse, Year 5.

Plant community	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Hand vane 0 m (April)	108.00	100	120*	115.5	108	95*	53
Hand vane 0.25 m (April)	105.00	90.2	37*	70.75	71	96*	47
Proving ring penetrometer	956.00	949	280*	791	500	554*	310
Soil pH (April)	8.00	7.9	7.5*	8	7.9	7.9*	7.9
Surface moisture (April)	24.00	27.2	21.3*	20.7	23.4	33.2*	25.6
0.30 m depth moisture (April)	22.00	19.9	25.6*	16.2	23.7	21.6*	19.1
Roots (April)	1.68	21.99	3.8*	2.41	11.78	1.18*	1.51
Organic matter (April)	6.2	8.1	14.7*	9.4	13	9.1*	10

* Based on a single sample.

Analysis of the number of fissures and plant communities at Ely Ouse showed that in April, Year 5, the species-rich Communities A and B as well as the species-poor Communities D, E and F had relatively few fissures recorded Community C, which occurred on the landward face of Treatment 5 and therefore may have been exposed to burning at some stage, showed the greatest number of fissures at both Class 1 and 2 categories (Figure 4.193).

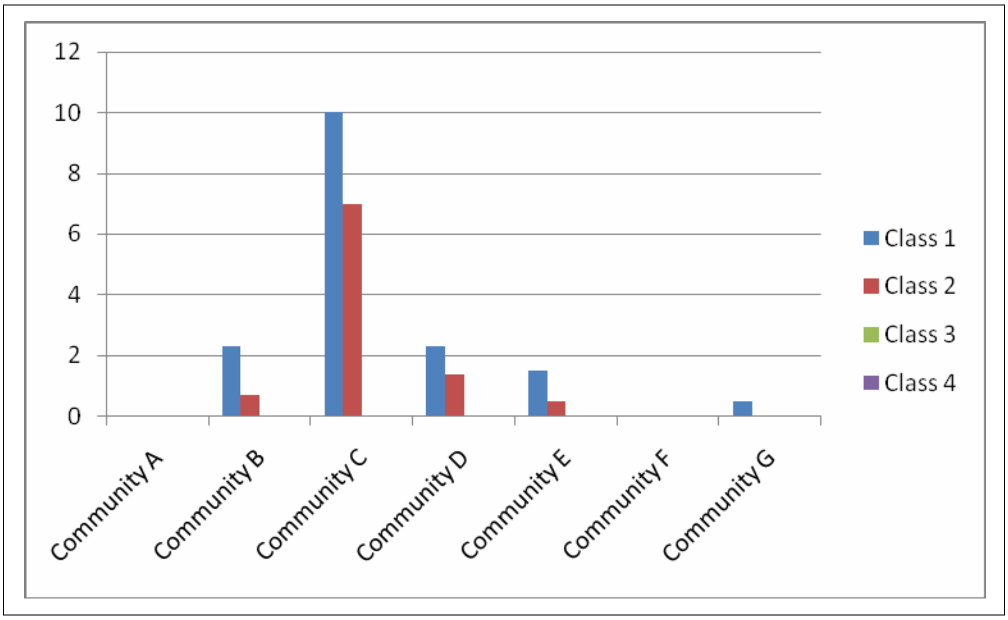


Figure 4.193 Number of size of fissures recorded in each plant community at Ely Ouse in April, Year 5.

The August survey followed a wet summer and therefore the results are likely to be somewhat obscured. However, they showed that once again Treatment 5 (cut three times a year with arisings removed) had the greatest number of fissures in Class 1 and 2. However, on the whole very few fissures were recorded at this site in August, with the majority only falling into Class 1 (Figure 4.194).

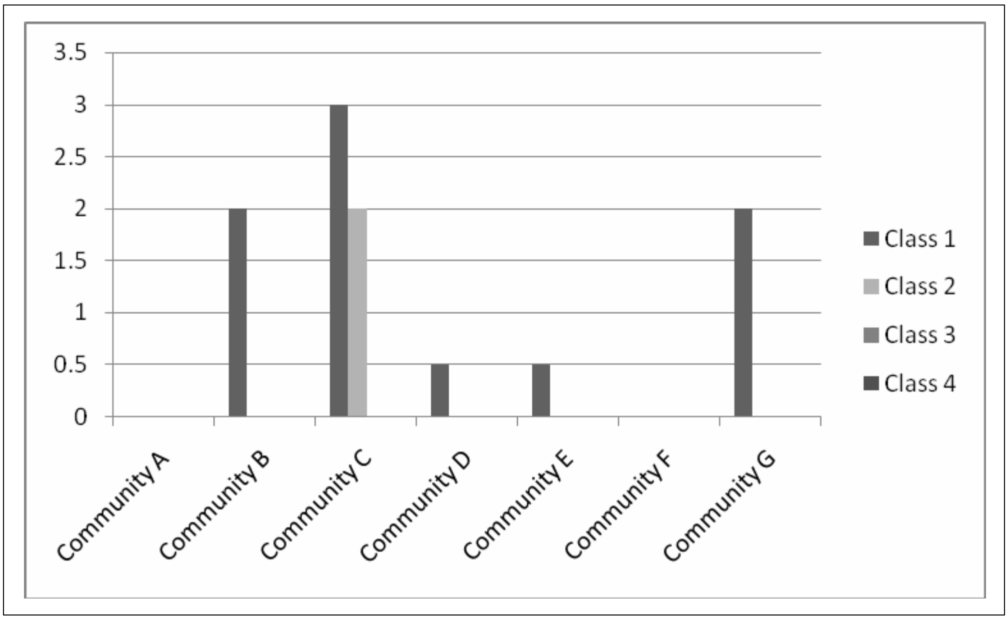


Figure 4.194 Number and size of fissures recorded in each plant community at Ely Ouse in August, Year 5.

4.9 Operational factors

4.9.1 Time requirements and costs

During each round of treatments, the time required to undertake the treatment and the cost involved was logged for each trial site. The costs incurred from each treatment per site are shown in Figures 4.195–4.197.

At Reach Lode and Ely Ouse, the management was undertaken by external contractors and the costs logged therefore include the mobilisation of machinery (R Ely, personal communication, 2008). The results from these sites (Figure 1.196 and Figure 4.197 respectively) suggest that, where cutting took place six times a year, cutting during the months of May and June was the most expensive. However, in these months very few other treatments were cut and the increased cost therefore reflects the need to bring machinery out to cut a relatively small area. In this respect, the time taken to maintain the treatments was much more informative than costs logged.

At Billingborough, the work was undertaken by Environment Agency staff rather than external contractors, the costs logged only include the manpower time taken and the cost of chemicals. They exclude the time taken to get machinery on-site and are therefore a better reflection of the costs involved if an entire bank were to be treated for example, six times a year.

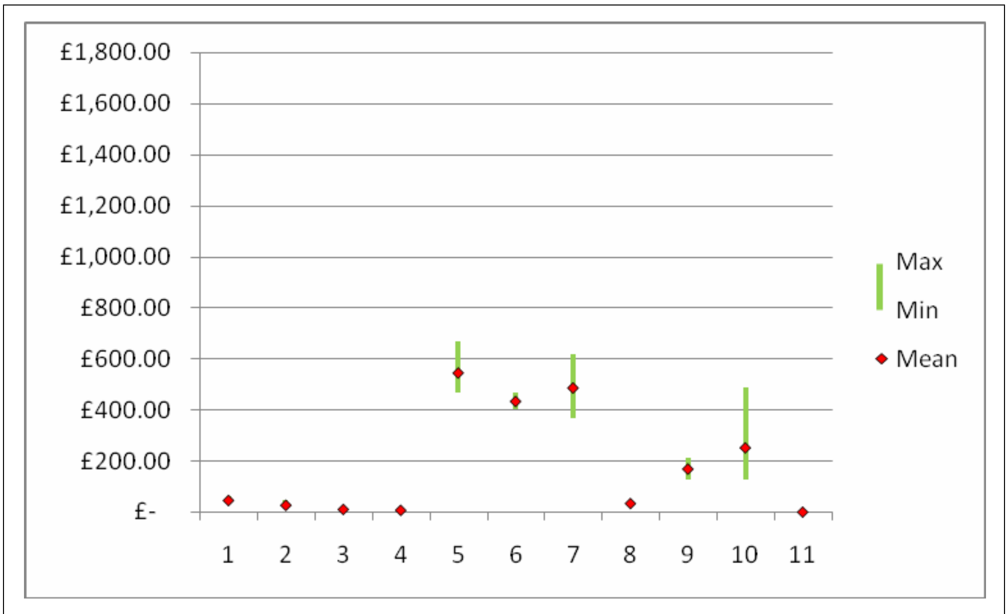


Figure 4.195 Costs incurred for each treatment during Years 1 to 5 at Billingborough.

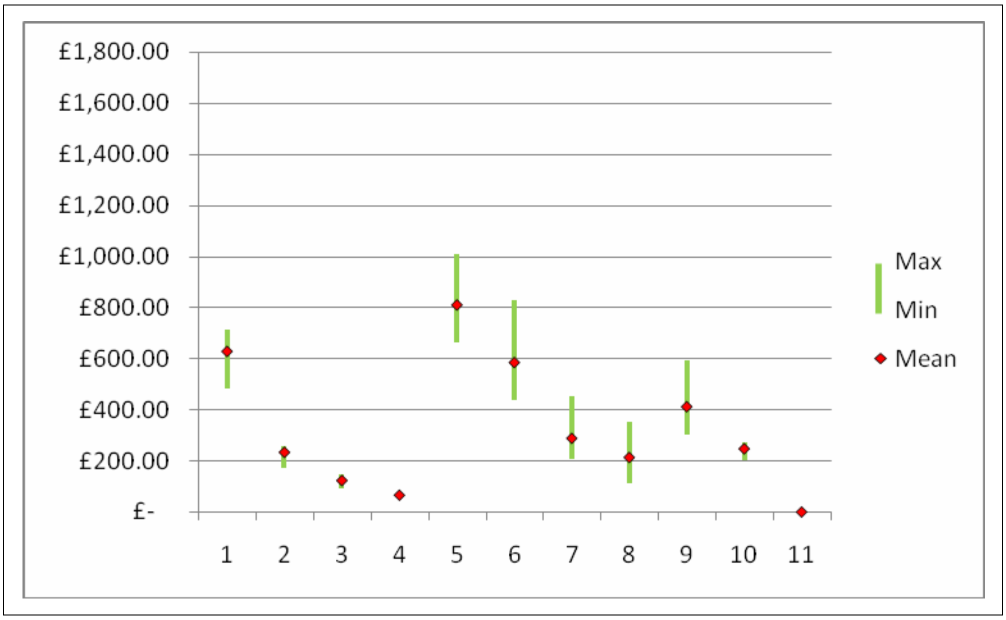


Figure 4.196 Costs incurred for each treatment during Years 1 to 5 at Reach Lode.

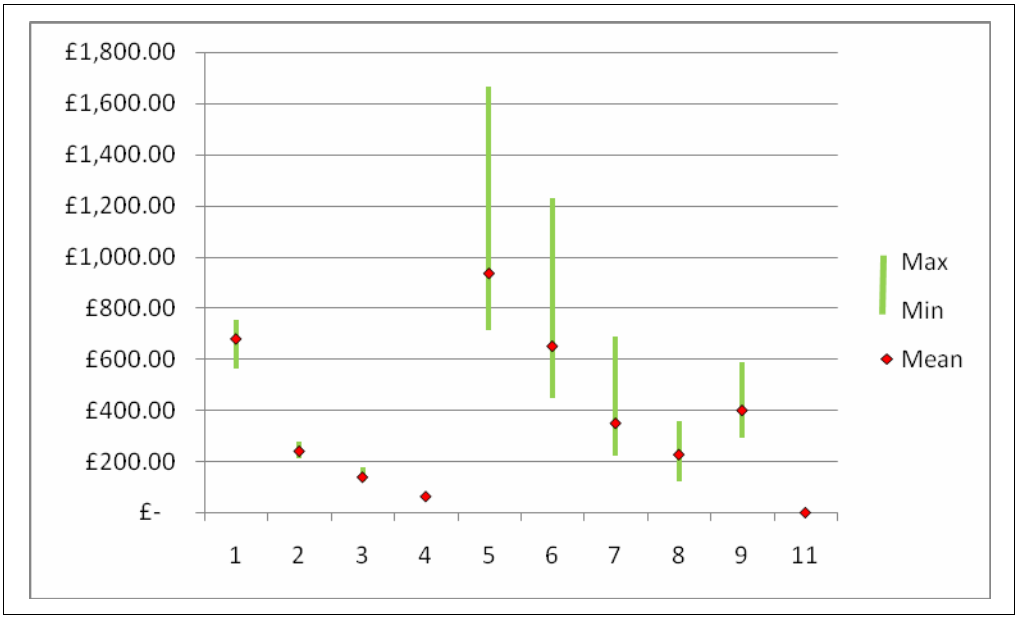


Figure 4.197 Costs incurred for each treatment during Years 1 to 5 at Ely Ouse.

Cutting and removing arisings three times a year was the most expensive treatment across all three sites. In fact, the collection of arisings added substantially to the cost of simply cutting the vegetation (e.g. when comparing Treatment 2 with Treatment 5, Treatment 3 with Treatment 6, and Treatment 4 with Treatment 7).

The cost of applying growth retardant compared to weed wipes was relatively similar, but the extra cut and two applications of weed wipes which Treatment 9 received meant that this treatment was more expensive than Treatment 8.

Cost data relating to Reach Lode and Ely Ouse also show a considerable range over the five year period. This was due largely on the amount of time needed to remove the grass arisings. However, the time taken to remove arisings tended to reduce as the workforce became familiar with the work.

At all three sites, the total time required to maintain a treatment per year where arisings were collected increased as the number of cuts per year increased (although this was least noticeable at Billingborough) (Figures 4.198–4.200). Once again, the variation in time taken was greatest where arisings were collected.

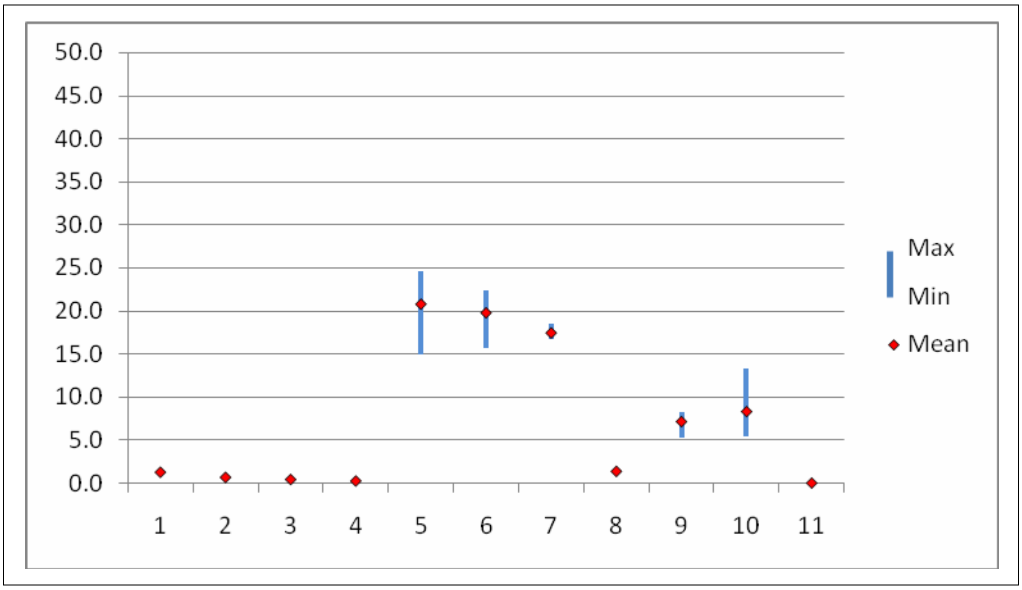


Figure 4.198 Time required for management of each treatment during Years 1 to 5 at Billingborough.

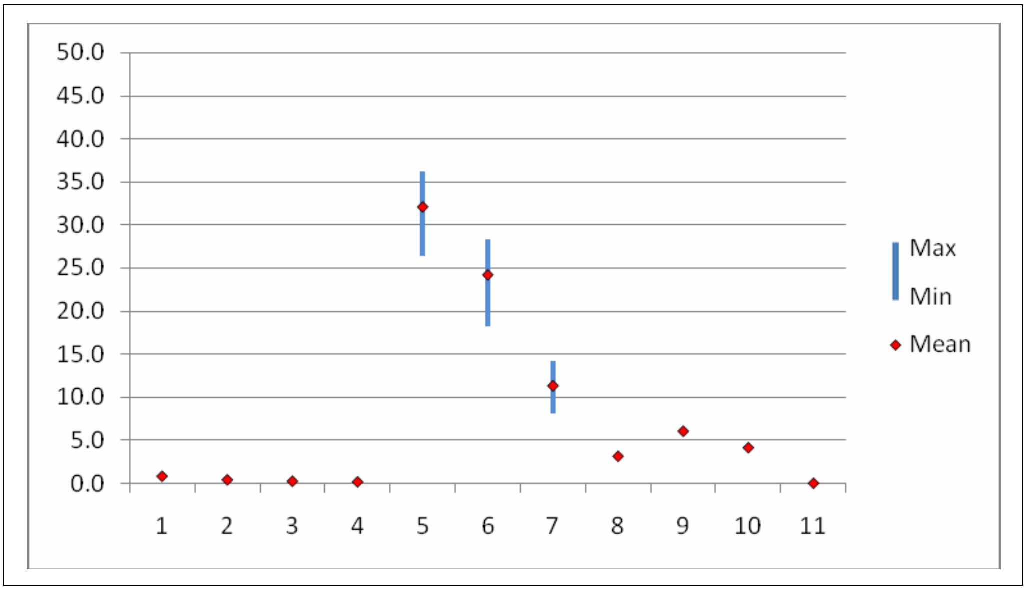


Figure 4.199 Time required for management of each treatment during Years 1 to 5 at Reach Lode.

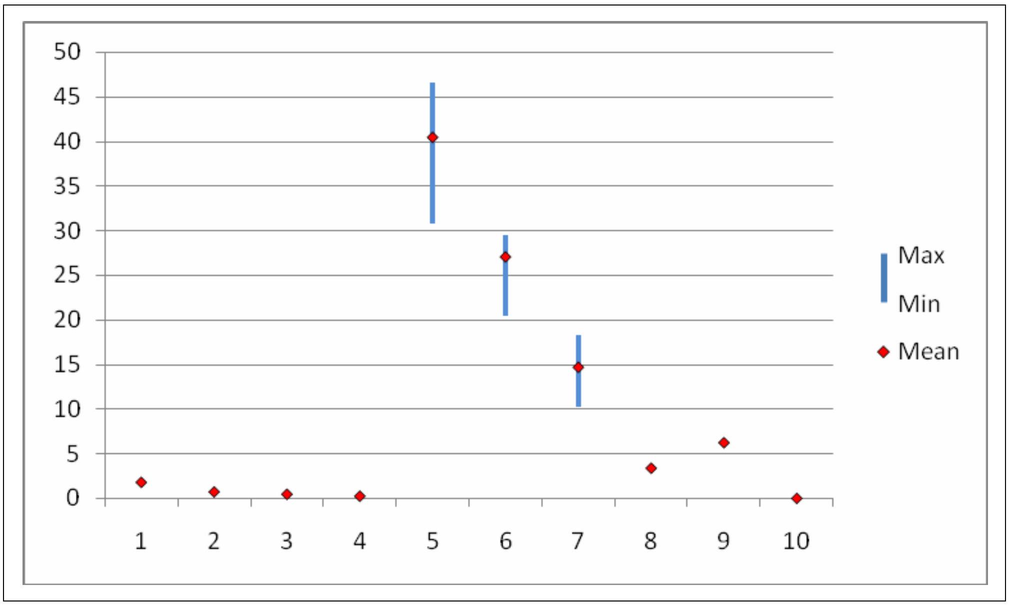


Figure 4.200 Time required for management of each treatment during Years 1 to 5 at Ely Ouse.

4.9.2 Health and safety

During the period of the trials, several issues relating to the health and safety of staff and the public arose in response to the different management treatments used.

Where the management involved allowing the vegetation to grow to more than 1 m on the crest, it became increasingly difficult for the flail operators to see where the crest ended, or in some cases where the watercourse began – raising the likelihood of accidents with machinery. Tall vegetation also meant that any other oncoming dangers to the flail operators, such as discarded debris, were not visible. Tall vegetation also presented a risk to pedestrians using the bank during wet conditions because the rain-flattened vegetation was particularly slippery. However, one advantage to letting the vegetation grow tall was that public users tended to stick to the formal paths, which were easier to walk through than uncut vegetation.

At Ely Ouse, the close proximity of the embankment to a busy road meant that any discarded cigarette ends could set the bank vegetation alight. Fire was particularly a concern where arisings were left on or where vegetation was left to grow tall. However, the use of a 2 m fire break cut at the base of the bank did limit this risk.

More detailed comments on the health and safety issues associated with the various treatments under investigation is covered by the operational issues report prepared by an Environment Agency official given in Appendix 1.

5 Discussion

5.1 Vegetation

5.1.1 Plant richness and diversity

How does cutting frequency affect vegetation composition?

Cutting frequency strongly affected vegetation composition on all three trial embankments. It was found to be the overriding factor at Billingborough and Ely Ouse (and to some extent Reach Lode) that dictated the plant communities found in Year 5. The most species-rich and diverse communities (usually consisting of mixtures of small herbs and fine-leaved grasses) were recorded predominantly where treatments included at least three cuts per year, but species-poor communities (dominated by coarse grasses and competitive ruderals) occurred where treatments received only one cut or less per year.

The effect of a frequent cutting regime on vegetation was in part illustrated in the PCA diagrams for these sites, which showed that three or more cuts per year shifted the vegetation over a period of five years towards communities containing species preferring greater light levels and where a greater percentage cover of bare ground was available for species colonisation. These factors (more light and bare ground) are the result of several processes. First, frequent cutting suppresses the dominance of competitive species such as *Arrhenatherum elatius* and *Sinapis arvensis* whose life strategies are aimed at shading out shorter or slower growing species. Second, less leaf litter cover was found in treatments receiving three or more cuts per year; this is believed to be due to the finer grasses present in those treatments exhibiting greater rates of decomposition. Frequent cutting was also found to coincide with greater cover of bryophytes, which once again is presumably due to the reduced leaf litter cover in these treatments.

Where treatments received one cut or less per year, the shift in vegetation on the PCA diagram was towards species found in more nutrient-rich situations. This is partly as a result of the greater cover of leaf litter found in these treatments (which will recycle nutrients once decomposition has occurred), but also because of the establishment of deeper rooting tall herbs and shrubs which can ‘forage at greater depths for nutrients, transferring these to the surface’ (Grime 2001). Analysis of macronutrients within the soil over the five year period showed no evidence that nutrient levels were greater in treatments cut only once a year or less. However, there are many published studies which show that such a process does occur (e.g. Melman and Verkaar 1991) and the Ellenberg Indicator Values for nitrogen suggest this is indeed happening at the three trial sites. It was therefore concluded that the use of a single sample of soil on each aspect of the bank for biological testing twice a year was inadequate to reflect the heterogeneity of the bank because of natural variability in the bank substrate. In contrast, the Ellenberg Indicator values were believed to indicate conditions throughout the year across the bank and therefore felt more likely to reflect typical conditions.

Ellenberg Indicator values for moisture at the trial sites suggest that species-rich communities (which are more frequently cut) coincide with drier conditions. Presumably this is because there is less leaf litter cover here and the shorter swards expose the soil surface to drying through evaporation. In turn, recorded data on soil moisture showed a positive correlation with total vegetation cover, so that recording plots with high soil moisture content also had a greater total percentage cover of vegetation. This relationship is somewhat cyclical and it is therefore hard to establish which the controlling factor is.

The relationship between cutting frequency and vegetation composition can be summarised as shown in Figure 5.1.

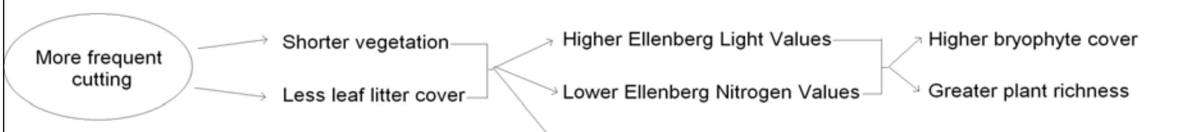


Figure 5.1 Summary of the relationship between cutting frequency vegetation composition.

The vegetation data from Billingborough and Ely Ouse indicate that six cuts per year was equally as effective at maintaining a species-rich sward as three cuts per year. But to suggest that mowing six times a year is the best way to produce species-rich swards is counter-intuitive and counter to conservation advice. Such an outcome at Billingborough can be attributed to the species-poor nature of the starting vegetation where the sward was made up of ruderals such as *Sinapis* and competitors such as *Arrhenatherum*. Frequent cutting will increase species-richness by controlling the highly dominant plants and allowing opportunities for species with other life strategies to colonise, but only where species with other life strategies exist as seeds. Therefore, at Billingborough, gaps created in the sward by frequent cutting were only being replaced by seedlings of competitive species already present and the sward may have reached its maximum richness.

At Ely Ouse, where a greater variety of plant species was found, the same outcome of a similar species-richness for three to six cuts per year is harder to explain. A diverse grassland sward in good condition typically contains representative species from each life strategy (e.g. some defoliation tolerators, some drought tolerators, some competitors, some ruderals, etc). Conservation theory suggests that mowing six times a year in species-rich vegetation would be detrimental because regular mowing is stressful to most plant species. Management regimes that employ frequent mowing (such as six cuts per year) tend to favour defoliation-tolerant species (e.g. rosette species like *Crepis vesicaria*) and discourage species unable to tolerate this kind of stress (e.g. *Trisetum flavescens, Lathyrus pratensis* and *Phleum bertolonii*). That species such as *Crepis vesicaria* were already present in moderate quantities at Ely indicates that the plant communities there were already at least partially geared towards tolerating sporadic stress (e.g. from trampling and from seasonal fire damage). However it is possible that, had the trials continued, plant richness in the treatment receiving six cuts per year would have begun to fall below treatments receiving three cuts per year, partly because of the increased loss of species not able to tolerate the high levels of defoliation, and partly because the majority of plants present would not be able to set seed in the time available between cuts. The rate of replenishment of the seed bank of certain species would then fall dramatically.

The PCA diagrams of data from Years 1 to 5 for both Reach Lode and Billingborough show a convergence of floristic composition in recording plots cut at least three times a year, indicating the communities were stabilising. In contrast, at Ely Ouse, the size of the shift in composition did not diminish from Years 1 to 5, suggesting that the communities had not stabilised by the end of the experiment. Continuing the experiment might have therefore recorded further changes.

How does cutting frequency affect plant productivity?

The annual dry weight of arisings collected per m^2 was greatest in those treatments receiving three or more cuts per year. This was because the plant communities that established through frequent cutting contained species were those with their growing point low to the ground (e.g. *Lolium perenne*); hence, cutting stimulated rejuvenation. This relationship is summarised in Figure 5.2.

In contrast, where plants are not cut frequently, after a time the development of the plant will change from one of leaf production to one of flower production, so that the overall biomass produced in a year is considerably less than when plants are prevented from reaching a flowering stage.

However, it is important to note that the higher production of arisings from treatment areas cut frequently also depends on the availability of water and nutrients.

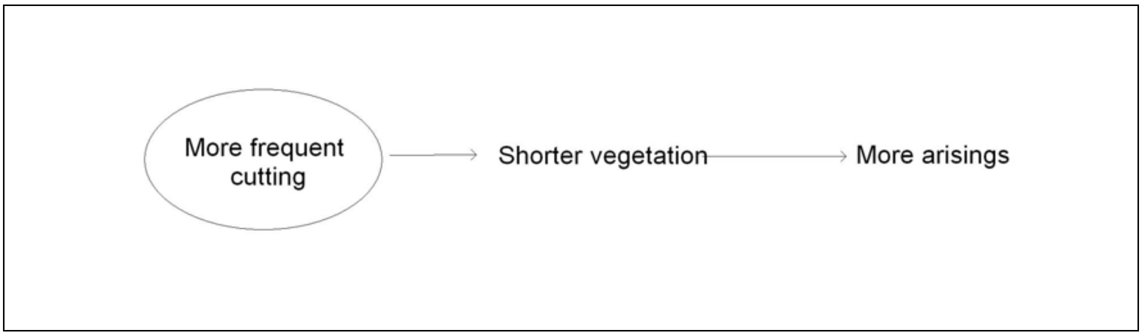


Figure 5.2 Summary of the relationship between cutting frequency and amount of arisings.

How does application of weed wipes affect the vegetation composition?

On treatments receiving one cut a year, the use of weed wipes generally made little difference to the vegetation composition recorded (i.e. the communities found were species-poor and dominated by competitive plants such as *Arrhenatherum*), although it did reduce sward height in all three trial sites. The exception was at Ely Ouse, where some of the vegetation recording plots treated with weed wipes showed greater plant diversity than recording plots cut annually, as well as a slightly higher increase in species richness by Year 5. This may well be due to the greater variety of species with different life strategies found at this site and therefore able to colonise new areas.

At both Reach Lode and Ely Ouse, the use of growth retardant did result in less dry weight of arisings produced per m^2 compared to where weed wipes were used. However at Billingborough, where *Sinapis arvensis* was present and highly invasive, weed wipes were more successful at suppressing plant productivity than growth retardant. This is believed to be because growth retardant was only applied in April (when most *Sinapis arvensis* plants would still be below grass height and therefore not be treated) whereas weed wipes were reapplied in June (when *Sinapis arvensis* is tall and chemical treatment can be applied easily).

Timing of chemical treatment is therefore a key factor in the effectiveness of limiting the productivity of certain invasive species. In particular, an application of weed wipes or growth retardant early in the year is ineffective if the target species is not sufficiently well-grown to be treated effectively.

In addition, degrees of growth are dictated by the weather conditions experienced in the spring.

How does the collection of arisings affect the vegetation composition?

The effect of the collection of arisings on floristic composition was found to depend very much on the cutting regime employed. On treatments cut only once a year, there was little noticeable difference in the plant communities found regardless of whether arisings were collected or left *in situ*. This is believed to be because competitive grasses and tall herbs become dominant at this frequency of cutting, overriding the benefit of the removal of arisings.

Where treatments received three cuts per year, the act of removing arisings might have coincided with slight differences in the plant community depending on external factors such as the availability of seed from species with different life strategies and the presence of any overriding conditions. For example at Billingborough, removing arisings after cutting led to the establishment of a more species-rich plant community. At Reach Lode, arising removal led to the same plant community as arisings left *in situ*, but the individual species-richness and diversity of recording plots where arisings were removed was slightly higher than where arisings remained. The benefit of removing cut material is partly due to thatch shading out new seedlings but also because, where arisings are left *in situ*, soil fertility is maintained and consequently favours competitive species with high nutrient requirements.

Experiments carried out on road verges in the Netherlands showed that, although no discernable trend was observed in total nitrogen and phosphorus in soil where arisings had been removed after twice yearly cutting, extractable phosphorus and potassium decreased sharply in the field (Oomes et al. 1996). This removal of available nutrients resulted in the appearance of lower growing species able to tolerate reduced nutrient environments. The Dutch study also showed that dry matter production was reduced when cuttings were removed but were dramatically increased where cuttings were left *in situ* (up to 11 tonnes/ha/year). The results mirror the findings in this report that arising removal led to more new species than leaving arisings *in situ*. The authors of the Dutch study suggested that the productivity of this kind of grassland would be reduced to 4–6 tonnes/ha/year. In comparison, the most productive treatments (1, 2 and 5) in Year 5 at Billingborough, Reach Lode and Ely Ouse were still producing around 13.5, 19 and 19 tonnes/ha/year respectively.

Interestingly, removing arisings after cutting at Ely Ouse showed no change in species-richness or diversity. This may in part be because Ely Ouse is slightly more infertile and therefore supports a more species-rich sward than the other two sites. This, combined with regular fire events, provides sufficient opportunities for new species to set seed in treatments cut three times per year, regardless of whether or not some arisings are present.

A clear relationship was recorded between arisings being left *in situ* and a reduction in the cover of bryophytes at all three sites. This is because of the reduced light reaching the bryophyte layer where thatch is present in large quantities.

How does the deposition of aquatic arisings affect the vegetation composition?

Data on the effects of aquatic arising removal were only available from the Reach Lode trial site. However, the vegetation data clearly showed that direct application of large quantities of aquatic vegetation and associated dredgings resulted in a species-poor vegetation community. The exception was where six cuts per year took place, which combined with aquatic arisings, resulted in a separate community dominated by *Elytrigia repens* but with large areas of bare ground and scattered individuals of ruderal species such as *Picris echioides, Stellaria media* and *Sonchus spp*. As a consequence, this community had comparatively high species-richness but a low diversity,[16] and was therefore of little ecological value.

Field observations in the early years of the trial suggested that wetland marginal plant species such as *Phragmites australis* were quicker to colonise banks where aquatic arisings were deposited. However, this does not appear to have significantly affected the vegetation community recorded in Year 5. It can therefore be concluded that the application of aquatic vegetation and dredgings is very detrimental to the establishment of a tightly knit, diverse sward.

The effects of the deposition of aquatic arisings on vegetation composition are summarised in Figure 5.3. Where aquatic arisings were removed from the bank one week after cutting, no noticeable difference in the vegetation community was found.

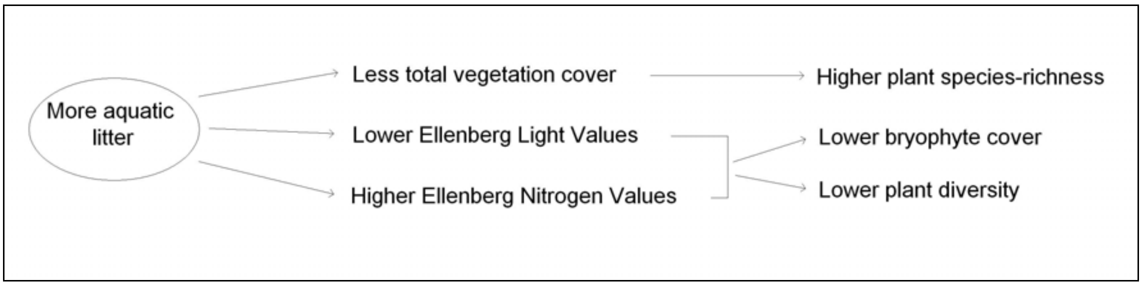


Figure 5.3 Summary of the effects of the deposition of aquatic arisings on vegetation composition.

What other variables were found to affect vegetation composition?

Embankments are not self-contained units but have all kinds of relationships with their surroundings (van der Sluijs and van Bohemen 1991). Many factors affect the vegetation communities in addition to management.

In the majority of cases, the variables discussed below will affect the vegetation composition as a secondary factor, in addition to the overriding influence of management. However, where there is a strong variation between the environmental conditions of the embankment (such as at Reach Lode) the importance of management may be less significant.

[16] Species-richness is a simple count of the number of species recorded, whereas diversity takes into account the abundance of each species as well as the number of species. Therefore a species that occurs only once in a sward adds little to its diversity.

Starting condition of the sward

The starting condition of the sward affects how successful cutting regimes will be on plant richness and diversity. For example at Billingborough, where the bank was isolated from any species-rich semi-natural habitats and contained several highly competitive species, the potential botanical value of the bank will be severely restricted.

Runham et al. (1998) found that only three out of 25 sections of surveyed bank across the UK had more than 10 plant species per 200 m. If this is the case, there are likely to be many stretches of embankment in a similar situation to Billingborough and which will have a low potential botanical value. Therefore, where resources are limited, management should be targeted on those stretches of bank with a high botanical potential through low-to-moderate nutrient levels and a seed rain from species with a range of life strategies.

The presence of invasive species such as *Sinapis arvensis* means that even those treatments cut frequently to favour a short and more diverse sward will be constantly exposed to seed rain from *Sinapis arvensis* if it is in neighbouring areas. *Sinapis arvensis* is able to retain a viable seed bank in the soil for several years and, as a consequence, any temporary lapse in management where bare ground is exposed can lead to an explosion of such species. In this way, the embankments can act as a corridor for invasive species to spread to new areas.

Bank substrate

The substrate of the bank will influence what plant communities are possible, with those soils containing high levels of nutrients being unlikely to support a diverse sward unless a frequent cutting regime is implemented. Melman and Verkaar (1991) suggest, for this reason, that a nutrient-poor topsoil of only 2 per cent humus should be used for road verges.

The substrate of the bank will also influence the ability of the soil to hold moisture and therefore the likelihood of the sward containing moisture-loving or drought-tolerant species. At Reach Lode, for example, the river face had considerably higher soil moisture than the landward face and consequently contained a much greater component of plants such as *Phragmites australis, Filipendula ulmaria, Carex* spp. and *Carex hirta*.

In contrast, the dry conditions on the landward face of Ely Ouse during the summer led to regular fire events. As a consequence, the sward contained species such as *Elytrigia repens*, *Picris echioides* and *Convolvulus arvensis*, which are able to tolerate such stresses. Interestingly, where monitoring was temporarily extended to include recording plots that had been burnt the previous year, the vegetation of the neighbouring bank quickly re-established within the burnt plots in quantities very similar to plots that were not burnt. This would suggest that fire events have been occurring on this site for several years.

Disturbance of vegetation

Disturbance of embankment vegetation will affect the communities found. This is best illustrated at Reach Lode where regular trampling and vehicle access along the crest resulted in a single plant community, regardless of the management regime. Trampling not only crushes the vegetation but affects the soil through compaction, which in turn affects the vegetation types. Although neither were part of the original experimental design, they are nevertheless types of treatment that have affected the vegetation community.

5.2 Soil and engineering

5.2.1 Bank strength

How does cutting frequency affect bank strength?

There is some evidence from the data gathered during this study that cutting regime can affect surface soil strength, as a result of the vegetation structure which the cutting regime dictates. Figure 5.4 summarises the relationship between cutting frequency and bank strength.

At Billingborough, those treatments cut three or more times a year had the highest surface soil strength values (as measured using both pocket and proving ring penetrometers). This was presumably because these treatments contained less leaf litter cover and therefore had lower soil moisture levels, thus hardening the surface of the clayey soil found here.[17]

This trend was less clear at the other two trial sites, possibly because they do not have the same soil type but also because considerably fewer samples were taken of soil variables than of vegetation variables. However, Treatment 1 (receiving six cuts per year) at Ely Ouse did show some of the highest surface soil strengths using a hand vane and proving ring penetrometer; in addition, a significant correlation was found between shorter vegetation and greater surface soil strength (using a proving ring penetrometer).

Figure 5.4 Summary of the relationship between cutting frequency and bank strength.

Where invasive species such as *Sinapis arvensis* were abundant, field observations during the trials suggested that, where this species was allowed to dominate (by infrequent cutting), the surface of the soil became unstable and was prone to slumping. However there were insufficient data to prove this statistically.

When the bank soil strength and the extent of cracking was analysed using plant communities, it was clear that treatments that generate short, species-rich swards showed greater soil strength at the surface compared with species-poor communities cut only once per year. Although frequently cut communities were found to contain several hairline cracks (particularly when they occurred on the crest), these communities generally contained few larger cracks – unlike the species poor-communities. This can be seen as the result of short swards of fine-leaved grasses knitting the surface soil together and preventing large cracks from forming. However it was not evident at all three sites.

Soil strength at depth (up to 0.3 m) did not generally appear to be affected by the cutting regime or subsequent communities which the management generated. At Billingborough

[17] It is important to recognise that soil strengths will vary with soil moisture content.

there was some evidence to suggest that soil strength at depth was greater in those treatments receiving only one cut per year, but this was not consistent across the whole bank or evident at the other two sites. Peat soils in particular (such as those at Reach Lode) showed low soil strength at depth regardless of the vegetation management used. This variable therefore appears to be outside of the control of floodbank managers and is largely dictated by the material used in the bank construction.

How does weed wipe application affect bank strength?

No relationship was found between the use of weed wipes on vegetation and soil strength at depth or at the surface.

How does collection of arisings affect bank strength?

Although no direct relationship was found between soil strength and arising collection, there was an indirect relationship through soil moisture. Where there is extensive leaf litter cover, soil moisture tends to be higher (a mulching effect well known to gardeners), which leads to lower soil strength at the surface. Ely Ouse was an exception to this rule, where increased soil moisture positively correlated with increased surface soil strength. The reasons for this were not clear.

Ely Ouse data also showed that, where maintenance included three cuts per year with the arisings removed, the plant community that emerged had more cracking and larger cracks on the landward face than found where arisings were left on. This suggests that, on faces exposed to drought conditions (and related events such as seasonal fires), this type of treatment may encourage the formation of cracks.

How does the deposition of aquatic arisings affect the bank strength?

At Reach Lode, where aquatic arisings were applied to the landward bank, the plant community that subsequently developed was associated with low soil strength at the surface. This was believed to be partly due to the higher levels of soil moisture where plant litter was plentiful and partly due to the depositing of silty channel dredgings applied with the aquatic litter (these subsequently dry to form a layer of friable, unresisting topsoil containing very few roots). Few cracks were recorded, but this was largely because the true surface of the bank was often obscured by the build-up of aquatic dredgings.

No significant differences in soil strength were evidence where aquatic arisings were removed after one week of cutting (i.e. in Treatment 10). Figure 5.5 summarises the relationship between aquatic litter and bank strength.

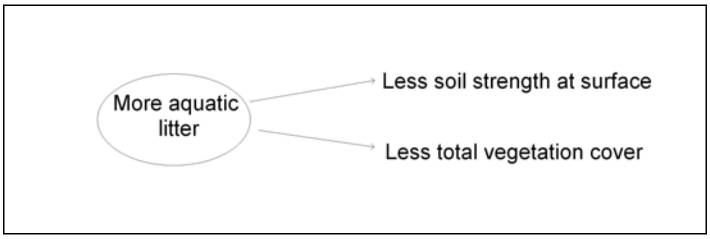


Figure 5.5 Summary of the relationship between aquatic litter and bank strength.

What other variables were found to affect soil strength?

Although surface soil strength appears to be affected by vegetation management, the primary factor in soil strength at depth appears to be the nature of the material with which the bank is constructed.

Billingborough was constructed largely with clay and, as a consequence, showed the most relationships between vegetation management and soil strength. Ely Ouse was also constructed with clay but with a sandy, occasionally gravelly element, whereas the soil of Reach Lode was more organic, and also much more variable with fragments of brick and coal as well as sandier patches. This variability is likely to be the cause of occasional seepage areas observed on the landward face of this bank.

A key factor in the soil strength of the banks appears to be the organic matter content of the soil. Where the proportion of organic matter is high, soil moisture is also high and, as a result, soil strength at the surface is poor. This pattern was not observed in soil strength at depth presumably because the organic content of the soil beyond the A horizon (the top layer of soil where biological activity mainly occurs) is less.

Soil moisture can also be influenced by the situation of the bank. For instance, at Billingborough, the structure appeared to be blocking the natural drainage of adjacent land. Here the landward face showed higher soil moisture values than the crest and river face and also poorer soil strength values at depth.

All three sites recorded the crest with the most consistently high surface soil strength values. This was undoubtedly due to compaction of the soil on this face through maintenance vehicle access and trampling.

Figure 5.6 illustrates the relationships found between organic matter content and other recorded soil variables. These relationships were not found consistently across all three sites but all sites showed at least some of them. It is probable that the low number of soil samples taken from each site limited the possibility of finding statistically significant relationships across the board.

The positive correlation between organic matter content and soil nutrient levels can be linked to taller vegetation, which in turn tended to result in greater cracking on the surface. The link between soil moisture and bryophyte cover suggests that, although in themselves bryophytes are unlikely to weaken a bank, they do serve as indicators of higher soil moisture levels, which can affect surface soil strength.

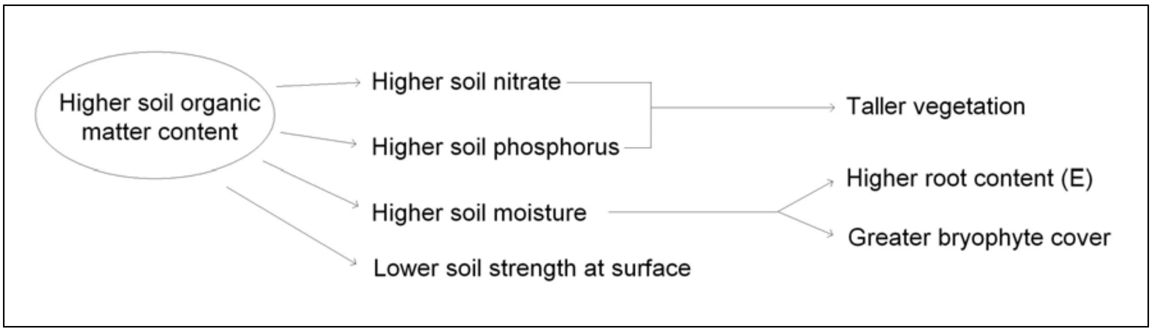


Figure 5.6 Summary of the relationships between organic matter content and other soil variables.

5.2.2 Erosion resistance

The following conclusions are drawn from *Testing the Erosion Resistance of Vegetated Floodbanks* (Environment Agency 2009).

How does cutting frequency affect erosion resistance?

The results of tests using an erosion measurement device (EMD) at the trial sites principally showed a positive correlation between the amount of erosion recorded and the extent of bare ground (Environment Agency 2009). This suggests that any vegetation management that encourages the development of bare ground will lead to surface soils with less erosion resistance.

Although the results of the flood embankment management trials suggest banks cut three times or more a year can develop short species-rich swards which contain more areas of exposed bare ground, this ground is generally devoid of leaf litter and therefore is exposed to hardening through compaction, sunlight and the prevailing winds. In contrast, the taller grasses and extensive leaf litter found in treatments cut only once a year often conceal large areas of bare ground which may be more vulnerable to soil erosion. This is confirmed by the conclusion that Treatments 1, 2 and 5 (cut three or more times a year) were some of the treatments ‘most likely to increase erosion resistance’ (Environment Agency 2009). Treatment 7 (cut once per year with arisings removed) also showed some erosion resistance, possibly because it involved the removal of arisings and therefore the surface soils were baked harder than where a covering of arisings was present.

Treatment 11 (where no management took place) was found to be ‘by far the weakest and liable to erode’ (Environment Agency 2009). The conclusion that ‘at least one cut is necessary to limit soil erosion’ is consistent with the results of surface soil strength tests performed during the flood embankment management trials.

In both reports, the evidence for more frequent cutting leading to greater soil strength and erosion resistance is less clear, at least in part because of other overriding factors (see below). However the results do indicate that, within a site, vegetation management can influence erosion resistance. This was particularly true where short, tightly knit swards consisting of *Festuca rubra* were present, which typically resulted in erosion-resistant soils (Environment Agency 2009). Interestingly it was also observed that species such as *Urtica dioica* might be maintaining the cohesion of larger soil particles which the roots of fine-leaved grasses cannot achieve. This may reinforce the limited evidence found during the flood embankment management trials that soil strength at depth was greater in treatments cut only once a year.

At all three sites, 'poor'[18] patches of ground were frequent even in those stretches of bank receiving the most effective vegetation management. Erosion rates within 'poor' areas were found to be up to 5–10 times greater than 'good' areas, and generally eroded more readily in winter (Environment Agency 2009).

How does weed wipe application affect erosion resistance?

In general, the use of herbicides was not found to significantly improve erosion resistance when compared with other treatments receiving one cut or less per year. However it was observed that 'control of certain weeds can contribute significantly to reducing the extent of bare ground', through removing species that shade out shorter species and then die back to reveal areas of exposed ground (Environment Agency 2009). Billingborough is a particularly good example of this, where the dominance of *Sinapis* in some treatments results in large areas of bare ground being exposed once the plants begin to die back in autumn.

How does collection of arisings affect erosion resistance?

There was little evidence that suggested arising removal led to improvements in erosion resistance, but it was observed that 'uneven distribution of arisings can lead to bare patches' (Environment Agency 2009).

What other variables were found to affect soil strength?

As in this study, the EMD study consistently found that other factors could override the effects of vegetation management in increasing soil strength and erosion resistance.

In particular, the material with which the bank is constructed from plays an important role in defining what soil strength at depth and erosion resistance of the surface are achievable regardless of management. For example at Reach Lode, early erosion rates were found to reduce when a clay layer was hit in several of the tests (Environment Agency 2009).

Vole and mole activity was also found to have the potential to strongly influence the rate of erosion, with rapid erosion occurring once a burrow has been hit (although caution should be used to prevent skewing data unfavourably and implying soils are weak). Vole activity was observed at all three trial sites and is therefore likely to be a component of most floodbanks within the region.

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[18] Defined as 'areas within the recording plots that have a reduced vegetation cover and noticeable areas of bare ground' (Environment Agency 2009).

5.3 Habitat utilisation

5.3.1 Invertebrate diversity

How does cutting frequency affect invertebrates?

The results suggest that cutting frequency does affect invertebrate populations, largely through the vegetation sward that each cutting regime promotes.

At Billingborough in Year 3, greater numbers of individuals were recorded in treatments receiving only one cut a year. This pattern was not apparent in Year 5 presumably due to the wet conditions at the time of survey. At Reach Lode, invertebrates were only recorded in Year 5 in treatments receiving an annual cut. All three sites showed a strong positive relationship between the number of invertebrate individuals and the quantity of arisings collected. Both Billingborough and Reach Lode also showed a significant correlation between greater cover of leaf litter (both through aquatic dredging and mowing) and greater numbers of invertebrates. This strongly suggests that leaf litter is a valuable resource in promoting at least some species of invertebrate.

As expected, certain groups of invertebrates were found to favour certain treatments, depending on the site. For example at Billingborough, earwigs, parasitic solitary wasps and true bugs preferred treatments cut only once a year or less (i.e. where there is considerable leaf litter cover and greater structural heterogeneity). At Reach Lode, only treatments receiving one cut or less contained large numbers of rove beetles. This group of invertebrates, which consists of predatory species, may prefer the structural heterogeneity provided by taller vegetation. In contrast, primitive flies were only recorded in Year 5 in treatments cut at least three times a year at Billingborough, while sawflies, grasshoppers/crickets and crane flies tended to favour these treatments at Reach Lode. Beetles were recorded at Billingborough at greater numbers in Year 5 where fewer than three cuts took place. However the beetle *Malachius bipustulatus* was recorded at Ely Ouse from treatments generally cut three times a year; this species requires open, structured flowers in its adult stage, which are encouraged by this type of management.

There was some evidence that a greater frequency of cutting resulted in greater invertebrate diversity, but it was not consistent across all three sites.

At Billingborough, the treatment receiving three cuts per year showed the greatest variety of invertebrate groups and the treatment receiving six cuts the lowest variety. This suggests that, although more than one cut is beneficial to increasing the variety of groups found (presumably by providing a greater variety of food plants), high frequencies of mowing such as Treatment 1 (six cuts per year) may cause too much disturbance. Studies by Melman and Verkaar (1991) found that, for ground beetles, diversity was found to be greatest in vegetation cut once or twice a year but in 1988 Grosskopf (within Melman and Verkaar, 1991) suggested that cutting more frequently was not to be recommended. In contrast, Treatment 1 did have a comparatively high diversity score, which suggests that although few invertebrate groups were able to utilise this kind of sward, several species were present within each of those groups.

Reach Lode and Ely Ouse also showed comparatively high invertebrate diversity in treatments receiving three or more cuts per year, with the unmanaged treatment also fairing well. Ely Ouse had greatest diversity of invertebrates, representing a range of life strategies and food requirements. Several of the species recorded mainly at this site require open flowered plants, which are abundant here in treatments cut more than once a year.

How does weed wipe application affect invertebrates?

There were no clear patterns in the data to confirm if the use of weed wipes affected invertebrate populations.

How does collection of arisings affect invertebrates?

The total number of invertebrates recorded did show a positive correlation to the amount of arisings and leaf litter cover found at each of the three sites. This suggests that the removal of arisings is not beneficial to total invertebrate populations.

Conservation theory suggests that invertebrate diversity is linked to plant diversity and thus those treatments (i.e. three or more cuts) that create a species-rich plant community are more likely to support a diverse invertebrate community.

Some of the results of this study suggest that this line of thinking is correct but there is insufficient data to confirm it statistically. Data from the three sites broadly indicate that, where arisings are removed in Treatment 5, invertebrate diversity is lower than where they are left *in situ*. However, no such differences were observed in treatments receiving only one cut a year.

What other variables were found to affect invertebrates?

The weather conditions at the time of survey had the strongest influence on invertebrate numbers. Weather overrode any other variable at all three sites, though each site appeared to show a somewhat distinctive mix of invertebrate species depending on its situation. For example, Billingborough was distinctive for the occurrence of invertebrates regarded as pest species to crops (principally because it is surrounded by commercial crops). Reach Lode was distinctive for its large number of mosquitoes and greater numbers of semi-aquatic species (particularly at larval stage), presumably due to proximity of the Lode.

Although vegetation management can influence the number and diversity of invertebrates, it is concluded that the environment within which the bank is situated is the overriding factor.

5.3.2 Mammal, reptile and bird diversity

How does vegetation management affect other species?

Unfortunately there were too few mammal, reptile or bird records at any of the trial sites to provide an analysis of the effects of management.

Voles were the most abundant mammal recorded at the trial sites. They tended to favour the river or landward faces, presumably due to the greater soil strength on the crest of the banks, making tunnelling harder. No clear pattern was evident between vole abundance (using the frequency of vole holes recorded) and the vegetation treatment used. However it was observed that on all three sites, the majority of vole tunnels were concentrated in the top 200 cm of soil and therefore unlikely to seriously undermine the stability of the main body of the bank (despite one incident where an observed slip occurring as a result of the lubrication of the slip planes by water flowing though vole burrows).

With regard to those mammal species particularly of concern within a riverine environment (e.g. otters and water voles), their presence is much more likely to be affected by, for example, the structure of the bank or the presence of predators. This is primarily because otters, for example, are reported to spend an average of 24 per cent of their time within 1 m of the water's edge and only 12 per cent of their time 1–2 m from the edge, the remaining time being spent in the water (Bekker and van Bohemen 1991). Consequently, management aimed at encouraging such species only needs to focus on the margins of the watercourse. The vegetation management of the main part of the flood embankment at Billingborough and Ely Ouse, for example, would therefore have very little effect on such species.

5.4 Summary

The main outcomes of the discussion can be summarised as following:

- Cutting frequency strongly affected vegetation composition on all three trial embankments. It was found to be the overriding factor at Billingborough and Ely Ouse (and to some extent Reach Lode) dictating the plant communities found in Year 5.
- Frequent cutting will increase species-richness by controlling the highly dominant plants and allowing opportunities for species with other life strategies to colonise, but only where species with other life strategies exist as seeds.
- Had the trials continued, it is possible that plant richness in the treatment receiving six cuts per year would have begun to fall below that of treatments receiving three cuts per year – partly because of the increased loss of species not able to tolerate the high levels of defoliation and partly because the majority of plants present would not be able to set seed in the time available between cuts. The seed bank of certain species would eventually become exhausted.
- The dry weight of arisings collected per m^2 was greatest in those treatments receiving three or more cuts per year.
- Timing of chemical treatment is a crucial factor in the effectiveness of limiting the productivity of certain invasive species. In particular, application of weed wipes or growth retardant early in the year is ineffective if the target species is not sufficiently well grown to be treated effectively. Degrees of growth will be dictated by the weather conditions experienced in the spring.
- A clear relationship was recorded between arisings being left *in situ* and a reduction in the cover of bryophytes at all three sites. This is because the presence of thatch in large quantities reduces the light reaching the bryophyte layer.
- Direct application of large quantities of aquatic vegetation and associated dredgings resulted in a species-poor vegetation community.
- The substrate, the levels of disturbance and the botanical starting conditions of a bank all affected the vegetation.
- Although frequently cut communities were found to contain several hairline cracks (particularly when they occurred on the crest), these communities generally contained few larger cracks (unlike the species poor-communities).
- No relationship was found between the use of weed wipes on vegetation and soil strength at depth or at the surface.

- Where there is extensive leaf litter cover, soil moisture tends to be higher (a mulching effect well known to gardeners). This leads to lower soil strength at the surface.
- No significant differences in soil strength were evident where aquatic arisings were removed after one week of cutting.
- Although surface soil strength appears to be affected by vegetation management, the primary factor in soil strength at depth (up to 300 cm) appears to be the nature of the material from which the bank is constructed.
- A key factor in the soil strength of the banks appears to be the organic matter content of the soil.
- The link between soil moisture and bryophyte cover suggests that, although in themselves bryophytes are unlikely to weaken a bank, they do serve as indicators of higher soil moisture levels, which can affect surface soil strength.
- Treatment 11 (where no management took place) was found to be 'by far the weakest and liable to erode'. It is concluded that 'at least one cut is necessary to limit soil erosion.
- On all three banks, 'poor' patches of ground were frequent – even in those stretches of bank receiving the most effective vegetation management. Erosion rates within 'poor' areas were found to be up to 5–10 times greater than 'good' areas, and generally eroded more readily in winter
- 'Control of certain weeds can contribute significantly to reducing the extent of bare ground' through removing species that shade out shorter species and then die back to reveal areas of exposed ground.
- Uneven distribution of arisings can lead to bare patches.
- The material with which the bank is constructed plays an important role in defining what soil strength at depth and erosion resistance of the surface is achievable regardless of management.
- Vole and mole activity was found to strongly influence the rate of erosion, with rapid erosion occurring once a burrow has been hit.
- Leaf litter is a valuable resource in promoting at least some species of invertebrate.
- There was some evidence that a greater frequency of cutting resulted in greater invertebrate diversity, but it was not consistent across all three sites.
- There were no clear patterns in the data to confirm if the use of weed wipes affects invertebrate populations.
- Although vegetation management can influence the number and diversity of invertebrates, the environment within which the bank is situated is the overriding factor.
- Management aimed at encouraging species such as otters and water voles only needs to focus on the margins of the watercourse. The vegetation management of the main part of the flood embankment at Billingborough and Ely Ouse, for example, would have very little effect on such species.

6 Conclusion

This study has shown that sites can respond differently to the vegetation management chosen depending on:

- their existing species;
- situation in the landscape;
- substrate used in construction;
- soil nutrient status;
- proximity to the water table.

Thus before the most appropriate management technique can be established, certain background information must be available. This need not involve complicated and lengthy surveys, but could be obtained by a single preliminary visit to complete a standard recording form. Identification of the key plant species present on a bank is arguably the quickest and easiest way of estimating nutrient status and productivity levels, as well as the presence of invasive species which may need special attention. Information on the embankment constituents and structure also needs some investigation. Without this background data on a site, it is impossible to determine the most appropriate management.

6.1 Criteria

Once this information has been obtained, each treatment can be assessed against standard criteria which Environment Agency floodbanks may need to meet (Table 6.1).

Table 6.1 Assessment criteria for floodbank management options.

Aspect	Issue
Health and safety	Does the management increase the risk during maintenance operations and to other users?
Embankment operational performance	Does the vegetation management option provide a fit-for-purpose condition of the embankment?
Bank strength	Both at the soil surface and at depth
Cost	Both in terms of on-site maintenance and off-site management
Erosion resistance	If the embankment is overtopped by flood water
Plant diversity	Does the management lead to diverse swards?
Invertebrate diversity	Does the management lead to diverse communities
Mammal/reptile and bird interest	Does the management provide opportunities for ground nesting birds, otters, water voles, etc.
Impacts on other users	Does the management cause increased access difficulties to the public, etc.?

6.2 Determination of criteria scores

Tables 6.2–6.5 provide a score of the effectiveness of each management technique trialled based on the type of site encountered.

Each criteria has been scored on a scale of 1 to 10 (with 1 = very poor and 10 = very good).[19] Thus a score of 10 would equate to:

- very diverse sward in terms of plant diversity;
- very safe bank in terms of health and safety;
- very cheap in terms of maintenance costs;
- very strong in terms of soil strength and erosion resistance etc.

Where possible, the scores correspond directly with the average values obtained from the data in Year 5 of the trials[20] or have been moderated accordingly to the observations over the five-year trial period (as indicated below). Details of the scores are given in Appendix 6.

- **Cost of treatment** scores were calculated using the average annual cost of each treatment, dividing the range of costs into 10 categories and assigning each cost bracket a score.
- **Bank strength** scores were calculated for the surface using the average pocket penetrometer and proving ring penetrometer values for each treatment at each site. These values were divided into 10 categories and assigned a score. A similar process was followed using hand vane readings for soil strength at 0.25 m depth. Trial sites were scored separately in order to take account of differences in other variables such as bank substrate.
- **Erosion resistance** scores were calculated using the average erosion measurements for each treatment at each site. These values were divided into 10 categories and assigned a score.
- **Plant diversity** scores were calculated using the average Shannon's Diversity Index scores recorded for each treatment at each site. These values were divided into 10 categories and assigned a score. Trial sites were scored separately in order to take account of differences in other variables such as nutrient status and surrounding land use.
- **Invertebrate diversity** scores were calculated using the average Shannon's Diversity Index scores recorded for each treatment at each site. These values were divided into 10 categories and assigned a score. Trial sites were scored collectively in order to obtain sufficient sample numbers to reduce the affect of any uncharacteristic data due to climatic differences during the survey
- **Embankment operational performance** scores are based largely on assessments on visual condition by competent Environment Agency asset inspectors for each treatment option at each site separately. Scores were moderated to take account of local defects that could be attributed to the effects of undertaking the maintenance over all the trial plots in close proximity, e.g. excessive crest rutting.

[19] Scores for Treatments 3, 6 and 8 are not based on detailed data but have been extrapolated from data on similar treatments.
[20] So that any further studies can use repeatable methods in order to calculate comparable scores.

- **Offsite maintenance costs** scores were determined by considering the costs associated with providing suitable plant and equipment, number of visits and likely transport arrangements.
- **Health and safety** scores were determined by considering:
  - likely method employed;
  - use of existing plant;
  - alternative equipment;
  - inspection requirements and access;
  - number of maintenance visits;
  - likely site configuration;
  - other common hazards.

The remaining criteria were scored based on a combination of Environment Agency staff experience and broad results from the study, though the scoring was somewhat circumstantial in nature. Some of the scores for Treatments 3, 6 and 8 were determined by interpolating scores for other similar treatments. These are indicated in Tables 6.2–6.4.

6.3 Relative performance tables

The tables are as follows:

- Table 6.2 Scoring system for existing floodbanks with a low nutrient status and/or high ecological value (e.g. Ely Ouse);
- Table 6.3 Scoring system for existing floodbanks with a high nutrient status and/or those containing or in close proximity to invasive competitive ruderals (e.g. Billingborough);
- Table 6.4 Scoring system for existing floodbanks with a notable peat content and/or those with high soil moisture levels (e.g. Reach Lode);
- Table 6.5 Scoring system for existing floodbank faces which receive large amounts of channel dredgings/aquatic litter (e.g. Reach Lode, landward face).

It is likely that individual sites may require particular emphasis on certain criteria, for example, bank strength and erosion resistance being of primary importance where flood risk is of higher relative importance, plant diversity being of primary importance where rare species are present, etc. This aspect is not included in the guidance tables because it will require the specific knowledge of the local operational staff. As a consequence, Treatment 2 appears to be the highest scoring form of management trialled in all site scenarios, with Treatments 1, 3 and 4 also scoring highly.

Development of a weighing system is therefore essential to differentiate between the effectiveness of each management treatment at sites with special requirements. For example:

- Sites near designated conservation areas should give a higher weighting to conservation criteria such as plant diversity and invertebrate diversity (partly because the banks could provide migration routes for species between protected areas and partly because the nearby seed source may result in diverse swards establishing on the banks).

- Sites that contain an element of peat in their construction should give a higher weighing to flood risk (leakage can often occur).
- Sites exposed regularly to events such as fire, fly-tipping, etc. should give a higher weighting to health and safety.
- Sites with marginal wetland vegetation on the river face should give a higher weighting to conservation criteria. This face may contain protected species such as water vole and otter as well as a more diverse range of plant and invertebrate species.
- Sites with low nutrient status should give a higher weighting to conservation criteria because it is more likely that a diverse plant community can be established on these sites.
- Sites that receive frequent trampling by the public may override any effects of management in terms of plant community establishment.

Table 6.1 Scoring system for existing floodbanks with a low nutrient status and/or high ecological value (e.g. Ely Ouse).

	Treatment									
	1	2	3*	4	5	6*	7	8*	9	11
Criteria	Six cuts + arisings left on	Three cuts + arisings left on	Two cuts + arisings left on	One cut + arisings left on	Three cuts + arisings removed	Two cuts + arisings removed	One cut + arisings removed	One cut + growth retardant and weedkiller	One cut + Two weed wipe treatments	no treatment
Health and safety	3	6	8	7	4	6	6	3	4	8
Embankment operational performance	10	10	8	5	9	8	5	6	5	2
Bank strength (surface)	6	6	6	6	5	6	7	4	4	3
Bank strength (deep)	7	5	7	8	5	6	7	7	8	6
Cost of treatment	4	8	9	10	1	4	7	8	7	10
Associated off-site maintenance costs	1	3	5	7	1	3	5	5	6	10
Erosion resistance	10	9	10	10	10	10	9	3	3	1
Plant diversity	9	10	5	1	10	6	1	4	3	1
Invertebrate diversity	7	9	7	5	4	4	3	4	5	9
Mammals, reptiles, birds	4	6	6	10	6	6	10	4	6	10
Impacts on other users	8	10	6	2	10	6	2	4	4	2

*Interpolated values

Table 6.2 Scoring system for existing floodbanks with a high nutrient status and/or those containing or in close proximity to invasive competitive ruderals (e.g. Billingborough).

	Treatment										
	1	2	3*	4	5	6*	7	8*	9	10	11
Criteria	Six cuts + arisings left on	Three cuts + arisings left on	Two cuts + arisings left on	One cut + arisings left on	Three cuts + arisings removed	Two cuts + arisings removed	One cut + arisings removed	One cut + growth retardant and weedkiller	One cut + Two weed wipe treatments	One cut + aquatic litter removed	no treatment
Health and safety	3	6	8	7	4	6	6	3	4	8	8
Embankment operational performance	10	10	8	5	9	8	5	6	5	2	2
Bank strength (surface)	6	7	6	5	7	6	4	5	5	6	3
Bank strength (deep)	7	5	6	7	7	8	10	9	10	8	8
Cost of treatment	4	8	9	10	1	4	7	8	7	8	10
Associated off-site maintenance costs	1	3	5	7	1	3	5	5	6	7	10
Erosion resistance	10	10	7	4	7	7	7	6	6	4	1
Plant diversity	10	9	8	7	6	6	6	6	5	4	1
Invertebrate diversity	7	9	7	5	4	4	3	4	5	5	9
Mammals, reptiles, birds	4	6	6	10	6	6	10	4	6	4	10
Impacts on other users	8	10	6	2	10	6	2	4	4	2	2

*Interpolated values

Table 6.3 Scoring system for existing floodbanks with notable peat content and/or those with high soil moisture levels (e.g. Reach Lode).

	Treatment										
	1	2	3*	4	5	6*	7	8*	9	10	11
Criteria	Six cuts + arisings left on	Three cuts + arisings left on	Two cuts + arisings left on	One cut + arisings left on	Three cuts + arisings removed	Two cuts + arisings removed	One cut + arisings removed	One cut + growth retardant and weedkiller	One cut + Two weed wipe treatments	One cut + aquatic litter removed	no treatment
Health and Safety	3	6	8	7	4	6	6	3	4	8	8
Embankment operational performance	10	10	8	5	9	8	5	6	5	2	2
Bank strength (surface)	6	4	5	6	6	5	5	6	6	6	6
Bank strength (deep)	4	3	3	4	9	7	6	6	6	4	6
Cost of Treatment	4	8	9	10	2	5	8	8	6	8	10
Associated off-site maintenance costs	1	3	5	7	1	3	5	5	6	7	10
Erosion resistance	1	9	9	10	10	10	10	7	7	6	8
Plant diversity	9	10	5	1	10	5	1	4	3	1	1
Invertebrate diversity	7	9	7	5	4	4	3	4	5	5	9
Mammals, reptiles, birds	4	6	6	10	6	6	10	4	6	4	10
Impacts on other users	8	10	6	2	10	6	2	4	4	2	2

*Interpolated values

Table 6.4 Scoring system for existing floodbank faces which receive large amounts of channel dredgings/aquatic litter (e.g. Reach Lode, landward face).

	Treatment										
	1	2	3*	4	5	6*	7	8*	9	10	11
Criteria	Six cuts + arisings left on	Three cuts + arisings left on	Two cuts + arisings left on	One cut + arisings left on	Three cuts + arisings removed	Two cuts + arisings removed	One cut + arisings removed	One cut + growth retardant and weedkiller	One cut + Two weed wipe treatments	One cut + aquatic litter removed	no treatment
Health and safety	3	6	8	7	4	6	6	3	4	8	8
Embankment operational performance	10	10	8	5	9	8	5	6	5	2	2
Bank strength (surface)	4	3	3	4	5	4	4	4	4	4	4
Bank strength (deep)	4	5	5	5	5	5	6	5	5	5	4
Cost of treatment	4	8	9	10	2	5	8	8	6	8	10
Associated off-site maintenance costs	1	3	5	7	1	3	5	5	6	7	10
Plant diversity	10	9	7	5	1	1	1	2	2	9	5
Invertebrate diversity	7	9	7	5	4	4	3	4	5	5	9
Mammals, reptiles, birds	4	6	6	10	6	6	10	4	6	6	10
Impacts on other users	6	4	2	2	4	2	2	2	2	2	2

*Interpolated values

6.4 Further potential areas of research

The flood embankment management trials have shown a number of relationships between vegetation management, bank strength and conservation interest. However there may be other forms of vegetation management that could achieve better results in terms of bank strength or conservation interest which would benefit from being trialled.

In particular, conservation theory suggests that grazing is an effective way of maintaining vegetation while improving conservation interest and it would be useful to assess this using the above scoring system (after a period of monitoring). If such a study were to be undertaken, it is recommended that cost savings could be made by removing monitoring of some of the soil biological parameters (Ellenberg Indicator values reflected conditions more successfully) and soil geotechnical parameters (there was considerable overlap in the results of different forms of measurement such as penetrometers and the hand vane).

A suitable trial of different sort of grass mixes would be also useful, probably utilising suitable existing and established swards.

Both these trials could be assessed against the criteria outlined in this report to allow suitable comparisons to be made.

7 Recommendations

- Develop suitable initial embankment study checklist/form including:
  - dominant plant species;
  - broad nutrient status;
  - soil type;
  - embankment constituents, aspect and configuration.
- Consider weighting of suggested criteria depending on the relative importance to the particular site(s).
- Develop clear guidance for operating authorities considering the relevant priorities.
- Undertake further research into alternative maintenance techniques and grass mixes (as outlined in Section 6.4).

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Glossary

'A' horizon The top layer of the soil horizon, which tends to be darker in color than deeper layers and contain more organic material, or lighter but contain less clay. The 'A' is a surface horizon and as such is also known as the zone in which most biological activity occurs.

Aquatic plant litter The dead plant material sourced from the cutting of wetland vegetation at the margins of the watercourse that has been placed on the embankment during maintenance procedures.

Arisings Cut vegetation (measured as air-dried weight). The process involves collection and weighing of the cuttings 1–2 hours after mowing over a 0.5m^2 area. A sub-sample is then extracted and air-dried, and the results incorporated to establish the total air-dried weight of the 0.5 m^2 area.

Axillary bud A bud that lies at the junction of the stem and leaf (or another stem) of a plant. For grasses, this is at or slightly above ground level.

Bare ground The extent of bare soil visible once underneath the foliage of the herb layer (i.e. bare ground cover, leaf litter cover, bryophyte cover and the stems of living plants should total 100 per cent).

Breed A single pass of cutting machinery such as a flail.

Bryophytes A non-flowering group of plants without a vascular (circulatory) system, known as mosses and liverworts.

Competitor Term used in describing a plant species life strategy meaning a physiology based on low stress and low disturbance environments. Competitors exhibit features such as a dense canopy of leaves, extensive lateral spread and rapid growth rates in order to prevail in highly competitive situations.

Domin A scale used in vegetation studies to estimate cover/abundance. The values relate to percentage cover as follows:

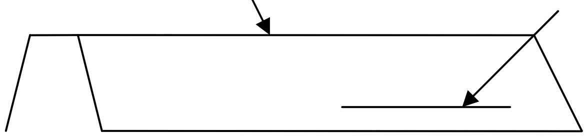
Domin value	Cover
10	91–100%
9	76–90%
8	51–75%
7	34–50%
6	26–33%
5	11–25%
4	4–10%
3	<4% with many individuals (scattered)
2	<4% with a few individuals (clumped)
1	<4% with 1–2 individuals.

Source: Dahl and Hadac (1941)

Ellenberg Indicator values Values given to each plant species to describe its requirements in terms of moisture, light, reaction and nitrogen.

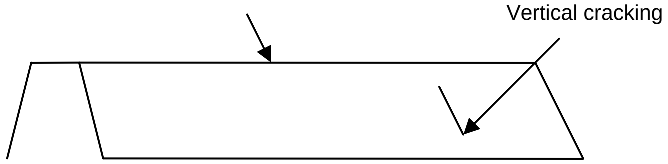
Feno-marker A 600 mm spike with an aluminium head flush with the soil surface used to identify the boundaries and middle section of each treatment plot.

Horizontal cracking	Cracks that run parallel with the top of the embankment (see diagam).



Leaf litter	The extent of both dead plant material that is still connected to the plant and the cuttings left after mowing (i.e. bare ground cover, leaf litter cover, bryophyte cover and the stems of living plants should total 100 per cent).
Organic content	Percentage loss on ignition based on the difference between 220°C and 440°C.
Ruderal	Term used in describing a plant species life strategy meaning a physiology based on low stress and high disturbance. Ruderals generally have a small stature, a high growth rate (typically channelled into seed production) and a short life history with flowers produced early.
Species diversity	The number of different species in a particular area (species richness) weighted by some measure of abundance such as number of individuals or biomass. This is often measured using an index such as Shannon's or Simpson's diversity indices.
Species richness	The number of species recorded within a single sample.
Stress-tolerator	Term used in describing a plant species life strategy meaning a physiology based on high stress but low disturbance environments such as surviving in conditions where there is a very limited supply of nutrients, where the soil is strongly acidic/calcareous, waterlogged or contaminated by heavy metals. Species in this category often have a long life history with intermittent flowering, low growth rates, stress-tolerant leaves/roots and a high longevity of roots.
Synoptic table	A summary of the principal species and their abundance within each community.
Vegetation height	Measured using a drop disk method consisting of a disk of hardboard (30 cm in diameter and weighing 200 g) with a slit in the centre within which a 1 m rule is placed. The disk is dropped 1 m from the ground, over the vegetation, and the height at which the disk settles is read off the rule.

Vertical cracking Cracks that run perpendicular with the top of the bank (see diagram).



Appendix 1: Operational issues

Source: Mark Adams, Environment Agency

During the Phase 4 (site survey) of the trials, it became apparent to the project team that additional aspects of flood embankment management with an influence on the selection of management techniques were not being fully considered.

Many of these additional aspects were not within the scope of the objectives of the trials but the influences of these issues should be considered. Such issues would be a major factor on the selection of a method to undertake embankment management.

The additional key issues considered in this appendix are:

- **Health and safety.** The health and safety issues associated with undertaking the activities to provide the management options in the trials should include issues associated with:
  - access;
  - methods employed;
  - plant used;
  - general site restrictions.
- **Associated costs.** Although the cost of undertaking each treatment option on the site was collated as part of the main trial survey works, the associated off-site costs to enable these methods to be undertaken were not. This appendix looks at the additional influences on costs.
- **Embankment operational performance.** The performance of a flood defence asset can be measured in several ways, all of which have a greater or lesser influence on the maintenance method adopted for a particular embankment. This appendix considers the methods used to maintain an embankment in a fit-for-purpose condition, including visual inspections undertaken on the trial sites. The erosion resistance and environmental performance of the embankments are fully explored in Environment Agency (2009).

A relative rating for each of these operational issues is given for the different treatment options (Table A1).

Many other operational matters influence the method used such as public access and other users, changes to strategy, influences of climate change, land owner liabilities, etc. This appendix discusses some of these issues but does not provide a relative rating for each treatment option for them.

Health and safety issues

The following issues were considered to rate each of the treatment options against the relative health and safety performance given in Table A1.

- use of available plant and equipment;
- current methods used;
- use of alternative equipment or changed method;

- PUWER[21] requirements (equipment selection criteria);
- site configuration and profile (particularly available crest width);
- site access for maintenance and in an emergency;
- site constraints and hazards (e.g. overhead/underground cables);
- number of maintenance visits required;
- asset inspection requirements.

Any particular needs to provide extra mowing due to public footpaths or legally required access are not considered.

Associated costs

The following issues were considered to rate each of the management options against the relative associated off-site costs given in Table A1.

- plant and equipment needed;
- number of maintenance visits required;
- alternative equipment;
- location and access;
- site configuration and profile.

The higher the relative cost, the lower the rating.

Embankment performance

The following issues were considered to rate each of the management options against the relative operational performance given in Table A1.

- target condition required (fit-for-purpose standard);
- visual condition inspections;
- further inspection requirements;
- influence of equipment and method used;
- impact on channel flow conveyance;
- avoidance of vermin infestation;
- adaptation to changing performance needs.

The key performance issue of erosion resistance is covered in Environment Agency (2009).

The results of the visual asset inspections undertaken by trained staff are given in Appendix B. These inspections were made after the completion of the trials in Years 5 and 6 for all three trial sites during typical winter and summer conditions.

[21] Provision and Use of Work Equipment Regulations 1998

Table A1 Relative ratings of each treatment option for additional issues.

Treatment Option	Health and safety issues	Associated off-site maintenance costs	Embankment operational performance
1 (six cuts + arisings left)	3	1	10
2 (three cuts + arisings left)	6	3	10
3 (two cuts + arisings left) [1]	8	5	8
4 (one cut + arisings left)	7*	7	5
5 (three cuts + arisings removed)	4	1	9
6 (two cuts + arisings removed) [1]	6	3	8
7 (one cut + arisings removed)	6*	5	5
8 (one cut + growth retardant and weedkiller)	3	5	6
9 (one cut + two weed wipe treatments)	4	6	5
11 (control–no treatment)	8 [2]	10	2

Notes
[1] Incomplete survey data collected as part of the trials.
[2] Risk associated with undertaking activity on embankments with higher vegetation is offset by reduced risk due to lower frequency of necessary visits.

Further issues

Maintenance of embankments is a very variable activity and is subject to a number of technical (including health and safety), environmental and political priorities. The maintenance of each embankment needs to be considered individually, taking into account all the various elements and risks that come together to deliver the performance required.

The aspects considered in this appendix (together with the associated ratings) do not necessarily consider the influence of locally important factors (e.g. the proximity of designated conservation sites) that may influence the selection of maintenance method.

Nor do they take account of any locally applied risk management policies and practices that influence the maintenance techniques currently used. For example, many lengths of the crests to flood embankments in Anglian Region (particularly those with narrow crest widths) are cut six times per year to:

- provide clear definition of side slope tops;
- deter nesting birds.

Alternative methods to maintaining embankments (e.g. grazing livestock) beyond the scope of this report are available which bring different risks and advantages.

Alternative grass mixtures are another aspect that could influence the maintenance regime employed.

The selection of a particular method may be the most appropriate for the current circumstances but, with a changing climate and risk strategies, solutions many have to be moderated or amended in the future.

Recommendations

It is recommended that:

- The issues raised here are considered as part of work to produce best practice guidance notes for all operating authorities in the management of watercourses, land drainage, flood and coastal defences.
- To develop a more representative selection model, the aspects influencing the choice of maintenance method should be critically weighted in order of perceived importance.

Appendix 2: Visual asset inspection report summaries

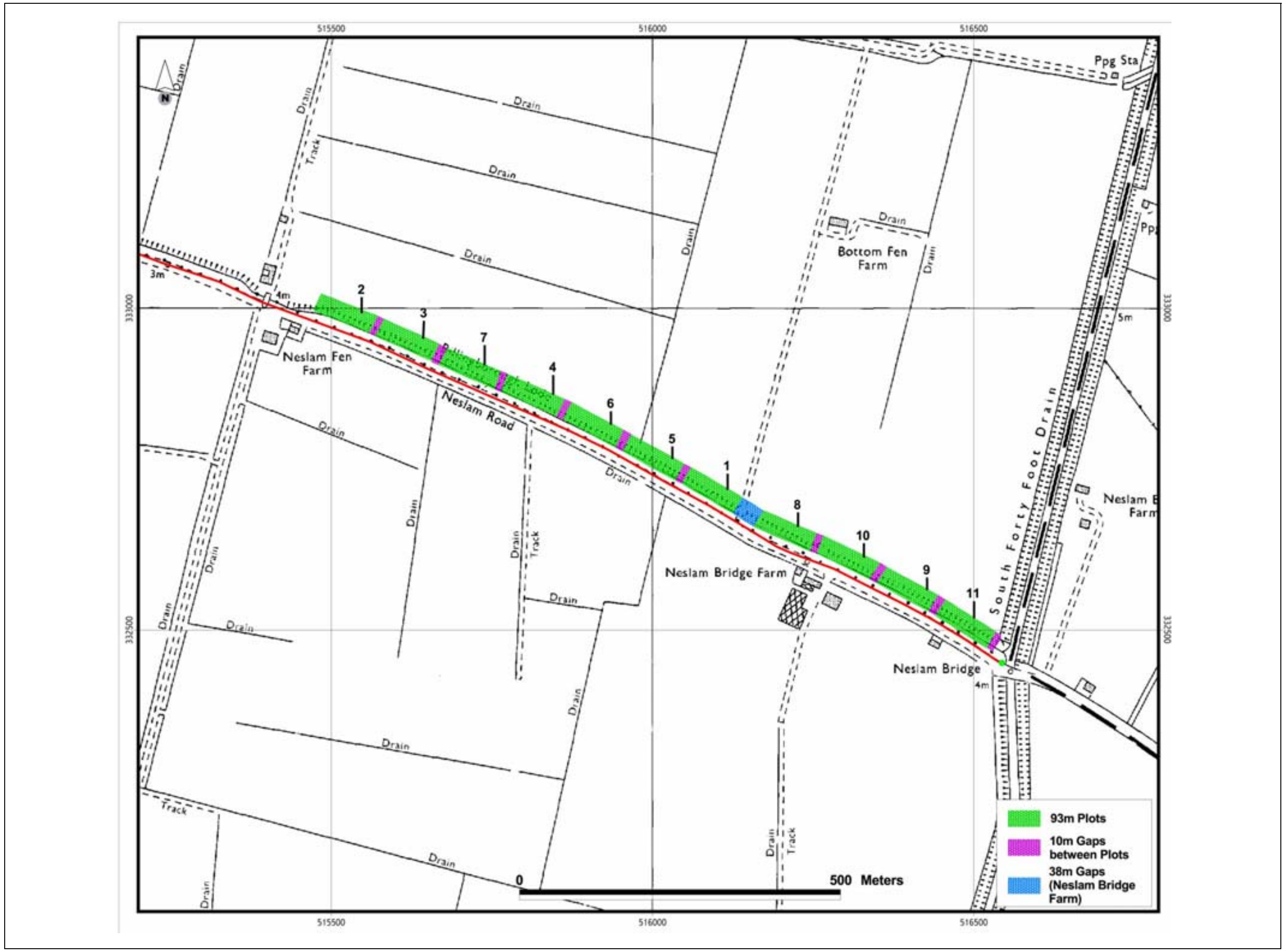
Visual asset inspections were made independently by suitable trained and experienced asset inspectors after the completion of the trials in Years 5 and 6 for all the treatment plots for all three sites during typical winter and summer conditions. They followed the principles for visual inspections adopted by the Environment Agency's standard procedures and were assessed in accordance with Condition Assessment Manual 166_03_SD01.

Due to the proximity of Treatment Option 1 (six cuts per year) to the access points, observed crest rutting to these type of plots is probably exaggerated relatively to other treatments. The inspection condition rating for the crest is adjusted accordingly.

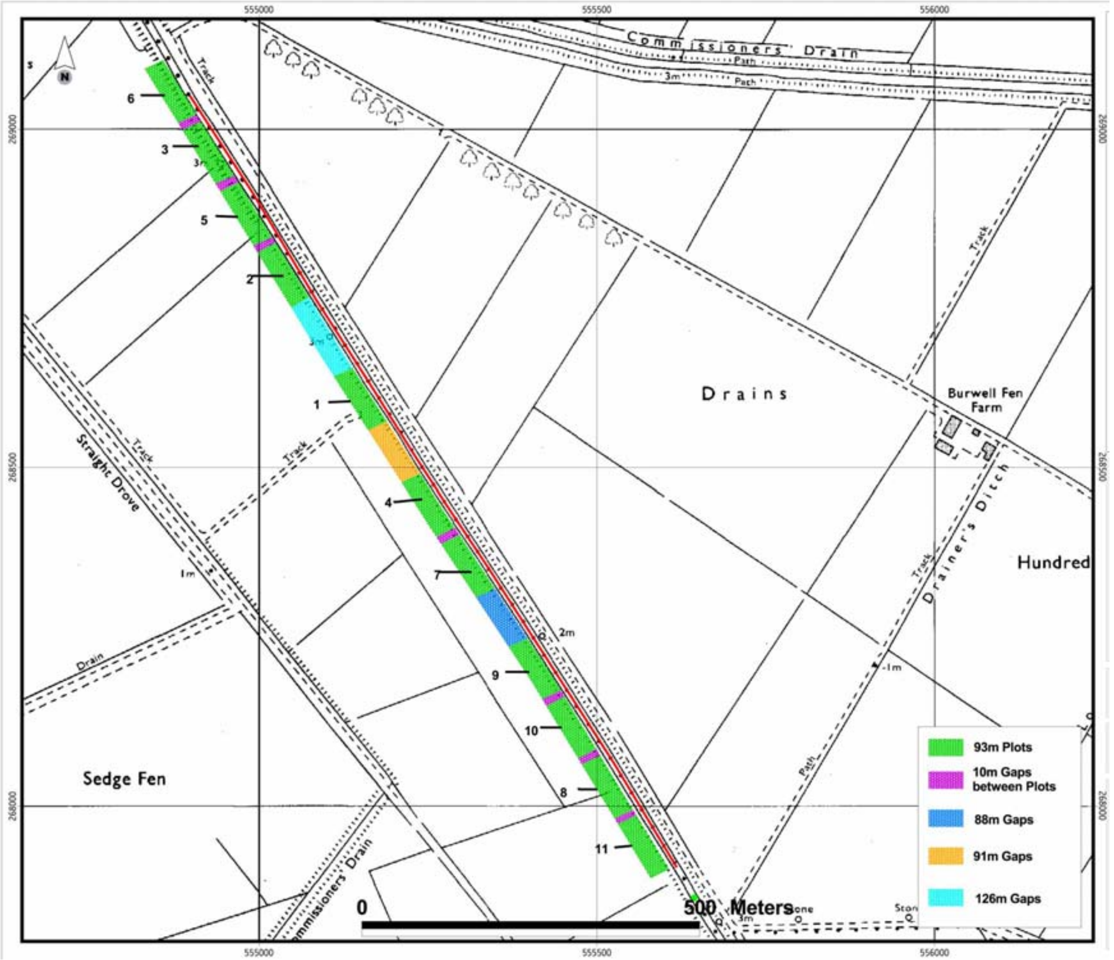
These records have been used, in part, to make informed judgements on the embankment operational performance for each of the treatment options.

Appendix 3: Detailed location of treatments at the sites

Billingborough

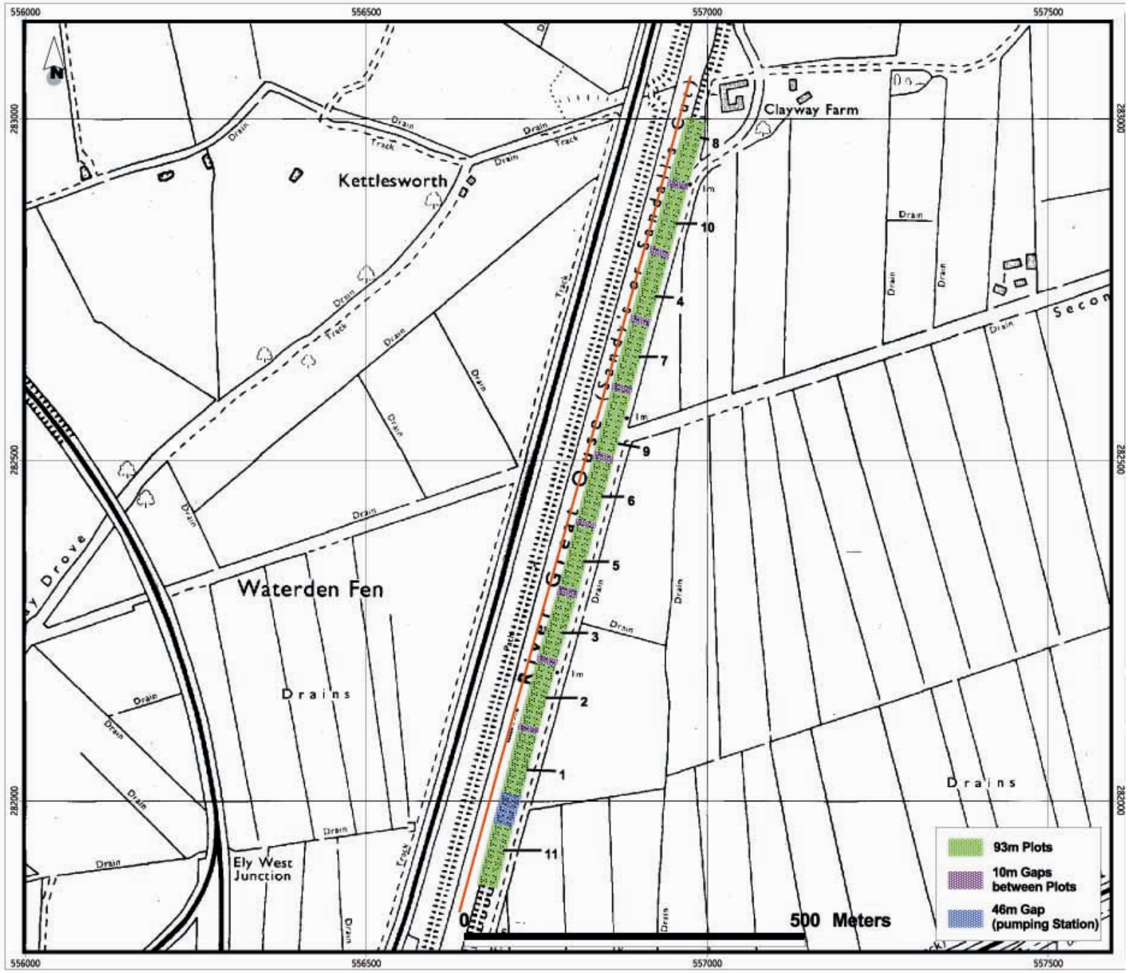


Reach Lode

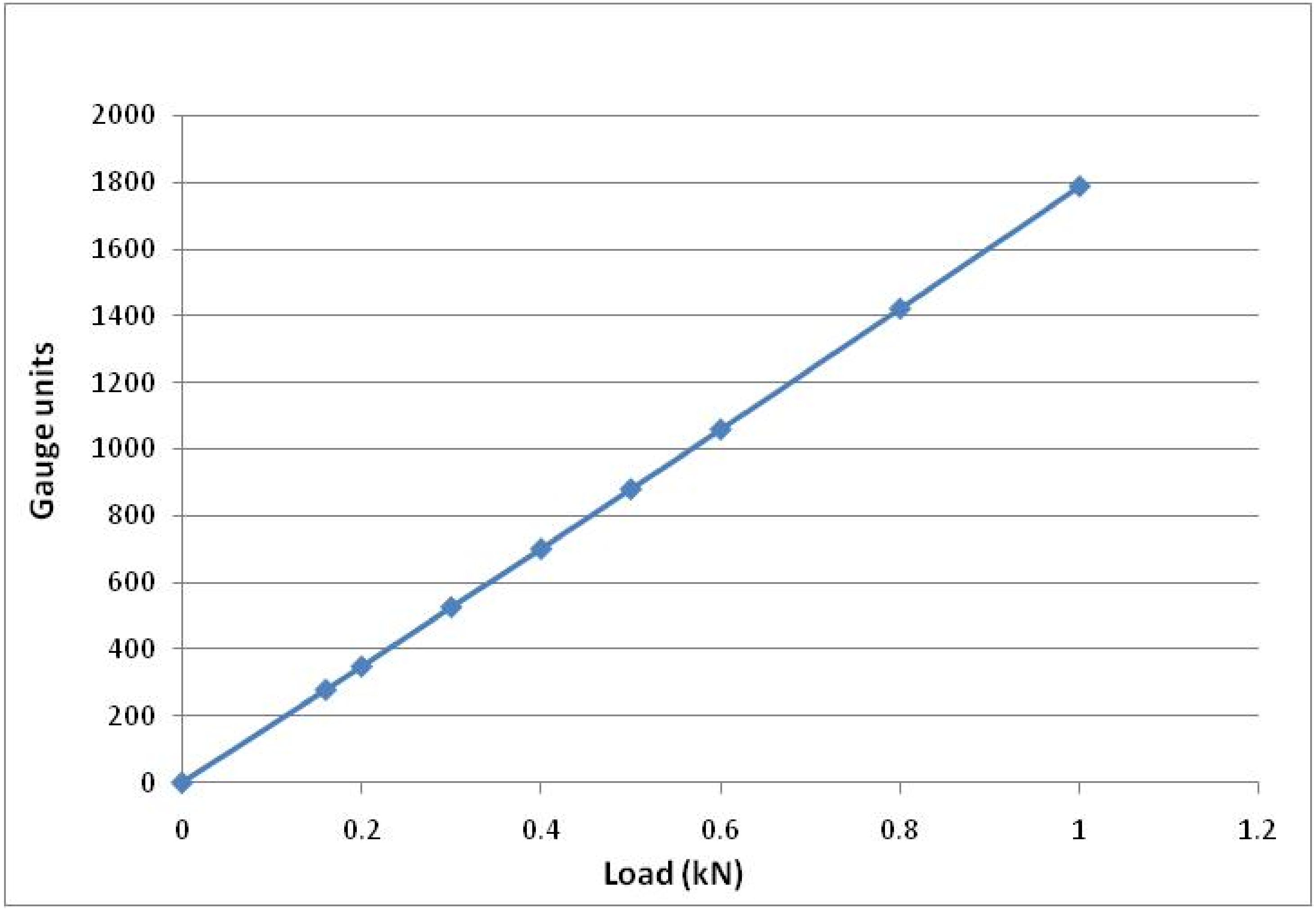


Commissioners' Drain
Drains
Burwell Fen Farm
Hundred
Drainer's Ditch
Straight Drove
Sedge Fen
Commissioners' Drain
0
500 Meters
93m Plots
10m Gaps between Plots
88m Gaps
91m Gaps
126m Gaps

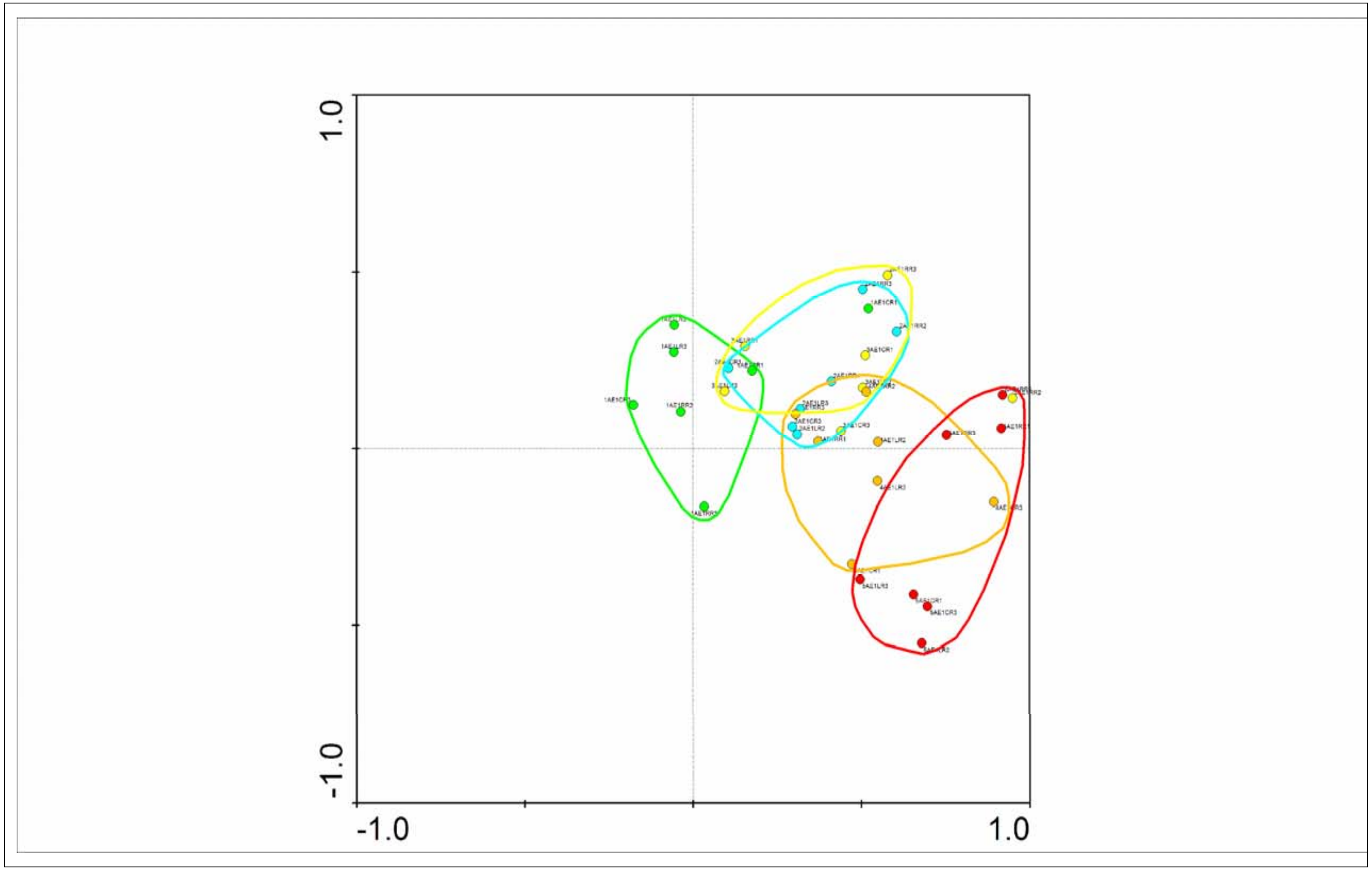
Ely Ouse


556000
556500
557000
557500
283000
282500
282000
N
Kettlesworth
Clayway Farm
Waterden Fen
Drains
Ely West Junction
River Great Ouse (Sandys Cut)
Drove
Drain
Track
1
2
3
4
5
6
7
8
9
10
11
1m
0
500 Meters
93m Plots
10m Gaps between Plots
46m Gap (pumping Station)

Appendix 4: Conversion chart for the proving ring penetrometer



Appendix 5: PCA diagram for Community A at Ely Ouse in Years 1, 2, 3, 4 and 5



green = Year 1, blue = Year 2, yellow = Year 3, orange = Year 4 and red = Year 5

Appendix 6: Scoring system details

Plant diversity scoring system

Billingborough (range 1.07–1.82)

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	1.82	10
1	1.02	1.1		2	1.7	9
2	1.11	1.18		3	–	8
3	1.19	1.26		4	1.52	7
4	1.27	1.34		5	1.49	6
5	1.35	1.42		6	–	6
6	1.43	1.5		7	1.45	6
7	1.51	1.58		8	–	6
8	1.59	1.66		9	1.42	5
9	1.67	1.74		10	1.29	4
10	1.75	1.88		11	1.07	1

Ely Ouse (range 1.48–2.3)

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	2.21	9
1	1.48	1.56		2	2.26	10
2	1.57	1.642		3	–	6
3	1.643	1.724		4	1.48	1
4	1.725	1.806		5	2.3	10
5	1.807	1.888		6	–	6
6	1.889	1.97		7	1.48	1
7	1.971	2.052		8	–	4
8	2.053	2.134		9	1.69	3
9	2.135	2.216		10		
10	2.217	2.298		11	1.52	1

Reach Lode – landward (range 1.33–1.60)

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	1.6	10
1	1.33	1.357		2	1.56	9
2	1.358	1.384		3	–	7
3	1.385	1.411		4	1.47	5
4	1.412	1.438		5	1.34	1
5	1.439	1.465		6	–	1
6	1.466	1.492		7	1.33	1
7	1.493	1.519		8	–	2
8	1.52	1.546		9	1.37	2
9	1.547	1.573		10	1.55	9
10	1.574	1.6		11	1.47	5

Invertebrate diversity scoring system

Billingborough

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	2.03	10
1	1.7	1.735		2	2.05	10
2	1.736	1.77		3		7
3	1.771	1.805		4	1.84	5
4	1.806	1.84		5	1.7	1
5	1.841	1.875		6		3
6	1.876	1.91		7	1.83	4
7	1.911	1.945		8		3
8	1.946	1.98		9	1.8	3
9	1.981	2.015		10	1.86	5
10	2.016	2.05		11	1.89	6

Ely Ouse

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	1.56	3
1	1.42	1.478		2	1.9	9
2	1.479	1.536		3		6
3	1.537	1.594		4	1.61	4
4	1.595	1.652		5	1.42	1
5	1.653	1.71		6		2
6	1.711	1.768		7	1.54	3
7	1.769	1.826		8		7
8	1.827	1.884		9	2.1	10
9	1.885	1.942		10		
10	1.943	2		11	1.99	10

Reach Lode

Score	Diversity classes			Treatment	Average diversity	Score
	Min	Max		1	1.7	7
1	1.06	1.165		2	1.81	8
2	1.166	1.27		3		7
3	1.271	1.375		4	1.68	6
4	1.376	1.48		5	2.11	10
5	1.481	1.585		6		6
6	1.586	1.69		7	1.22	2
7	1.691	1.795		8		2
8	1.796	1.9		9	1.06	1
9	1.901	2.005		10	1.58	5
10	2.006	2.11		11	2.09	10

Diversity score only (all three sites)

Treatment	Final score
1	7
2	9
3	7
4	5
5	4
6	4
7	3
8	4
9	5
10	5
11	9

Soil strength scoring system: surface

Billingborough

Score	PP value		Treatment	Average strength	Score
1	1		1	6.3	6
2	2		2	6.9	7
3	3		3		6
4	4		4	5.2	5
5	5		5	7.2	7
6	6		6		6
7	7		7	3.6	4
8	8		8		5
9	9		9	4.9	5
10	10		10	5.9	6
			11	2.7	3

Ely Ouse

Score	PP value		Treatment	Average strength	Score
1	1		1	5.6	6
2	2		2	5.8	6
3	3		3		6
4	4		4	5.5	6
5	5		5	4.7	5
6	6		6		6
7	7		7	7	7
8	8		8		4
9	9		9	4.1	4
10	10		10		
			11	3.4	3

Reach Lode – landward only

Score	PP value		Treatment	Average strength	Score
1	1		1	4	4
2	2		2	3.1	3
3	3		3		3
4	4		4	4.1	4
5	5		5	4.6	5
6	6		6		4
7	7		7	3.9	4
8	8		8		4
9	9		9	3.9	4
10	10		10	4.4	4
			11	3.8	4

Soil strength scoring system: depth

Billingborough

Score	HV value			Treatment	Average strength	Score
	Min	Max		1	89	7
1	20	30		2	69	5
2	31	40		3		6
3	41	50		4	85	7
4	51	60		5	82	7
5	61	70		6		8
6	71	80		7	112	10
7	81	90		8		9
8	91	100		9	112	10
9	101	110		10	91	8
10	111	120		11	92	8

Ely Ouse

Score	HV value			Treatment	Average strength	Score
	Min	Max		1	84	7
1	20	30		2	70	5
2	31	40		3		7
3	41	50		4	97	8
4	51	60		5	67	5
5	61	70		6		6
6	71	80		7	83	7
7	81	90		8		7
8	91	100		9	99	8
9	101	110		10		
10	111	120		11	71	6

Reach Lode – landward only

Score	HV value			Treatment	Average strength	Score
	Min	Max		1	60	4
1	20	30		2	63	5
2	31	40		3		5
3	41	50		4	66	5
4	51	60		5	62	5
5	61	70		6		5
6	71	80		7	75	6
7	81	90		8		5
8	91	100		9	64	5
9	101	110		10	67	5
10	111	120		11	61	4

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