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A Monitoring Methodology for Wetlands

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Environment Agency

A MONITORING METHODOLOGY FOR WETLANDS

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CONTENTS

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A Monitoring Methodology for Wetlands

1. Background

A wetland hydrological monitoring network has been set up at 51 sites within Anglian Region since 1996/7 with the aim of influencing abstraction licensing and policies, and gaining a better understanding about the hydrology of wetlands. The original 51 sites were chosen via liaison with English Nature and other bodies.

It has become clear over the past few years that there is a need to develop a 'quick and dirty' and cost-effective type of surveillance monitoring which can be carried out regularly at a large number of wetland sites. Such methods are needed to identify possible undesirable changes in the vegetation both at an early stage and without collecting large amounts of 'expensive' data. This problem is particularly pertinent to the present concerns over the potentially damaging effects of water abstraction from locations close to wetland sites of conservation importance.

In our experience, the collection of large amounts of detailed vegetation data is time consuming, and expensive. Moreover, even detailed studies do not always generate reliable data, and often much of the information is superfluous, or at least difficult to interpret. On the other hand, it is sometimes suggested that repeating vegetation mapping/sampling exercises (e.g. using NVC-type methodology) can be used to monitor change. We would contend that, while this might be helpful in identifying gross change, the results are too general to produce information which could be used in the current context. Moreover, the variability of 'communities' and the difficulty of specifying them clearly, both in the field and as abstract units, means that they have only limited value as units of resource.

The approach which has been developed here is one that was originally inspired by the 'butterfly transect' monitoring procedure (Hall, 1981) in which a set route is identified across a site, and records made within separate sections of this. A similar method has already been used with some success in monitoring vegetation at Woodwalton Fen (Alan Bowley, pers. comm.). However, during the discussion and development process, we were forced to conclude that following this type of approach would not provide a sufficiently robust indicator of change, and thus the method described here is based on recording from fixed quadrats, but with a reduced species data set.

2. Monitoring change in wetland vegetation

2.1 Approaches

Various approaches have been used to identify changes in the vegetation at wetland sites:

1. Informal observations

This is the most widespread 'methodology' used as it often provides...

- Rapid assessment

but it is .....

- Often not comprehensive nor consistent
- Not objective

The value of this form of monitoring varies with the circumstance. Revisits to a particular site by an experienced and careful observer can often provide a surprising effective method of detecting change, though it is limited by the experience, perceptions and memory of the observer and requires the same individual to revisit the site. Many informal observations are made on a casual basis, often by a succession of different observers, and often have limited value, especially when the 'quality' of the observations (species identifications, familiarity with the habitat *etc.*) is not known. However, such information frequently forms the *only* recorded information for wetland sites.

2. Objective species sampling

Various monitoring projects have been established based upon some form of 'objective' sampling, frequently random quadrat sampling.

This approach is often thought to be objective and reliable, but...

- even in detailed studies, it is unusual for a sufficient number of quadrats of adequate size to be used to generate results which have statistical validity;
- it is usually only attempted for small, specific areas; it is of little practical value for monitoring large sites;
- if sampling of appropriate intensity is to be satisfactory statistically, then (a) the monitoring protocol is often very time consuming and expensive; and (b) in some situations may engender such disturbance to the vegetation as to become a possible causal factor for subsequent vegetation change.

Whilst in principle, 'objective' species monitoring is an appropriate strategy, in practice it is rarely carried out so as to generate statistically-valid results. In this situation, the veneer of objectivity created by such protocols can be as misleading, or more so, than overtly subjective appraisals.

3. Species sampling based on permanent quadrats

Permanent quadrats are sometimes used as a basis for species monitoring because ...

- they indicate unambiguously species change that has occurred within them;
- location can be free from user bias, although when this is the case it is unusual for a sufficient number of quadrats of adequate size to be used to generate results with statistical validity;

but ....

- they do not provide information for any other areas (though this limitation can be mitigated if the sample areas are thought to be 'representative' in some way);
- location is often chosen subjectively (for specific species / a representative patch of vegetation / practical considerations *etc.*);
- they are usually only attempted for small, specific areas; of little practical value for monitoring large sites;
- they can be difficult to relocate – use of marker posts can be problematic (attracting attention of grazing animals *etc.*;
- repeated sampling can cause disturbance to the vegetation within the quadrat; or trampling damage around the quadrat can have un-natural effects upon the sample area (*e.g.* increased light penetration).

The main advantage of permanent quadrats is that changes observed within them are 'real' (*i.e.* they are not probabilistic). The main disadvantage is that they only represent the area of the sample, though this (inevitable) limitation can be reduced (a) by having as large a number of quadrats as is practicable; and (b) by locating the plots within representative (or 'critical') areas. It has to be recognised that when permanent quadrats are used – as is usually the case – the sampling strategy is essentially subjective. However, it is 'controlled' and recognised subjectivity and, in many respects, this is preferable to the 'pseudo-objectivity' of inadequate random sampling.

4. NVC-style surveys

NVC-style surveys have been made at a number of sites, opening the possibility that they can be used as base-lines against which to assess future change. However....

- the *NVC* sampling protocol (5 replicate samples per stand) is not likely to be sufficient to provide truly statistically-valid data for species sampling (though where permanent plots have been established, these can be used as monitoring base-lines);
- the use of communities, and community-maps, as methods for detecting vegetation change has various limitations, although may be useful in some circumstances (see 'Monitoring Units', below).

NVC-style sampling may have rather little practical value for monitoring change in wetlands. However, communities may provide a useful basis for the location of samples designed to detect species change.

2.2 Monitoring Units

1. Species

Species appear to provide the most valuable monitoring unit. They are:

- the fundamental biological unit;
- mostly well defined, though some can be difficult to identify or locate (depends on experience of operators);
- environmental requirements (and indicator value) of species are sometimes well known (though some species have a broad amplitude of tolerance, and in others tolerance to specific environmental variables can be modified by the character of other environmental conditions, or by biotic interactions; not all workers appreciate the complexity of species-environment inter-relationships);

- 'functional characteristics' of species permit some generic predictions of the characteristics of the environment to be made;

but ...

- wetlands can support a large number of species (which potentially increases the time, complexity and errors of monitoring);
- patchy distribution patterns often make simple objective monitoring difficult (or statistically insecure); likewise, they can limit the value of subjective sample placement protocols.

In many situations it would be desirable if the number of species to be monitored could be reduced to a subset of individuals which ideally would (a) be relatively easy to locate and identify; and (b) have clear, and complementary, environmental indicator value.

2. Communities

Communities are sometimes advocated as a unit of monitoring change, but they are ...

- abstract units and artificial constructs with no objective reality (different classifications of the same data set may recognise different communities)
- variable in floristic composition, both as abstract units and within individual field samples.

In addition ...

- considerable species change can occur within a particular vegetation stand before it ceases to be identifiable as an example of a particular community;
- the only property of an individual field example of a community *per se* that is usually monitored is the spatial position of its boundary (species composition of the community can, of course, also be monitored, but this is effectively species-level monitoring, not community-level monitoring);
- boundaries vary considerably in their discreteness; where boundaries between communities in the field are gradual, any split between the communities is invariably arbitrary.

The above considerations suggest that, whereas plant communities may be extremely valuable as generic categories for describing the character of sites, they have little objective value as units of resource, nor can they be used reliably *per se* for monitoring change, except in rather crude terms.

It seems likely that the main value of communities in a monitoring strategy is that they provide *foci* within which species monitoring points can be effectively located. However, community-level units do emphasise the need for assessment of the position of the boundaries of communities in the field as well as the species-composition of the stand. The location of community boundaries (where these can be detected with some objectivity and consistency) is undoubtedly potentially important as a monitoring property, as this is where change might be expected to happen first.

3. Development of the methodology

3.1 Objectives

The following 'ideal' objectives were set for the methodology:

1. an easy to use, cost-effective ecological monitoring method for use at hydrological monitoring sites.
2. applicable across all wetland types in the hydrological programme
3. tested in the field before being implemented
4. consulted over widely so that NGO's and statutory nature conservation bodies agree its value and usefulness
5. able to detect changes in site vegetation over a minimum 10 year period.
6. able to facilitate detection of impacts of changes in site hydrological regime (including water abstraction) on vegetation

This project was designed to link directly to the hydrological monitoring of wetlands project, running at 51 sites in Anglian Region. As such, it is part of a wider project and should not necessarily be considered as a replacement for established ecological monitoring regimes at these and other sites (although this may be appropriate at some sites). Standardised ecological monitoring would maximise the benefits of the hydrological project, enabling impacts of changes in hydrology to be interpreted ecologically. The Agency could not resource a very detailed monitoring programme, and would be entering into English Nature's remit if the Agency did commence very detailed monitoring at all sites without an explicit purpose.

The methodology is not necessarily:

- a replacement for detailed surveys or population studies
- applicable for all ecological monitoring activities.

However, the methodology could be used in other Agency activities, or at sites other than those within the Agency hydrological monitoring programme, although the primary objective must be to collect ecological data consistently and cost-effectively at these sites.

3.2 Consultees:

We have liaised with various people who have an interest in and experience of wetland monitoring in order to develop a method which can be widely accepted. These include Alan Bowley (EN Site Manager, Woodwalton NNR), Mike Harding (Independent Consultant), Gary Kennison (Broads Authority, Ecologist), Peter Roworth (EN Site Manager, Thorne Moors NNR), Rick Southwood (EN Site Manager, Woodbastwick NNR), Eddie Boosey (Honorary warden, Scarning Fen NWT Reserve).

We are particularly grateful to these individuals, and Environment Agency staff, especially Gary Murphy and John Adam, for their contributions and have incorporated their comments/feedback where possible. Experiences gained through work with English Nature to develop methods for monitoring grasslands (Hodgson & Colasanti, 1995) have also been valuable in the present project.

3.3 Requirements of method

In order to be considered satisfactory, the following criteria were set for the method:

- must not depend on recording every species in detail, but must be nonetheless, consistent and stand up to scrutiny (*i.e.* results must be convincing to experts and non-experts).
- should not depend on detailed taxonomic expertise for recording, (although basic botanical knowledge will be required, and expert input will be needed in the setting up and interpretation).
- must be able to demonstrate change in vegetation composition;
- ideally, should maximise the scope for interpretating vegetation change in terms of change in environmental conditions, such as dehydration or nutrient enrichment;
- should be simple to set up, and repeat with reasonable accuracy;
- the general approach should be applicable to all herbaceous wetland types (*i.e.* excluding woodland and aquatic habitats).

3.4 Species to be recorded

The approach developed here is one in which the number of species recorded at each point is reduced, where possible, by focusing on species with an 'indicator' value – *i.e.* those for which a change in abundance can be interpreted in terms of environmental change, for example in hydrological regime or nutrient availability. This has the benefit of reducing recording time in one location, and thus makes it possible to increase the number of points across a site from which records are taken, rather than concentrating on a few specific locations.

Wheeler & Shaw (1995) suggest that, ideally, a sensitive species for monitoring water-level change would have the following properties:

1. a known and consistent relationship to the hydrological environment;
2. response is well synchronised with water-level change, *i.e.* response lacks substantial inertia;
3. response is substantially independent of starting conditions, *i.e.* it is comparable in different vegetation-types and environmental conditions;
4. abundance is not strongly influenced by other variables that may be changing independently of, but concurrent with, hydrological change (*e.g.* management);
5. reasonably common - so that realistic determinations of abundance changes can be made, and to facilitate between-site comparisons;
6. reasonably easy to locate and identify in the field.

Clearly it is not possible to choose one species which will fulfil all of these criteria, in addition to which, it is important to identify where floristic change is occurring independently of change in hydrological regime. It is thus necessary to select a variety of species to represent a range of 'functional characteristics', including:

1. response to unfavourable water regime (choose indicators from both ends of the 'wet' and 'dry' axis);
2. extremes of size (relevant to changes in management regime);

3. response to nutrient enrichment (because of their lack of responsiveness, slow-growing species will not normally be recorded, unless a dominant species, or of particular conservation interest).

Other factors which have been taken into account in selection of species for recording are as follows:

1. dicots are easier to see and identify than many monocots;
2. allowance has been made for aggregation of species (*e.g.* the sedges *Carex riparia / acutiformis* and the willows *Salix aurita / caprea / cinerea*);
3. many taxonomically-difficult species, and those which are easily overlooked (*e.g.* many grasses, sedges, rushes and mosses) have been excluded (for some, it may be necessary to provide aids for identification in a monitoring manual).

Species can be divided into three main categories, as follows:

1. Dominant species
2. Characteristic fen species and target species

   NB: target species ('rare' or 'notable' species of particular conservation note) at a given site should be included within the fixed plots, where possible.
3. Potentially-invasive species

   'Undesirable' species (including non-wetland species) occurring on (or around) the site, which might be expected to invade if, for example, conditions became drier (*e.g.* rosebay willow herb (*Chamerion angustifolium*), noxious weeds and thistles).

All woody species should be recorded, even if not on the list provided

Species which have been selected for recording are listed in Table 1, and readers are invited to suggest improvements to the list provided[1].

[1] Note that trial analyses of existing data sets for Redgrave Fen are presented in Appendix 1, with a comparison of results using the full data set and the reduced monitoring species data set.

Table 1. List of species to be recorded

DOMINANTS

Acer pseudoplatanus
Alnus glutinosa
Betula pendula/pubescens
Calamagrostis canescens
Calamagrostis epigejos
Carex acutiformis/riparia
Carex elata
Carex paniculata
Chamerion angustifolium
Crataegus monogyna
Deschampsia cespitosa
Epilobium hirsutum
Frangula alnus
Fraxinus excelsior
Glechoma hederacea
Glyceria maxima
Humulus lupulus
Juncus acutiflorus/ articulatus/ subnodulosus
Juncus conglomeratus/effusus
Juncus inflexus
Phalaris arundinacea
Phragmites australis
Populus spp
Pteridium aquilinum
Quercus robur/petraea
Rosa spp
Rubus fruticosus agg.
Salix aurita/caprea/cinerea
Sambucus nigra
Sparganium emersum/erectum
Typha angustifolia/latifolia
Urtica dioica
Viburnum opulus

FEN SPECIES & TARGET SPECIES

Achillea ptarmica
Alisma plantago-aquatica
Anagallis tenella
Apium nodiflorum/Berula erecta
Bidens cernua/tripartita
Calluna vulgaris
Caltha palustris
Calystegia sepium
Carex flacca/panicea
Carex pseudocyperus
Cirsium dissectum
Cirsium palustre
Cladium mariscus
Dactylorchid spp.
Drosera intermedia/longifolia
Drosera rotundifolia
Epipactis palustris
Equisetum arvense
Equisetum fluviatile
Equisetum palustre
Erica tetralix
Eupatorium cannabinum
Filipendula ulmaria
Galium palustre
Galium uliginosum
Glyceria fluitans agg.
Hydrocotyle vulgaris
Hypericum elodes
Hypericum tetrapterum
Iris pseudacorus
Lathyrus palustris
Lemna minor
Lemna trisulca
Lotus pedunculatus
Lychnis flos-cuculi
Lycopus europaeus
Lysimachia nummularia
Lysimachia vulgaris
Lythrum salicaria
Mentha aquatica/arvensis
Menyanthes trifoliata
Molinia caerulea
Myrica gale
Osmunda regalis
Parnassia palustris
Pedicularis palustris
Pedicularis sylvatica
Pinguicula vulgaris
Potamogeton coloratus/polygonifolius
Potentilla erecta
Potentilla palustris
Pulicaria dysenterica
Ranunculus flammula
Ranunculus lingua
Rorippa nasturtium-aquaticum agg
Rumex hydrolapathum
Schoenus nigricans
Scrophularia auriculata
Senecio erucifolius
Sium latifolium
Solanum dulcamara
Sonchus palustris
Succisa pratensis
Thalictrum flavum
Thelypteris palustris
Utricularia spp
Valeriana dioica
Valeriana officinalis
Veronica beccabunga
Viola palustris

INVADERS

Achillea millefolium
Anthriscus sylvestris
Arctium minus/lappa
Atriplex patula
Atriplex prostrata
Brassica rapa
Carduus crispus
Chenopodium album
Chenopodium rubrum
Cirsium arvense
Cirsium vulgare
Conium maculatum
Crassula helmsii
Galeopsis tetrahit agg.
Galium aparine
Heracleum mantegazzianum
Heracleum sphondylium
Lamium purpureum
Matricaria discoidea
Matricaria recutita/ Tripleurospermum /Anthemis
Persicaria amphibia
Persicaria hydropiper/maculosa/ lapathifolia
Potentilla anserina
Potentilla reptans
Ranunculus acris/repens
Ranunculus sceleratus
Rumex crispus/obtusifolius
Senecio jacobaea
Senecio sylvaticus/vulgaris
Sinapis arvensis
Sisymbrium officinale
Sonchus arvensis
Sonchus asper
Sonchus oleraceus
Stellaria media
Taraxacum agg
Trifolium repens/pratense/fragiferum

4. 'Trialling' the method

4.1 Introduction

After initial consultation and formulation of a proposed methodology, a site meeting was convened. This looked at two sites with contrasting vegetation, Woodwalton Fen and Sutton Common (Cambs), in order to discuss in the field the various issues raised. Subsequently, the method was 'trialled' in more detail at Whitwell Common and Scarning Fen (Norfolk). The outcome of these 'trials' was reported to EA in the document "Development of wetland monitoring methdology, Progress report, November 1998", and the proposed methodology has been amended accordingly. In addition, a surrogate 'time' trial of the methodology has been undertaken using existing floristic data sets from Redgrave Fen (Suffolk). The results of this are reported separately in Section 4.2 and Appendix 1.

4.2 Assessment of the use of a reduced species data set for monitoring

One of the main features of the proposed monitoring method is the use of a reduced species data set. As it is possible that recording fewer species might mean that the system was less sensitive at detecting change, it is therefore important to investigate whether results obtained, and conclusions drawn, using a restricted number of species are comparable to those derived from analysing a full data set. The capacity of the reduced and full data sets to display change, and to sustain an ecological interpretation of the causes of this, has been examined by reference to three data sets from Redgrave Fen (1959, 1991 and 1997). This site was selected because of the availability of appropriate vegetation data, but also because it has been subject to considerable, and fairly well documented, environmental change over the period represented.

The data have been analysed by two different methods:

1. *Detrended Correspondence Analysis*

   This is an ordination procedure that is used to reveal the floristic inter-relationships between stands (or samples), and which can show (geometrically) differences between samples and years. This approach was used for data analysis by Fojt & Harding (1995) (using all species) and was repeated here (using all species and monitoring species), to determine the extent to which interpretable patterns emerged for the reduced species set.

2. *FENSPEC Analysis (Fen Species Prediction of Environmental Change)*

   This is a trait-based analytical procedure, developed at the University of Sheffield, that can be used to identify the apparent causes of floristic change between two or more samples. It provides a tool which can be used to determine the extent to which similar interpretations emerge for the changes observed using the full and reduced species sets.

The results of the analysis are presented and discussed in Appendix 1, the main conclusion being that the use of a reduced set of species is considered adequate for identifying vegetation change and acceptable from the point of view of the ecological interpretability of monitoring data.

5. Suggested sampling protocol

It is recommended that should the method be approved for use, a manual should be produced which sets out the recommended methodology, and provides detailed guidelines on its implementation. For example, the manual should include guidelines on the assessment of vegetation cover *etc.* and the identification of 'difficult' species (with illustrations, if necessary). It would also be useful to provide guidelines on appropriate analysis and interpretation of the data[1].

5.1 Preliminary work

It will be necessary to obtain an overview of the habitats and plant communities present on the site in order to appropriately locate the sampling points.

- Review existing information about the site (*e.g.* contact English Nature, Wildlife Trusts etc.), including habitat and vegetation maps, and information regarding current, and former, monitoring on the site (including hydrological monitoring).
- Obtain details of current and planned management regimes (this can have an important bearing on deciding on an appropriate return period for monitoring). *It should be stressed at the outset that it will be important for the site managers / owners to keep careful records of any management activities on the site through the monitoring period.*
- A preliminary walk-over of the site should be undertaken (preferably by an expert) to identify the main plant communities, and areas/species of particular interest, and decide upon sampling points.
- Prepare record cards in advance of the main site visit to simplify recording, and ensure a consistent approach.

5.2 Location and numbers of sample points

- Establish a series of fixed quadrats (0.5m x 2m) across the site in the main representative vegetation and hydrological zones (locations determined based on the information available and preliminary site walk-over).

  The frequency of sampling points will be site specific, but some general ground-rules can be applied:

  - *positioning of quadrats along a transect, or in relation to an existing path, can help with relocation.*
  - *quadrats should be positioned in the areas of highest conservation interest and in stands/locations where the vegetation is likely to be most responsive to change in environmental conditions;*
  - *representative communities and transitions should be covered, and with two replicates of each;*
  - *each of the major vegetation / hydrological zones should be represented more than once.*

  Less productive systems are likely to change more slowly than the more productive ones. Examination of as wide a range of communities as possible across a site may help to

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[1] Note that trial analyses of existing data sets for Redgrave Fen are presented in Appendix 1, with a comparison of results using the full data set and the reduced monitoring species data set.

identify site changes before major species losses occur from the less productive and more conservationally-important vegetation types.

- *there should be a bias in locating quadrats towards the edges of stands and in transition zones, as these are the areas likely to be amongst the first to show vegetation change*
- *'drier' communities and mono-dominant stands of species such as* Glyceria maxima *can usually be ignored, unless these are of particular concern.*

5.3 Recording

Recording should be done from one (long) side of the quadrat only, in order to reduce recording time and trampling damage.

Record cover-abundance of selected species (see Table 1) using the Braun-Blanquet scale:

5	> 75%
4	50 – 75%
3	25 – 50%
2	5 – 25%
1	Numerous, but <5% or scattered with cover up to 5%
+	Few, with small cover
r	Solitary, with small cover.

Record additional features, e.g.

- Total moss cover
- Total *Sphagnum* cover
- Total cover of falcato-secund mosses[1]
- Plant litter
- Bare substratum
- Canopy height

In addition, general notes should be made regarding each vegetation zone (*e.g.* general 'condition' of the vegetation, management and apparent water levels), in order to provide supporting background information about the site and the nature of the vegetation.

Photography from fixed points can be used to monitor gross changes. Taking a photograph of each quadrat (or at least of one replicate in each stand-type recorded) when the programme first starts could be beneficial to future interpretation of change.

5.4 Timing of recording

The optimum time for monitoring is when species are at maximum vegetation development (and preferably when species are in flower): for wetlands this is usually July. The timing of any management operations will need to be determined in advance and taken into account (a site manager may be willing to delay mowing if it is known monitoring is to be carried out). For mown sites, recording should not be carried out within two months after mowing, and preferably before mowing.

Time taken for recording quadrats will be variable, depending on the vegetation-type, distance between quadrats, and ease of re-location. However, it is estimated that it should be possible to re-record on average at least three sampling points per hour.

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1 For example, *Drepanocladus* spp., *Scorpidium scorpioides*, *Cratoneuron commutatum* ("curly-wurly" mosses!)

5.5 Marking transect and sample points

A detailed sketch map of the locations of the quadrats should be drawn, with sufficient markers to ensure that the sampling points can be re-located by another recorder in two or more years time. Any landmarks chosen should be reasonably permanent. Distances between sample points should be recorded.

Individual quadrats should be permanently marked.

Suitable markers for the quadrats may depend on the management regime on the site, and should be chosen in consultation with the owners/managers. Posts may be suitable in some locations (although should not be located within the sampling plots themselves because of possible problems with animals); in others it may be necessary to locate a plot by measurement between two fixed markers or even consider the use of transducers. The number/code of each sample point should be shown, if possible.

5.6 Repetition and review

Assuming year 1 acts as the baseline, and there is a 5-year licensing period for abstraction, recording should be undertaken in the first and second years, and then in the 4th or 5th year (depending on the management regime, and date of renewal).

Note that there will be a need to consider the current (and planned) management regime when deciding on the interval between sampling. Where vegetation management is carried out on a regular cycle, the repeat recording should be carried out at the same phase of the management cycle in order to avoid recording changes which are largely a response to management.

It is suggested that the person undertaking the recording should be responsible for collation of records, but that EA would be responsible for looking after records and obtaining expert, independent interpretation.

A formal assessment of the data should be made at least every 5 years. If a relevant abstraction licence is extended, the recording should subsequently be repeated in the year before that in which renewal is due (or after 5 years, which ever is the sooner).

Appendix 1 provides an analysis of existing floristic data from Redgrave Fen (Suffolk) and gives an indication of the type of analysis which would be helpful in interpretation of the data.

It is recommended that the location of the quadrats is reviewed every five years, and consideration given to adding, or removing, quadrats in accordance with changes (if any) on the site.

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Appendix 1:

Assessment of the use of a reduced species set for monitoring

CONTENTS

1. Introduction

One of the main features of the proposed monitoring method is the use of a reduced species set. As it is possible that recording fewer species might mean that the system was less sensitive at detecting change, it is therefore important to investigate whether results obtained and conclusions drawn using a restricted number of species are comparable to those derived from analysing a full data set. The capacity of the reduced and full data sets to display change, and to sustain an ecological interpretation of the causes of this, has been examined by reference to three data sets from Redgrave Fen. This site was selected because of the availability of appropriate vegetation data, but also because it has been subject to considerable, and fairly well documented, environmental change over the period represented by these.

2. Redgrave Fen data sets

Three species data sets are available for Redgrave Fen (Suffolk):

Author(s)	Survey Date	Details
D.J. Bellamy	1959	Estimates of *cover* in 5 stands using replicate quadrats. (Bellamy & Rose, 1961)
W. Fojt & M. Harding	1991	Estimates of *cover* in 5 stands using replicate quadrats (repeated Bellamy's methodology). (Fojt & Harding, 1995)
J. Parmenter	1997	Estimates of *frequency* in 5 stands using replicate quadrats (Parmenter, 1997).

As there is no reason to suppose that any of the samples in the 1991 and 1997 surveys were located in exactly the same position as Bellamy's quadrats in 1959, data comparison is possible only on a stand basis, not on a sample (quadrat) basis. Moreover, despite attempts to ensure comparability (especially in the 1959–1991 comparisons), it is possible that differences in methodology, precise location of samples and delimitation of stand boundaries in the three surveys may contribute to variation in the results obtained.

3. Quantitative Analyses

3.1 Introduction

Unfortunately, Parmenter did not record the cover of species in her quadrats, so the 1997 survey cannot be compared directly with the cover-based estimates of the previous two surveys. However, it is possible to covert the Bellamy and Fojt & Harding data to frequency estimates, which can be used as quantitative measures comparable with Parmenter's data.

Four sets of quantitative analyses were made:

1959/1991 (cover estimates):	all species
1959/1991 (cover estimates):	monitoring species
1959/1991/1997 (frequency estimates):	all species
1959/1991/1997 (frequency estimates):	monitoring species

It should be recognised that species frequency is a different quantitative measure to cover (a species can have high frequency but low cover in vegetation), so the results of the cover-based and frequency-based analyses may not necessarily coincide. These sets of analyses therefore provide some opportunity to evaluate the merits of the use of cover-based and frequency-based abundance estimates.

Each of the four data sets was analysed by:

Detrended Correspondence Analysis

This is an ordination procedure that is used to reveal the floristic inter-relationships between stands (or samples), and which can show (geometrically) differences between samples and years. This approach was used for data analysis by Fojt & Harding (1995) (using all species) and was repeated here (using all species and monitoring species), to determine the extent to which interpretable patterns emerged for the reduced species set.

FENSPEC Analysis (Fen Species Prediction of Environmental Conditions)

This is a trait-based analytical procedure, developed at the University of Sheffield (details in), that can be used to identify the apparent causes of floristic change between two or more samples. It provides a tool which can be used to determine the extent to which similar interpretations emerge for the changes observed using the full and reduced species sets.

The analyses were repeated using the full and reduced species lists, as shown in Table 1.

Table 1. List of species used in the analysis of data from Redgrave Fen.

SPECIES KEPT IN ANALYSES

Herbs:

Anagallis tenella
Betula pubescens
Betula seedling/sp
Calamagrostis canescens
Calluna vulgaris
Carex flacca
Carex panicea
Chamerion angustifolium
Cirsium arvense
Cirsium dissectum
Cirsium palustre
Cirsium vulgare
Cladium mariscus
Drosera rotundifolia
Epipactis palustris
Erica tetralix
Eupatorium cannabinum
Galium aparine
Galium uliginosum
Glechoma hederacea
Humulus lupulus
Hydrocotyle vulgaris
Juncus subnodulosus
Lotus pedunculatus
Lychnis flos-cuculi
Mentha aquatica
Molinia caerulea
Parnassia palustris
Pedicularis palustris
Phragmites australis
Pinguicula vulgaris
Potentilla erecta
Quercus robur
Quercus seedling/sp
Ranunculus repens
Rubus fruticosus agg.
Salix seedling/sp
Schoenus nigricans
Scorpidium scorpioides
Senecio sylvaticus
Solanum dulcamara
Sonchus asper
Stellaria media
Succisa pratensis
Ulex europaeus
Urtica dioica
Valeriana dioica
Valeriana officinalis

Mosses

Cratoneuron commutatum
Cratoneuron commutatum falcatum
Drepanocladus revolvens
Drepanocladus revolvens var. inundatum
Sphagnum russowii
Sphagnum subnitens

NB: *Note that it was not possible to aggregate species as recommended in the suggested sampling protocol (see Main Text, Section 5.3).*

SPECIES OMITTED FROM ANALYSES:

Herbs:

Agrostis canina
Angelica sylvestris
Briza media
Carex pilulifera
Carex pulicaris
Centaurea nigra
Cerastium fontanum
Dryopteris carthusiana
Epilobium montanum
Equisetum palustre
Festuca ovina
Festuca rubra
Galium saxatile
Genista anglica
Gymnadenia conopsea
Holcus lanatus
Leontodon hispidus
Linum catharticum
Luzula multiflora
Myosotis arvensis
Polygala serpyllifolia

Mosses & liverworts

Amblystegium riparium
Aneura pinguis
Aulacomnium androgynum
Aulacomnium palustre
Brachythecium rutabulum
Bryum pseudotriquetrum
Calliergon cuspidatum
Calypogeia muelleriana
Calypogeia sphagnicola
Calypogeia trichomanis
Campylium elodes
Campylium stellatum
Campylopus introflexus
Cephalozia bicuspidata
Cephalozia connivens
Ctenidium molluscum
Dicranum scoparium
Eurhynchium praelongum
Fissidens adianthoides
Hypnum cupressiforme
Lophocolea bidentata
Lophocolea cuspidata
Lophocolea heterophylla
Mnium hornum
Moerckia hibernica
Pellia endiviifolia
Pohlia nutans
Polytrichum juniperinum
Preissia quadrata
Pseudoscleropodium purum
Rhizomnium pseudopunctatum
Riccardia chamedryfolia
Riccardia latifrons
Riccardia multifida

3.2 Detrended Correspondence Analysis

The position of the centroids of the five stands, for 1959 and 1991 on the first three axes of the DECORANA ordinations are shown in Figure 1 (A–C). The following observations can be made:

1. The monitoring species data set provides evidence for consistent change between 1959 and 1991 along axis 1, in that all 1991 centroids occupied higher loadings along the axis than did those in 1959.
2. The full species data set also shows change along axis 1 (mostly in the opposite direction to that using the monitoring data set, though the centroids for stand 3 show a positive change along axis 1).
3. On the 2-D plot of axes 1 against 2, the stand centroids using the monitoring species show evidence of convergence with time, with respect to both axes (but especially axis 2), suggesting an increased degree of similarity amongst the communities. There is little obvious pattern in the changing position of stand centroids with respect to axes 1 and 2 when all of the species are included in the analysis.
4. There is no consistent change in the position of the stand centroids along axis 3, for either the analysis with the monitoring species or that including all species. In both cases, the position of different stand centroids may show either positive or negative change.

It is evident that the ordinations based on the full and reduced species sets are considerably different to one another. This is unsurprising, not least because the precise character of all ordinations is critically dependent on the number of species present in the sample set (the initial number of dimensions). Hence axis 1 in the reduced data set is *not* exactly the same as axis 1 in the full data set (nor need it even be very similar). In assessing ordinations it is therefore more important to establish the nature of the interpretations that can be derived from them, rather than to compare their structure. However, it is also important to bear in mind that the axes of the ordination just represent the main directions of floristic variation in the data set: these may, or may not, correspond with an associated environmental gradient.

One component of interpretability is the consistency of observed change. Neither the full nor the reduced data sets show evidence of consistent directions of floristic change with respect to axes 2 and 3 (*i.e.* different stands show different directions of change along these axes). By contrast, both data sets show a rather consistent direction of change with time along axis 1, with the pattern for the reduced (monitoring) species set being completely consistent. It is not known what may be the causal basis for species variation along DECORANA axis 1, but it seems probable that it represents a composite gradient, reflecting the combined effects of drying and dereliction that are known to have occurred between 1959 and 1991.

Another aspect of consistency is the tendency for convergence amongst the stand compositions that can be seen for the monitoring species data set in the axis 1 *versus* 2 ordination. This strongly suggests that, with respect to the first two main floristic gradients within the monitoring species data set, stands which in 1959 had quite different composition of monitoring species had become more similar by 1991 (possible mainly on account of species loss). However, no such convergence was evident in the full data set.

Conclusions

One of the main conclusions that can be drawn from these results is that the results of stand ordinations can be difficult to interpret! This was recognised at the outset, but as a DECORANA ordination had been used by Fojt & Harding (1995) to interpret change in the composition of vegetation at Redgrave Fen, it was considered appropriate to analyse the full and reduced data sets using the same approach. In making this comparison, it is important to note that, although Fojt & Harding used the full species set, they analysed their Redgrave data in conjunction with records from two other nearby sites (Thelnetham and Weston Fens) and these have almost certainly affected the trends shown by the Redgrave stands in their ordinations. This explains the differences between the ordination of the full data set presented here and the trends identified in the Redgrave samples in Fojt & Harding's ordinations (see Figure 2) , and leads to the rather uncomfortable conclusion that some of the trends identified by Fojt & Harding for Redgrave were probably partly influenced by changes in the composition of the vegetation at Weston and Thelnetham Fens as well as by the changes recorded for Redgrave!

It is also evident that the monitoring species set produces a clearer (*i.e.* more consistent) ordination than was found for the full data set. This probably reflects two important properties of the monitoring species set: (i) it is more coherent than the full species set (*i.e.* contains less noise); and (b) the species have been selected for their presumed indicator value.

Figure 1.
DECORANA ordination of floristic data from 5 stands at Redgrave Fen (1959 & 1991), using full species data set and monitoring species data set.

Figure 1A. Axis 1 vs. Axis 2

Figure 1B. Axis 2 vs. Axis 3

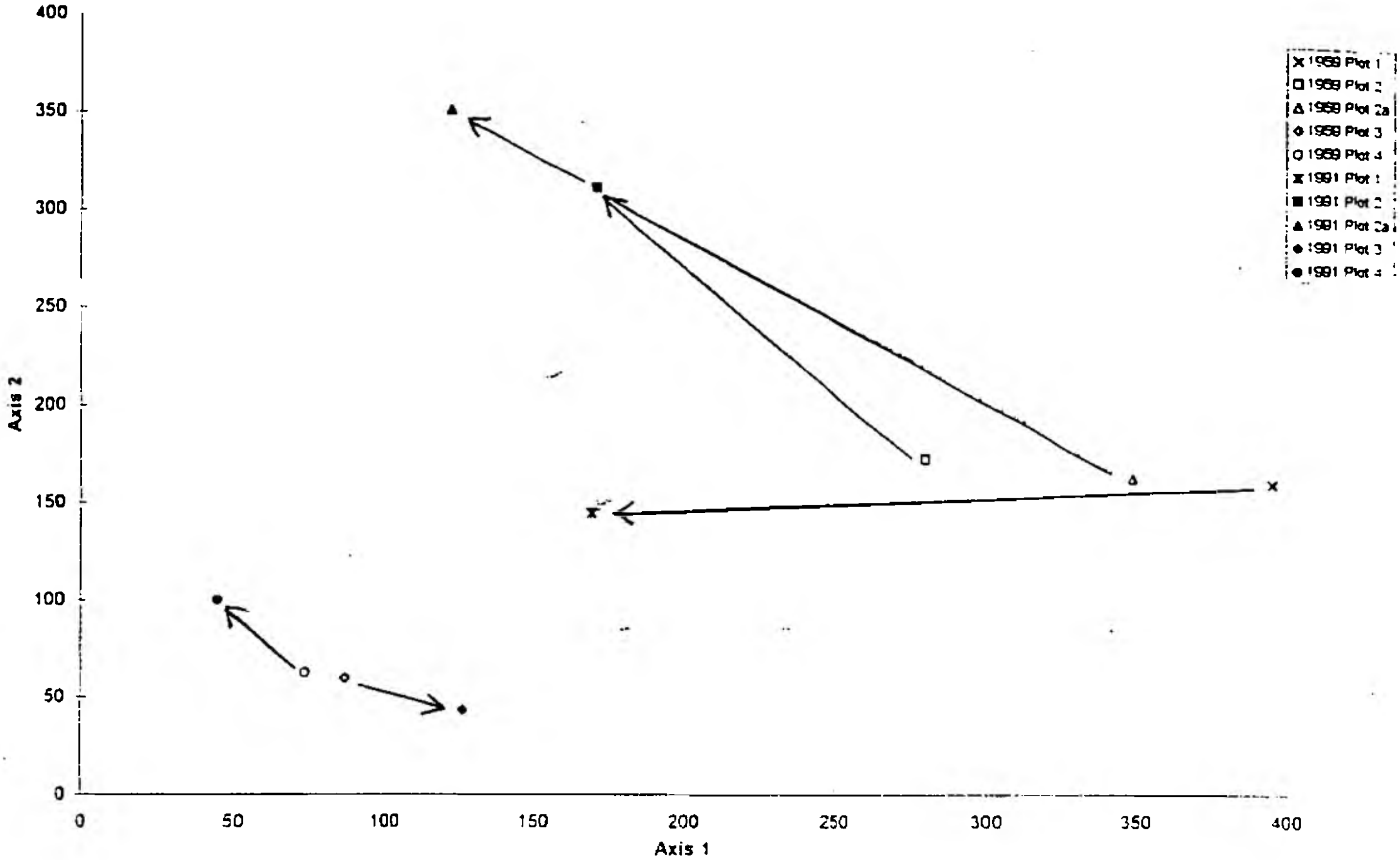
Figure 1C. Axis 1 vs. Axis 3

Data have been taken from Bellamy & Rose (1961) and Fojt & Harding (1995).

Arrows indicate the direction of change.

Figure 1A

Decorana ordination (axes 1 and 2) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Full species data set.



Decorana ordination (axes 1 and 2) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Monitoring species data set.

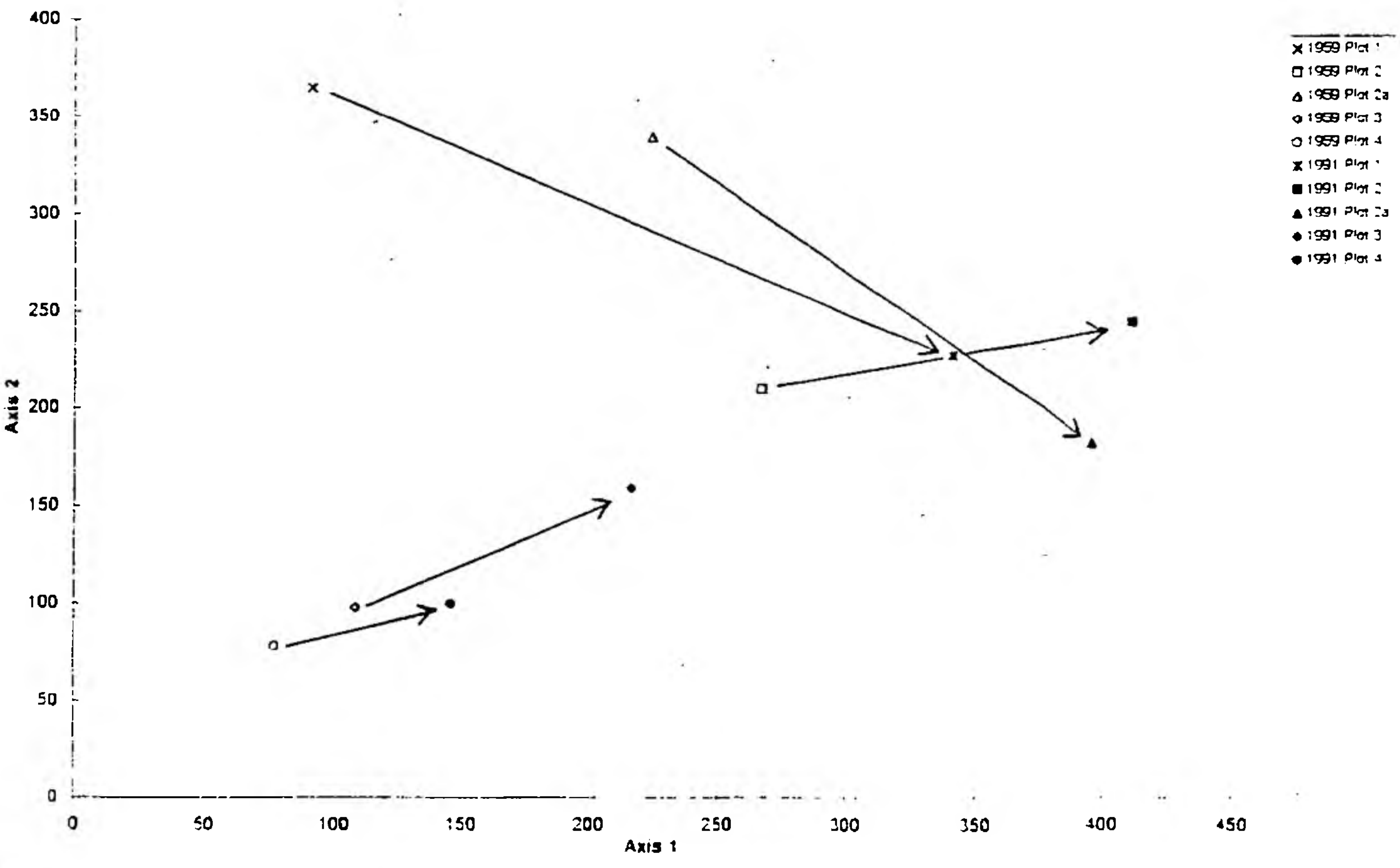
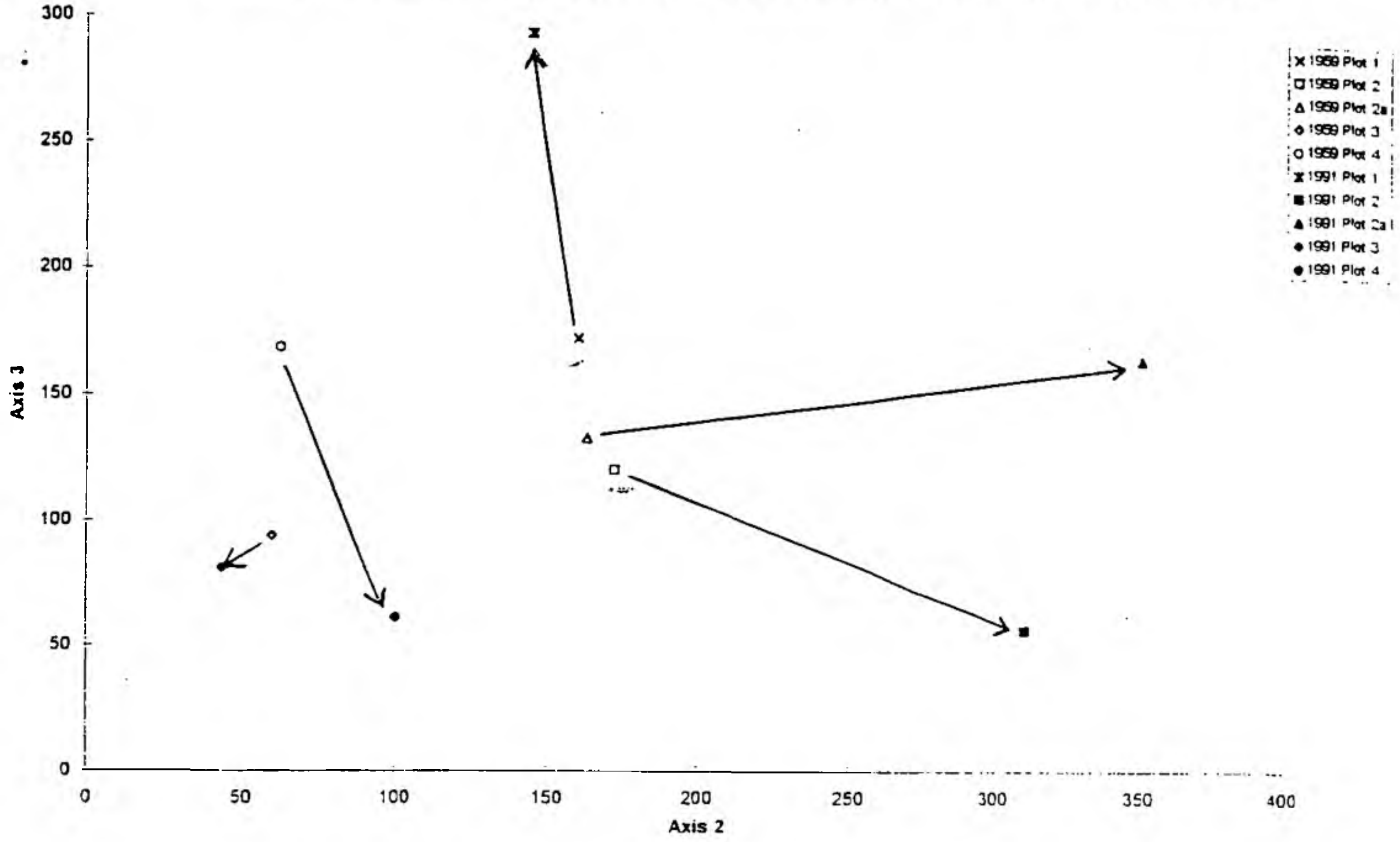


Figure 1B

Decorana ordination (axes 2 and 3) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Full species data set.



Decorana ordination (axes 2 and 3) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Monitoring species data set.

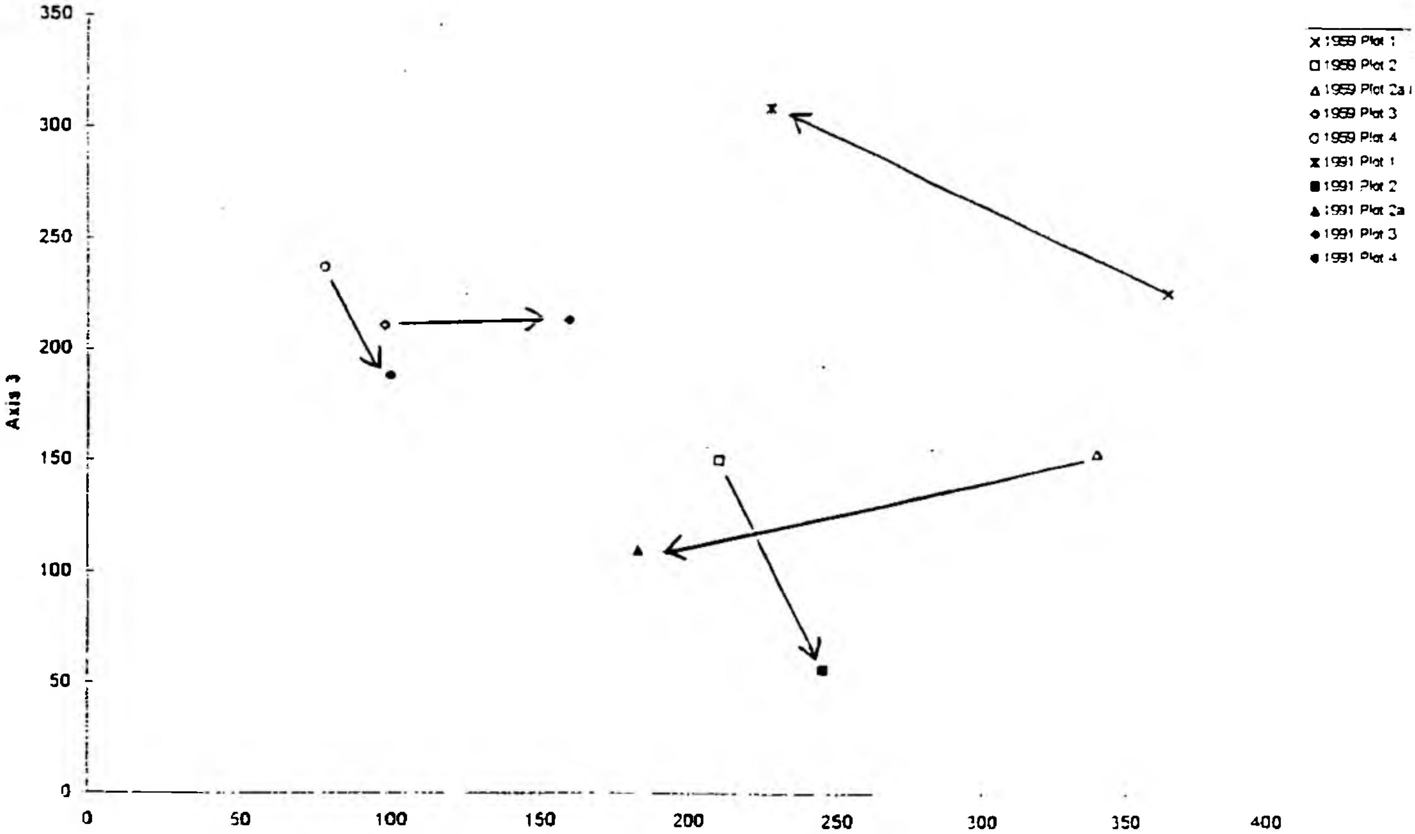
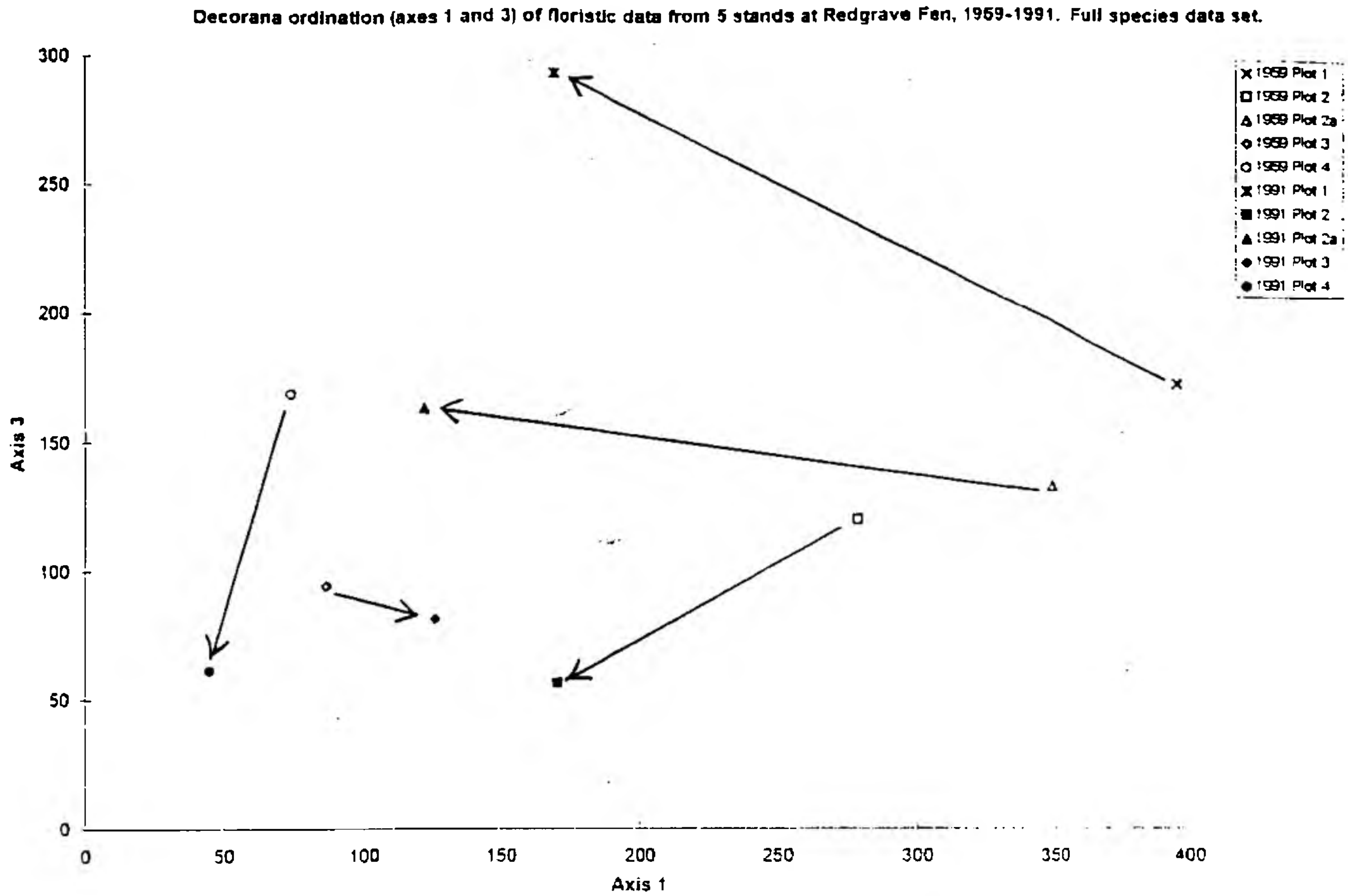


Figure 1C


Decorana ordination (axes 1 and 3) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Full species data set.
Axis 3
Axis 1
0
50
100
150
200
250
300
350
400
1959 Plot 1
1959 Plot 2
1959 Plot 2a
1959 Plot 3
1959 Plot 4
1991 Plot 1
1991 Plot 2
1991 Plot 2a
1991 Plot 3
1991 Plot 4

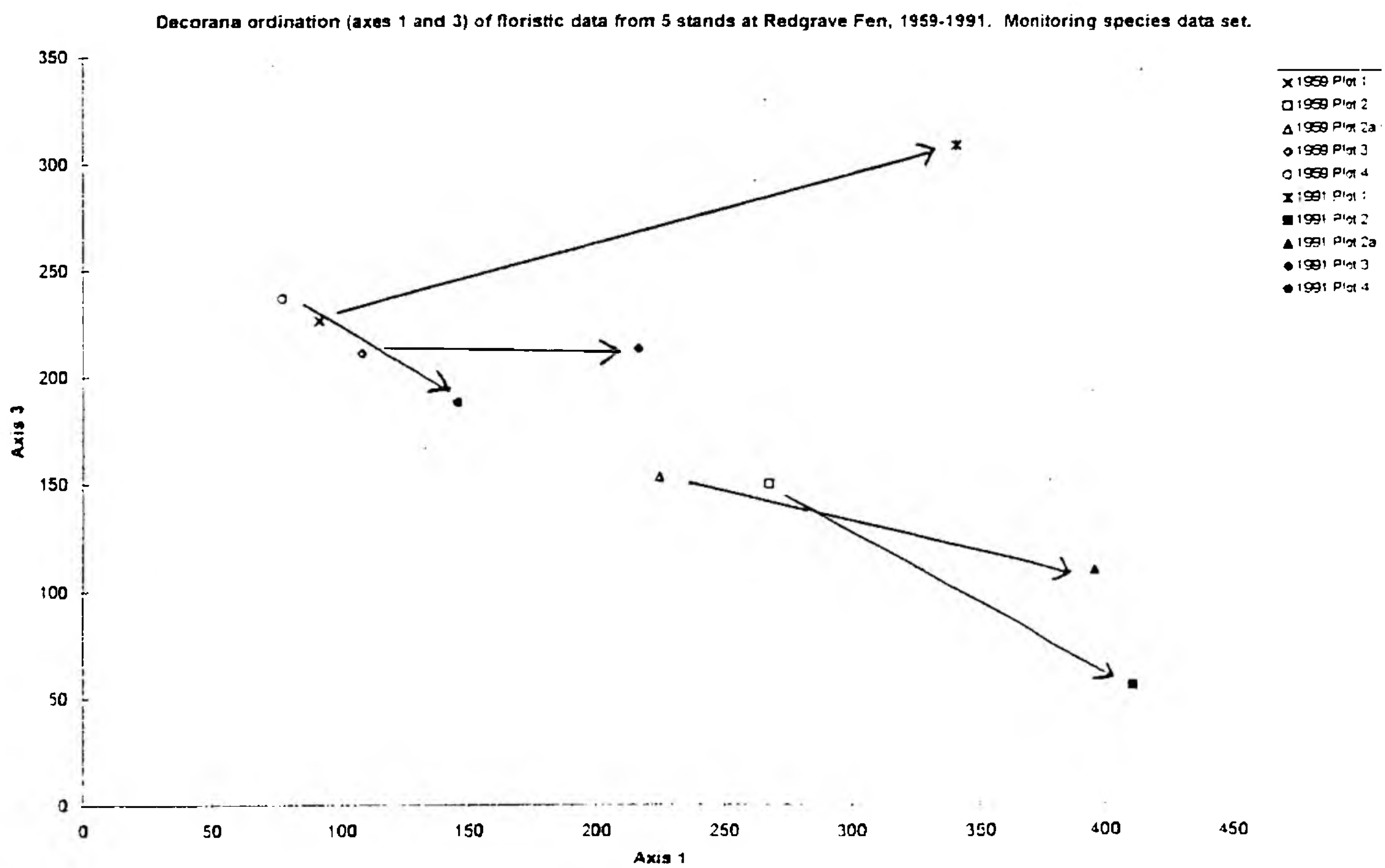

Decorana ordination (axes 1 and 3) of floristic data from 5 stands at Redgrave Fen, 1959-1991. Monitoring species data set.
Axis 3
Axis 1
0
50
100
150
200
250
300
350
400
450
1959 Plot 1
1959 Plot 2
1959 Plot 2a
1959 Plot 3
1959 Plot 4
1991 Plot 1
1991 Plot 2
1991 Plot 2a
1991 Plot 3
1991 Plot 4

Figure 2. Ordination diagram of floristic data from Redgrave, Market Weston and Thelnetham Fens (from Fojt & Harding, 1995).

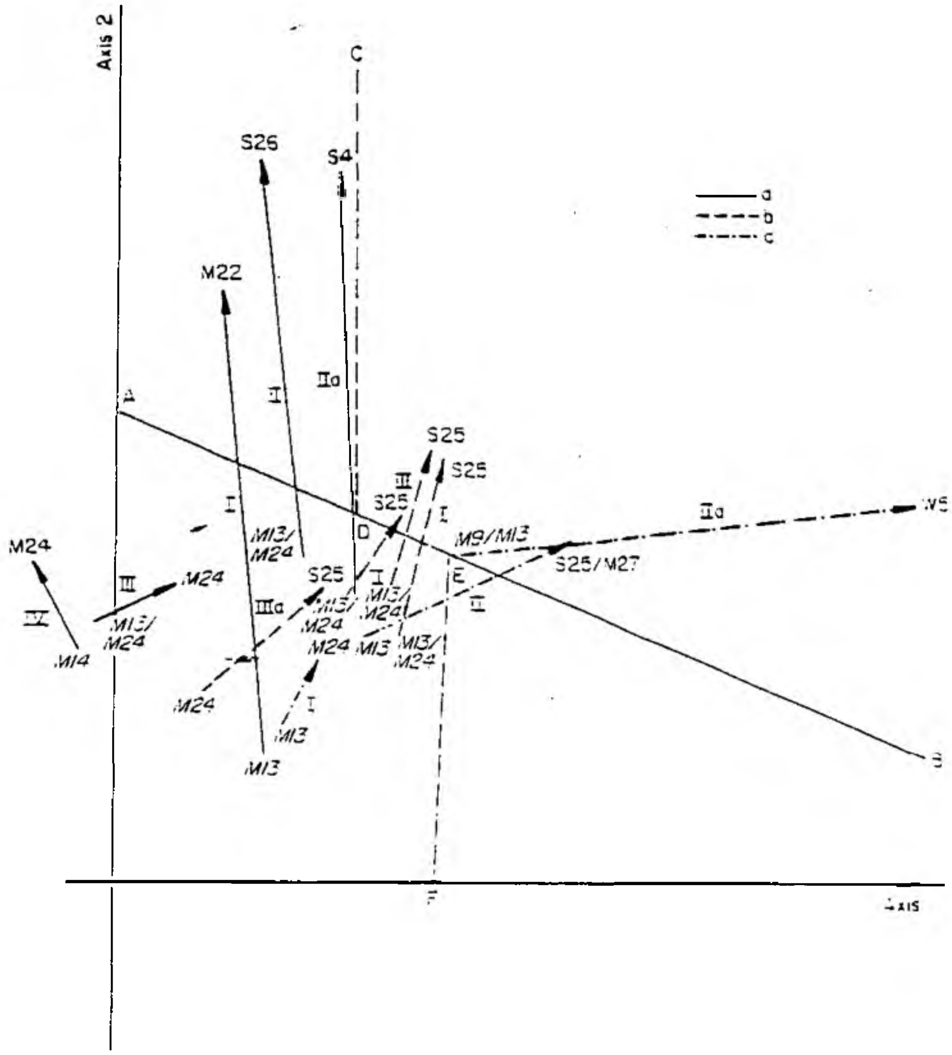


Fig. 3. Detailed ordination diagram, divided as in Fig. 2, showing vegetation changes (arrows) within study areas. Roman numerals at each fen. (a) Redgrave; (b) Market Weston; (c) Thelnetham. The plant communities are coded according to the British National Vegetation Classification as follows: M9. *Carex rostrata–Calliergon cuspidatum* mire; M13. *Schoenus nigricans–Juncus subnodulosus* mire; M14. *Schoenus nigricans–Narthecium ossifragum* mire; M22. *Juncus subnodulosus–Cirsium palustre* fen meadow; M24. *Molinia caerulea–Cirsium dissectum* fen meadow; M27. *Filipendula ulmaria-Angelica sylvestris* mire; S4. *Phragmites australis* swamp; S25. *Phragmites australis–Eupatorium cannabinum* fen; S26. *Phragmites australis–Urtica dioica* fen; W5. *Alnus glutinosa–Carex paniculata* woodland. The communities in 1959 are distinguished by italic codes.

3.3 *FenSPEC Analysis*

3.3.1 Introduction

FENSPEC (for details, see Section 4) analytical procedures were used to assess the consequences of reducing the number of species being monitored upon the interpretability of vegetation data (the rationale being that one important end-product of vegetation monitoring is to provide a means of assessing on-going environmental change as well as assessing species changes *per se*). The Redgrave data set also provides a valuable data source for validating the propensities of the FENSPEC approach.

For the purpose of the present analysis, FENSPEC was used to test the effectiveness of the full and monitoring species set in indicating four key features of change at Redgrave Fen: change in number of uncommon plant species, change in degree of dominance (dereliction), change in water tables and change in soil fertility.

Analyses were made separately using the 1959–1991 data set (cover data) and the 1959–1991–1997 data set (frequency data). Some analyses (*e.g.* change in the number of uncommon species) did not use any abundance estimates, but were based on presence / absence (binary) data.

3.3.2 Change in number of uncommon species

The 'Uncommon Species Index' is derived by weighting species present in samples by the reciprocal of the number of 10km OS grid squares in Eastern England from which they have been recorded (post-1940 records only). 'Eastern England' is used as defined in the EcoFlora database, and corresponds broadly with the Enviroment Agency's Eastern Region.

1959–1991 (binary) (Figure 3A & B)

All species:	Evidence for considerable species loss, especially in stands I and III
Monitoring spp:	Show the same pattern as all uncommon species

1959–1991–1997 (binary) (Figure 3C & D)

All species:	Evidence for considerable species loss between 1959 and 1991. Between 1991 and 1997, three stands show an increase in the number of uncommon species but two show further loss and, in the case of Stand IV, which had lost fewest species between 1959–1991, this further loss was substantial, so that overall between 1959 and 1997 this stand had lost more uncommon species than all but one of the other stands.
Monitoring spp:	Show the same pattern as all uncommon species, including losses and gains in the same stands between 1991 and 1997.

3.3.3 Change in index of vegetation dominance (dereliction)

The 'Index of Dominance' is derived from vegetation survey data (see Hodgson et al. 1999 for exact methodology). Dominants, which, when abundant, are major contributors to the biomass and which tend to competitively exclude other species have high values for the index (e.g. *Phragmites, Pteridium*). Such species are potentially a major threat to species of conservation importance and are favoured by dereliction and to some extent also by eutrophication.

1959–1991 (cover) (Figure 3E & F)

All species: All stands show an increase in species dominance (dereliction), though the effect is variable. The stands showing greatest dominance increase are not those which show greatest loss of uncommon species, suggesting that dereliction is probably not the primary cause of this species loss.

Monitoring spp: Show the same pattern of dominance increase as when all species are considered, with the stands ranked in the same order of dominance increase.

1959–1991–1997 (frequency) (Figure 3G & H)

All species: Four stands show a small increase in dominance between 1959 and 1991, but one shows a small decrease; pattern of dominance increase is not the same as that observed using cover data. Evidence for a *decrease* in dominance in all stands between 1991 and 1997, presumably reflecting vegetation management activities.

Monitoring spp: Show broadly the same pattern as all species, but with an increase in dominance in all stands between 1959 and 1991.

It is clear that the cover-based and frequency-based analyses generate different interpretations with respect to dominance, probably because species with large frequencies do not always also have high dominance. It would be interesting to know if the apparent reduction of dominance observed in the frequency data between 1991 and 1997 would also have been found in cover-based analyses.

3.3.4 Change in indicated water level

The 'Water Level Index' is derived from the water levels associated with each species in fens in eastern England (from FENBASE database), weighted by the estimate of abundance of the species (cover or frequency).

1959–1991 (cover) (Figure 3E & F)

All species: Indicate a reduction of water level in all stands, the effect being greatest close to the upland margin. Stands with greatest values of indicated water level decrease correspond to those showing greatest loss of uncommon species. The vegetation of stand IV, which has been subject to smallest loss of uncommon species, also indicates least reduction of water level.

Monitoring spp: Show the same pattern as do all species, but indicate a greater degree of water level reduction (probably because the species in the monitoring subset have less variable responses to the position of the water table than is the case for all species).

1959–1991–1997 (frequency) (Figure 3G & H)

All species: Indicate broadly the same pattern of water table reduction between 1959 and 1991 as above, but with a much smaller magnitude of change and some detail differences, (*e.g.* suggest that reduction was greatest in Stand II rather than Stand IIa, as is suggested by cover values). Data suggest an *increase* in water level between 1991 and 1997, the effect being greatest in the samples which had shown most water table lowering. Nonetheless, the data still indicate a considerable overall drop of water level between 1959 and 1997.

Monitoring spp: Broadly show the same pattern as do all species, with the same caveats applying.

The reason for the discrepancy between the 1959–1991 frequency- and cover-based analyses is not known, but probably relates to the different properties of the two measures. As visual inspection suggests that Stand IIa has been particularly damaged by drying, it seems likely that the frequency-based abundance estimates are not as satisfactory as those using cover. This conclusion may also call into the doubt the apparent increase in wetness indicated by the frequency estimates for 1991–1997.

3.3.5 Change in indicated soil fertility

The 'Soil Fertility Index' is derived from the soil fertilities associated with each species in fens in eastern England (from FENBASE database), weighted by the estimate of abundance of the species (cover or frequency). 'Soil fertility' has been assessed phytometrically, by growing a standard test species on soil samples in controlled conditions.

1959–1991 (cover) (Figure 3E & F)

All species: Indicate an increase in soil fertility in all stands, but especially in the stands where water table reduction is greatest. Greatest loss of uncommon species is not specifically associated with stands with greatest fertility increase.

Monitoring spp: Indicate the same pattern of fertility increase as do all the species, but with greater magnitude of effect (probably because the species in the monitoring subset have less variable responses to soil fertility than is the case for all species).

1959–1991–1997 (frequency) (Figure 3G & H)

All species: Also indicate the same pattern of fertility increase in all stands between 1959 and 1991, but with detail differences from the cover-based analysis. For example, the cover-based analysis suggest smallest fertility increase in Stand II, whereas frequency-based estimates suggest that fertility increase in this stand has been amongst the highest. Between 1991 and 1997 the data suggest a decrease in fertility in four stands, but a small further increase in Stand IIa.

Monitoring spp: Show more-or-less the same pattern as all species, but suggest a decrease in fertility in all stands between 1991 and 1997.

As with the water table analyses, there are discrepancies (in the details) between the cover-based and frequency-based analyses. Again, there is reason to suspect that the cover-based analyses are the more meaningful of the two. For example, Parmenter (1997) observed for Stand II that "This plot was situated in an area which seemed to have suffered less than others from the effects of desiccation and nutrient enrichment". This view is supported by the cover-based analyses (in which fertility increase and water level decrease in Stand II are amongst the smallest observed) but not by the frequency-based analyses.

3.3.6 Conclusions

Three sets of conclusions can be drawn from the FENSPEC analysis:

Value of using a reduced set of monitoring species

It is clear that use of the set of monitoring species in the FENSPEC analysis generated results that were almost identical to those based on the full species set, particularly in the cover-based analyses. The use of a reduced set of species is therefore acceptable from the point of view of the ecological interpretability of monitoring data. There is some evidence that the monitoring species set may lead to clearer ecological interpretation than the full set, probably because the monitoring species have been selected specifically for their indicator value.

Value of using cover* versus *frequency as an estimate of abundance

The data presented strongly suggests that species cover data (as proposed in the sampling protocol presented here) are considerably more useful in interpreting the ecological basis of vegetation change than are frequency data. The absence of cover data in the 1997 monitoring of Redgrave Fen significantly reduced the conclusions that could be made, as there was reason to suspect that the frequency estimates did not generate reliable ecological indicator values.

Value of the FENSPEC approach

The FENSPEC analysis was used in this study just as a tool to examine the consequences of using a reduced set of monitoring species in evaluating and interpreting monitoring data. However, the results of the analysis also indicate the potential value of the FENSPEC approach in the interpretation phase of monitoring programmes.

The FENSPEC procedures (for details, see below) provide a means of interpreting vegetational change in terms of likely environmental causes, and have been particularly developed for situations (such as Redgrave Fen) where there are time-series species data, but few (if any) associated environmental measurements. It is important to appreciate that, apart from those attributes which are directly measured properties of the species (*e.g.* number of uncommon species), the FENSPEC methodology is based on the predictive relationship between species assemblages and environmental conditions. As both traits and environmental conditions are often inter-correlated, individual species can sometimes indicate more than one environmental variable, which urges some caution of interpretation. Moreover, the *impact* of environmental change upon vegetation is not necessarily directly proportional to the *magnitude* of environmental change. It has therefore been instructive to examine how well FENSPEC can 'predict' the broad environmental changes that are known to have occurred at Redgrave Fen.

In summary, FENSPEC suggests that the following inferences can be drawn about events have occurred between 1959 and 1997 in that part of Redgrave Fen for which floristic data are available:

- substantial loss of uncommon species between 1959 and 1991, especially from the stands close to the upland margin that were particularly species rich in 1959, followed by a small increase between 1991 and 1997;
- substantial increase in species dominance (dereliction) between 1959 and 1991, but not specifically associated with the stands with greatest species loss, and therefore probably not the primary cause of this;
- substantial reduction of water table between 1959 and 1991, with possible suggestions of an increase in water table between 1991 and 1997;

- substantial increase in soil fertility between 1959 and 1991, particularly in some stands most subject to a reduction of water table; this localisation suggests that the fertility increase may be primarily a consequence of drought-induced mineralisation, rather than a more general problem of nutrient enrichment from agricultural sources.

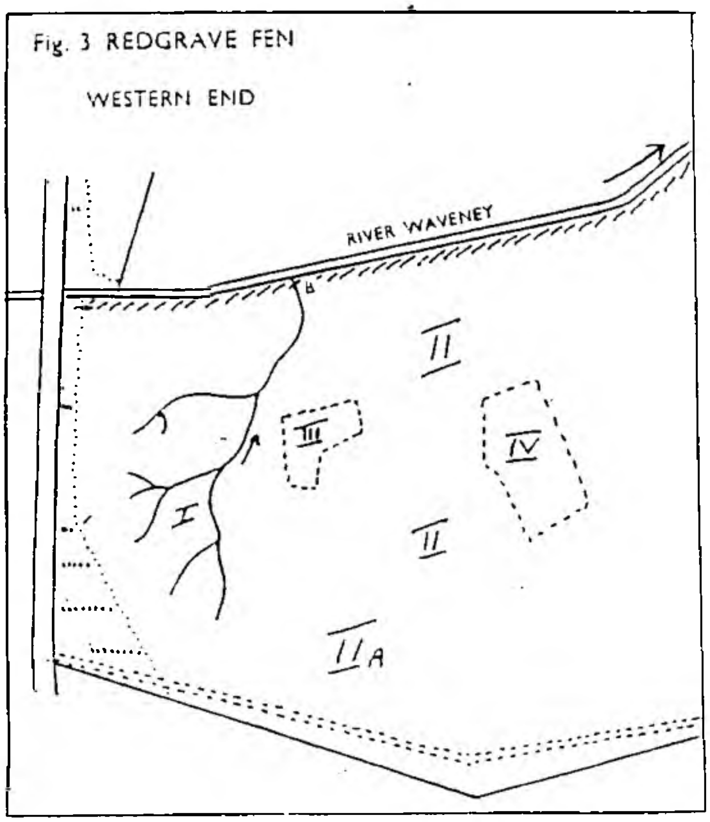
These inferences correspond closely to known environmental and management events at Redgrave Fen, suggesting that the FENSPEC protocols have considerable applicability for assessing the likely causes of vegetation change, and predicting the consequences of environmental change, in other fen sites.

Figure 3.

FENSPEC analysis of Redgrave species data from 1959, 1991 and 1997.

See text for details

The figures are based on the schematic diagram of the western end of Redgrave Fen shown below, taken from Bellamy & Rose (1961).



A visual impression of the broad relative degree of change in each index between the two dates compared is indicated by shading as follows:

low

moderate

high

(Note that the area shaded does not correspond to the stand area.)

Figure 3A. FENSPEC analysis of Redgrave species data: binary data, all species (1959, 1991).

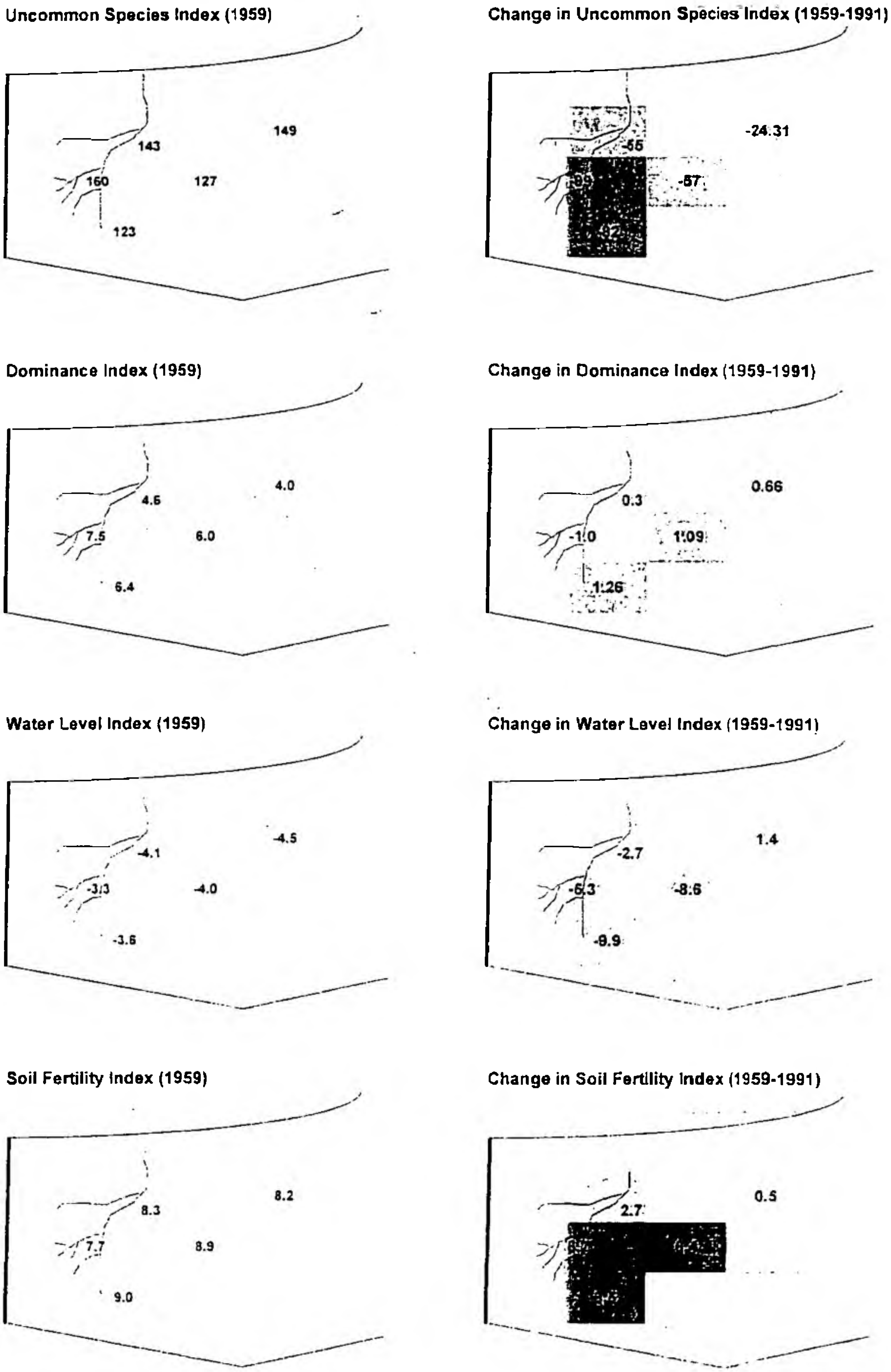


Figure 3B. FENSPEC analysis of Redgrave species data: binary data, monitoring species (1959, 1991)

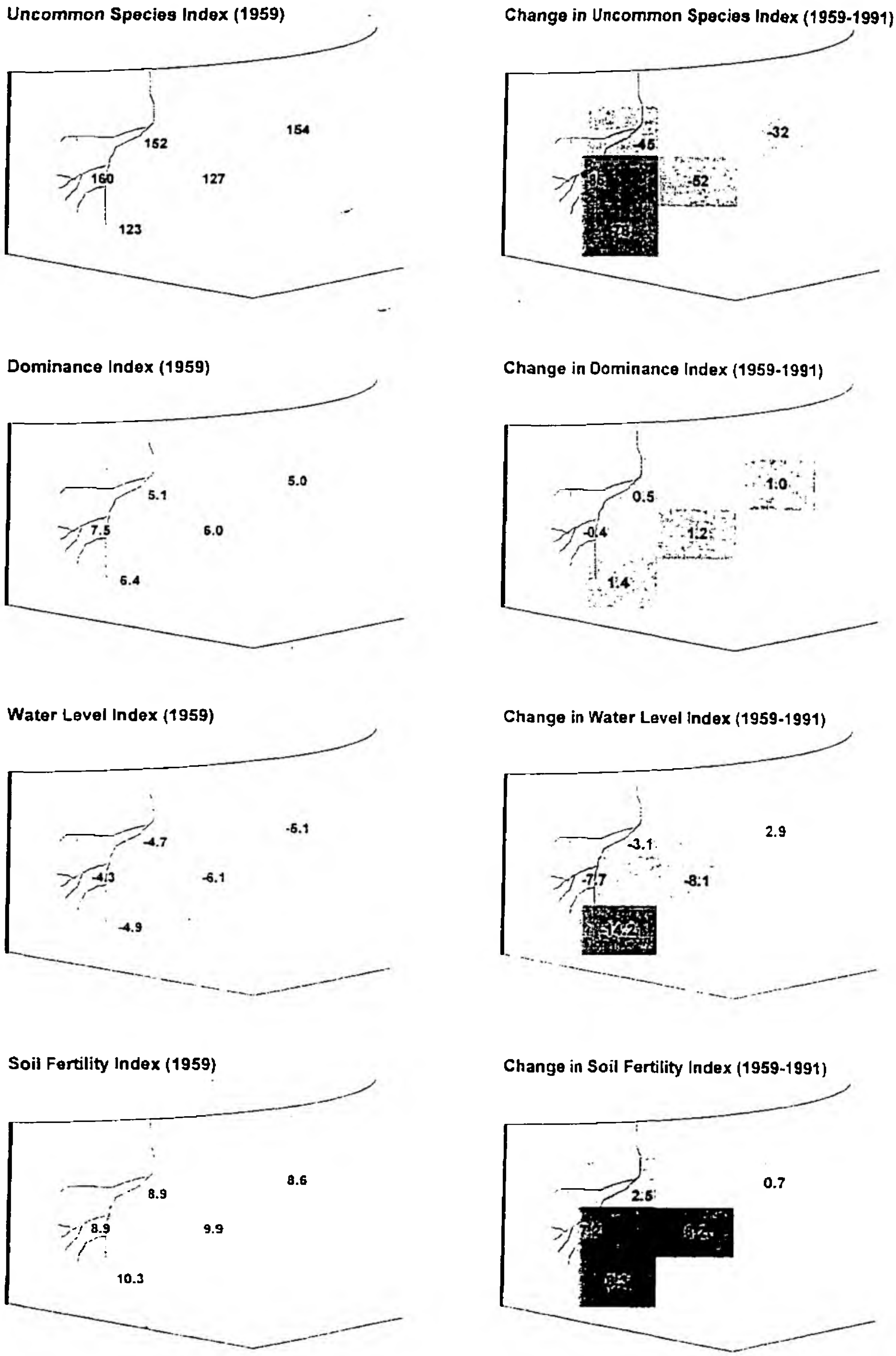
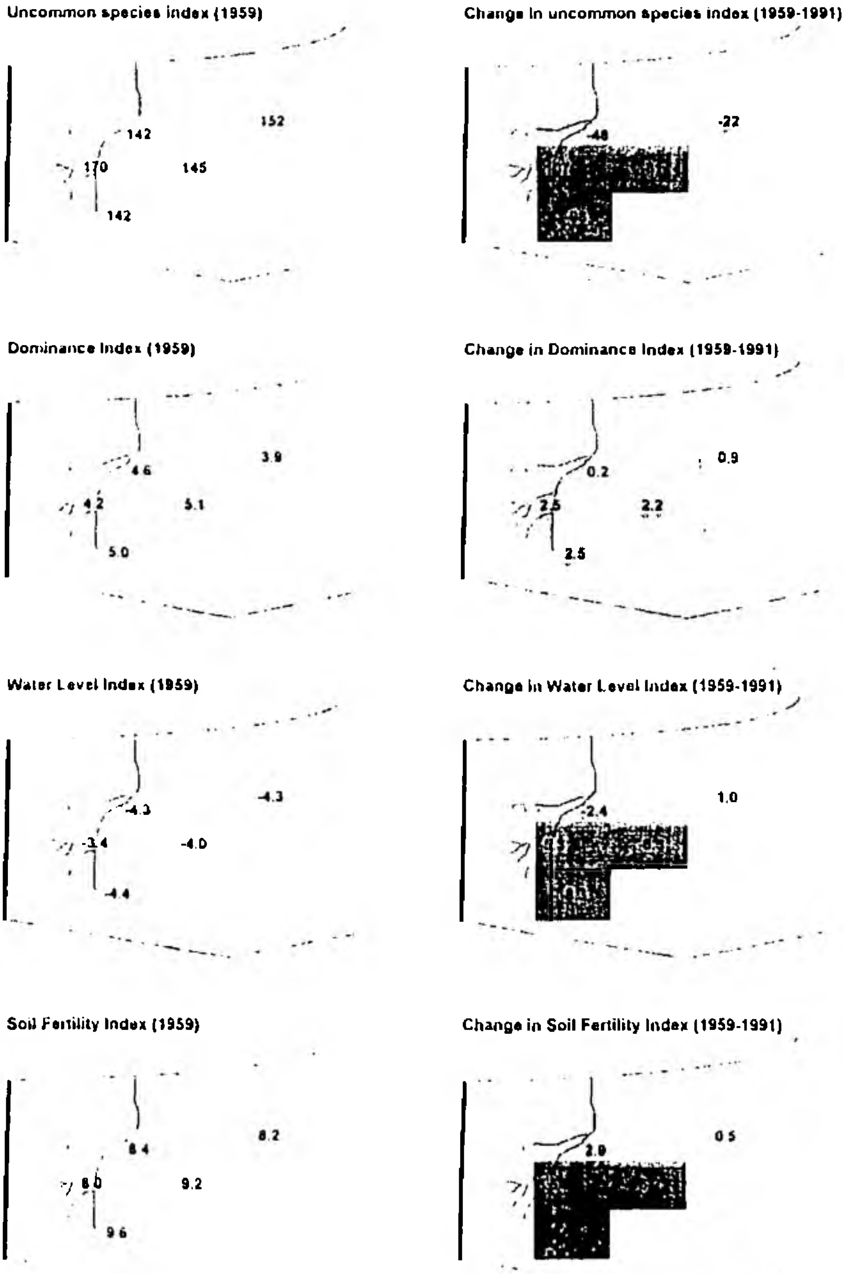
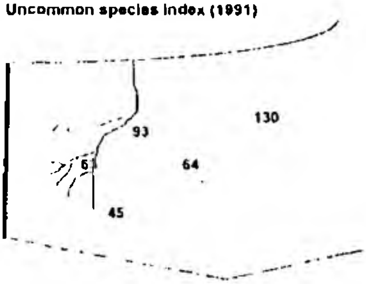


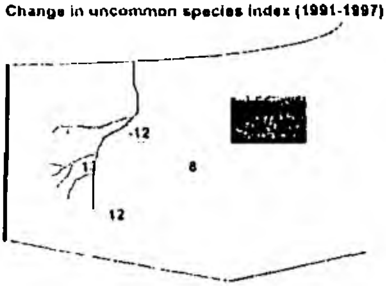
Figure 3C. FENSPEC analysis of Redgrave species data: binary data, all species (1959, 1991, 1997)



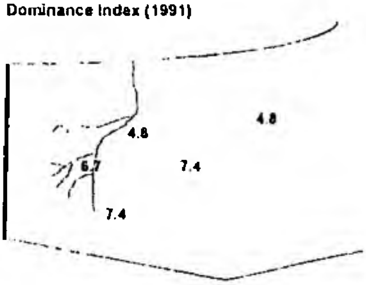
Uncommon species index (1991)



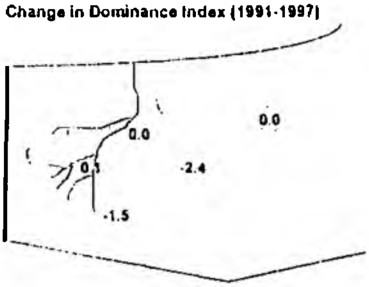
Change in uncommon species index (1991-1997)



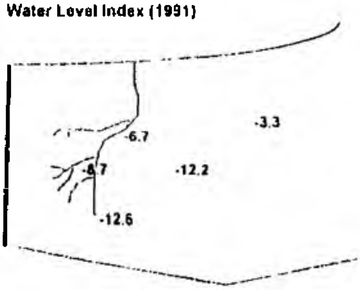
Dominance index (1991)



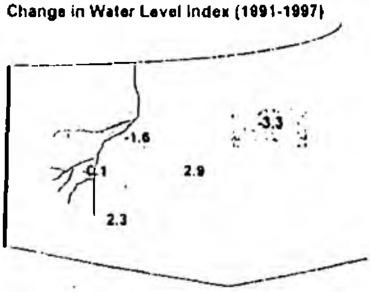
Change in Dominance index (1991-1997)



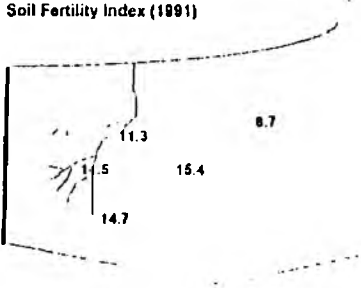
Water Level index (1991)



Change in Water Level index (1991-1997)



Soil Fertility index (1991)



Change in Soil Fertility index (1991-1997)

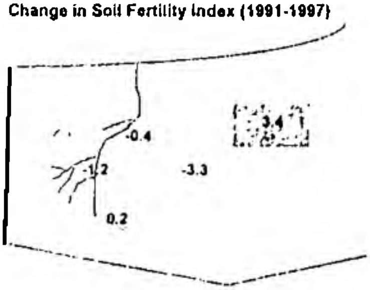
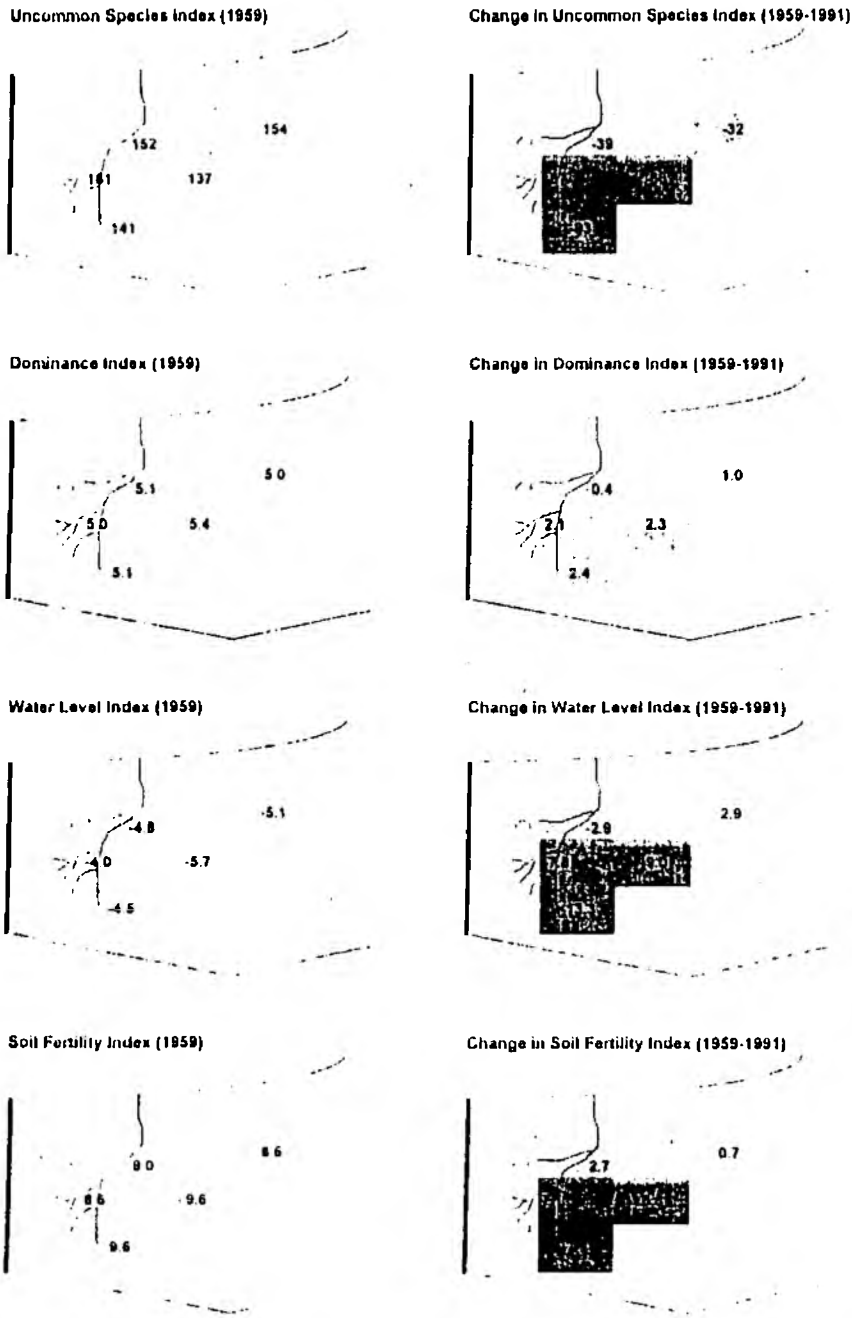
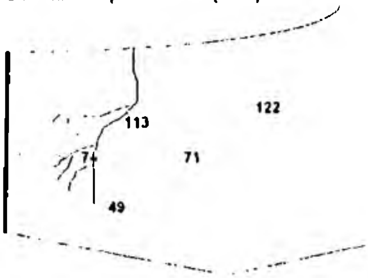


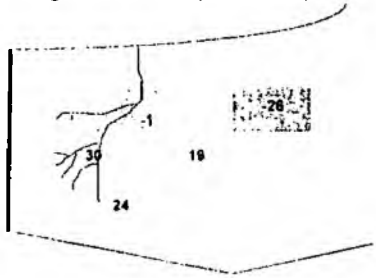
Figure 3D FENSPEC analysis of Redgrave species data: binary data, monitoring species (1959, 1991, 1997)



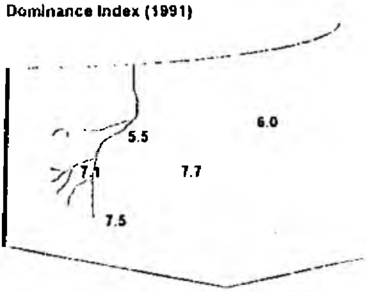
Uncommon Species Index (1991)



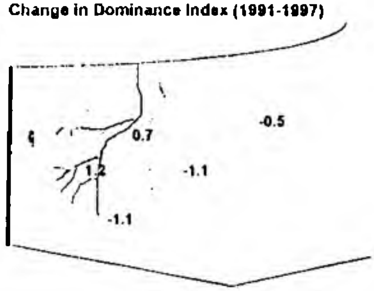
Change in Uncommon Species Index (1991-1997)



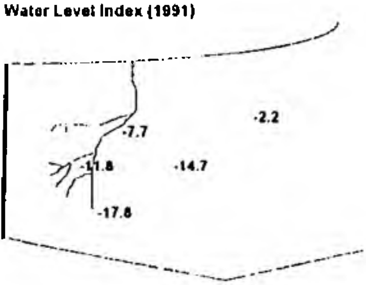
Dominance Index (1991)



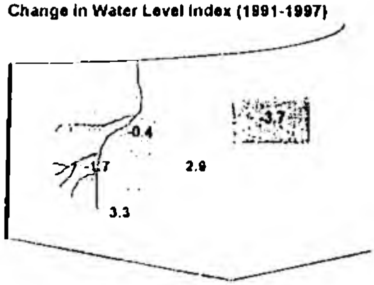
Change in Dominance Index (1991-1997)



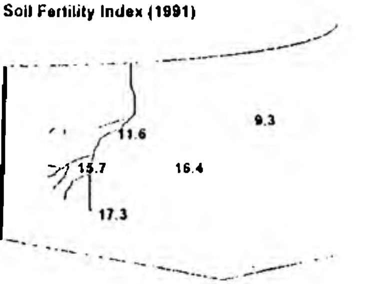
Water Level Index (1991)



Change in Water Level Index (1991-1997)



Soil Fertility Index (1991)



Change in Soil Fertility Index (1991-1997)

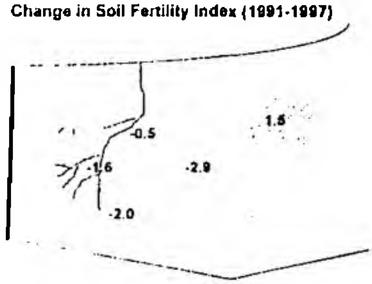
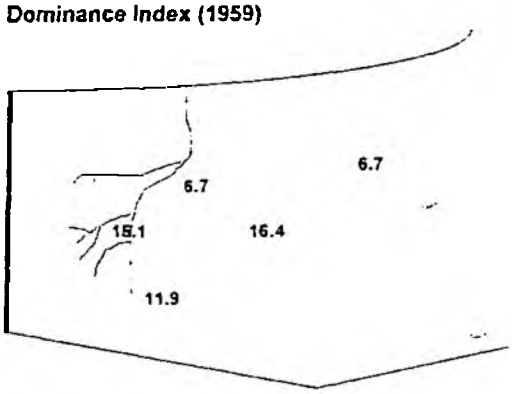
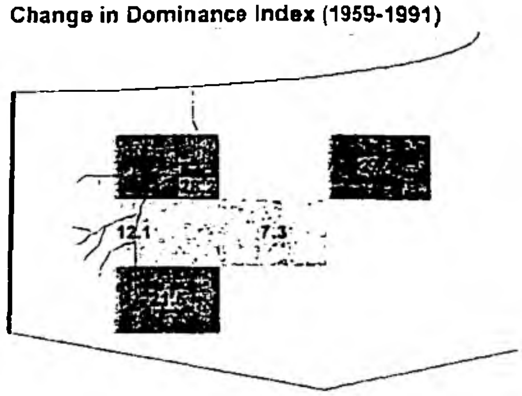


Figure 3E. FENSPEC analysis of Redgrave species data: cover data, all species (1959, 1991).

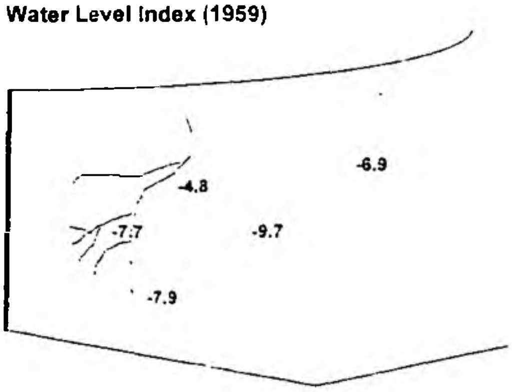
Dominance Index (1959)



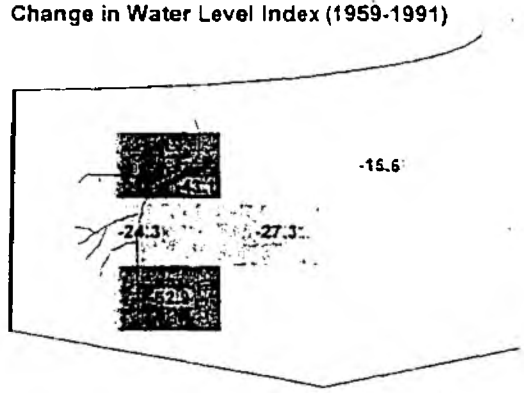
Change in Dominance Index (1959-1991)



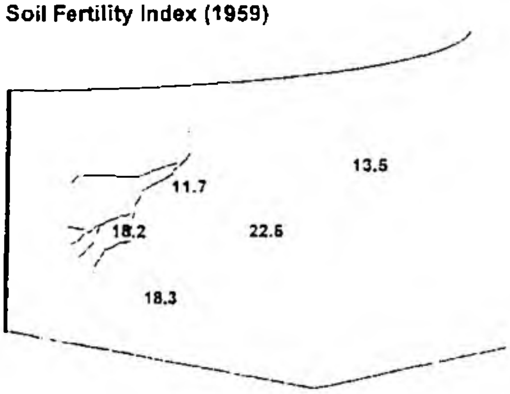
Water Level Index (1959)



Change in Water Level Index (1959-1991)



Soil Fertility Index (1959)



Change in Soil Fertility Index (1959-1991)

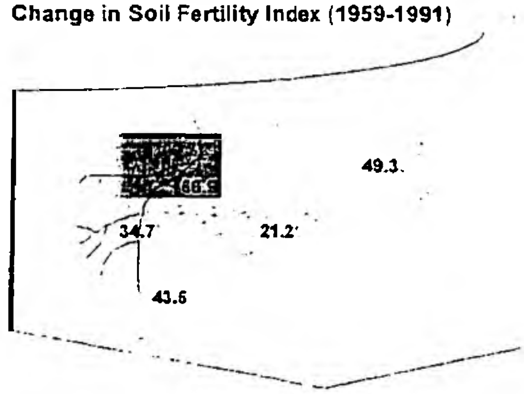
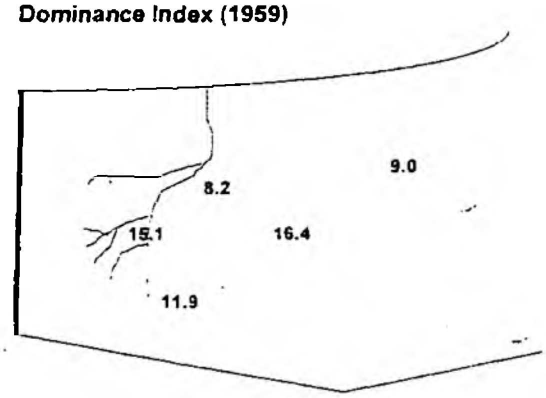
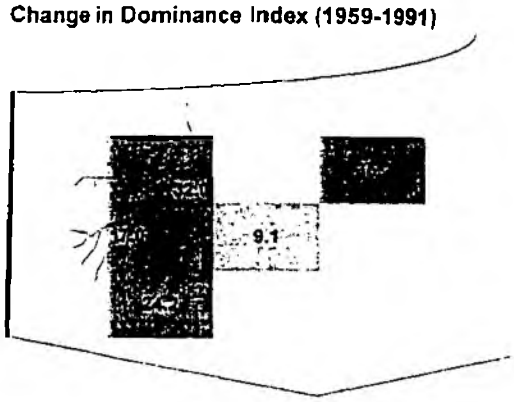


Figure 3F. FENSPEC analysis of Redgrave species data: cover data, monitoring species (1959, 1991)

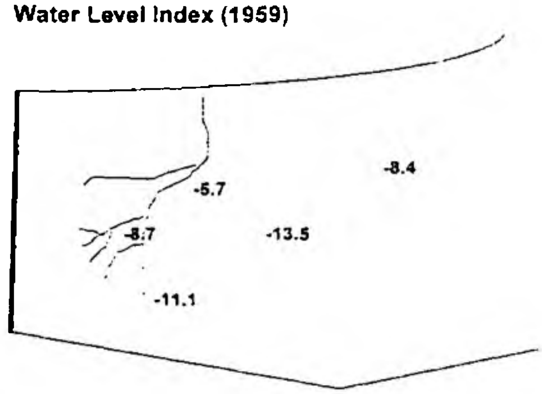
Dominance Index (1959)



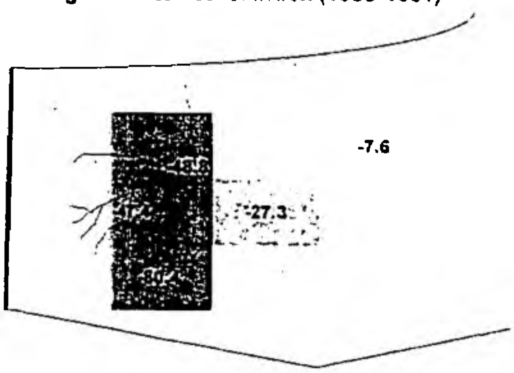
Change in Dominance Index (1959-1991)



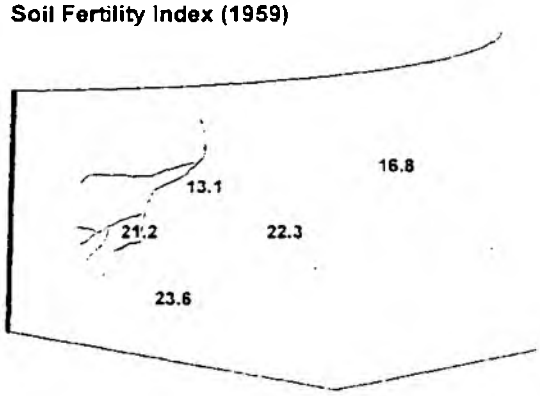
Water Level Index (1959)



Change in Water Level Index (1959-1991)



Soil Fertility Index (1959)



Change in Soil Fertility Index (1959-1991)

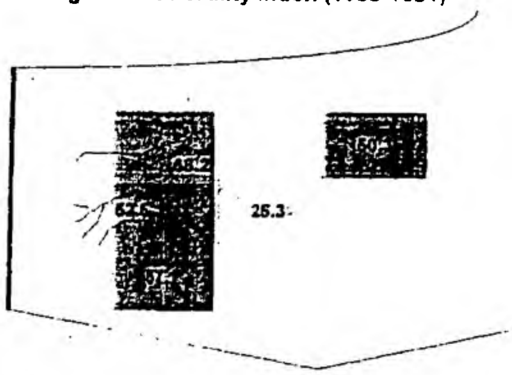
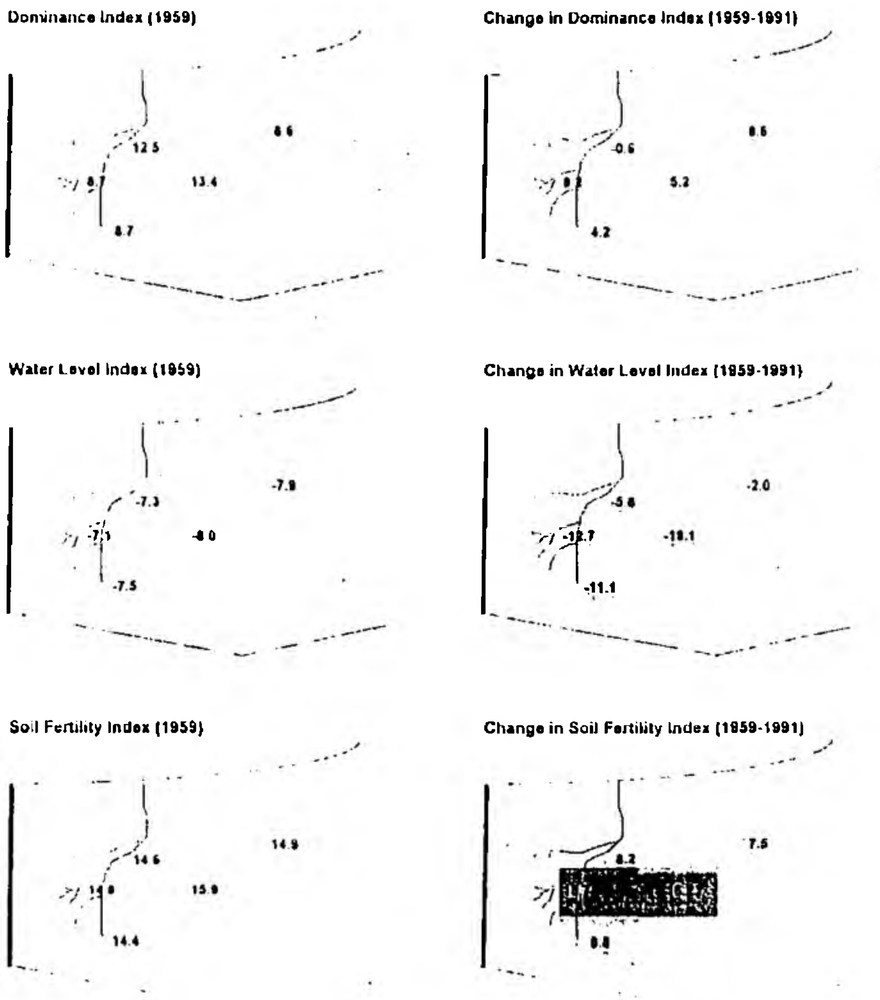
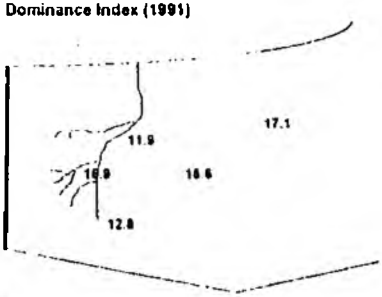


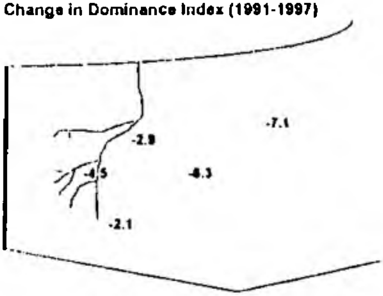
Figure 3G. FENSPEC analysis of Redgrave species data: frequency data, all species (1959, 1991, 1997)



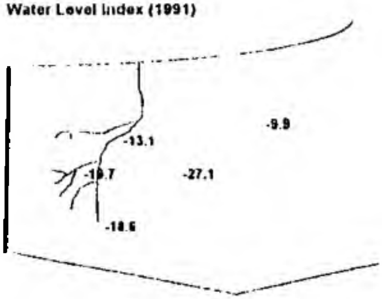
Dominance Index (1991)



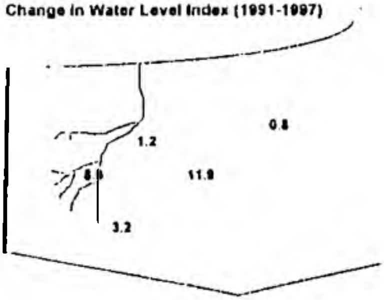
Change in Dominance Index (1991-1997)



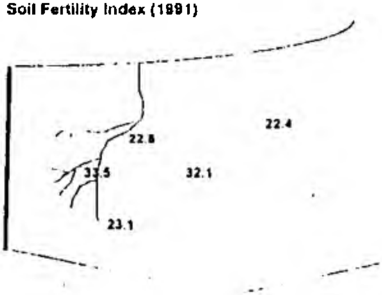
Water Level Index (1991)



Change in Water Level Index (1991-1997)



Soil Fertility Index (1991)



Change in Soil Fertility Index (1991-1997)

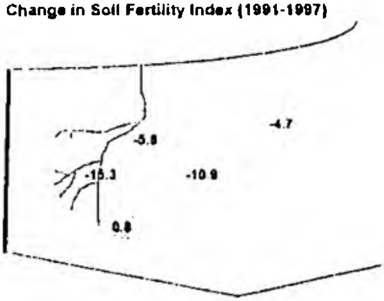
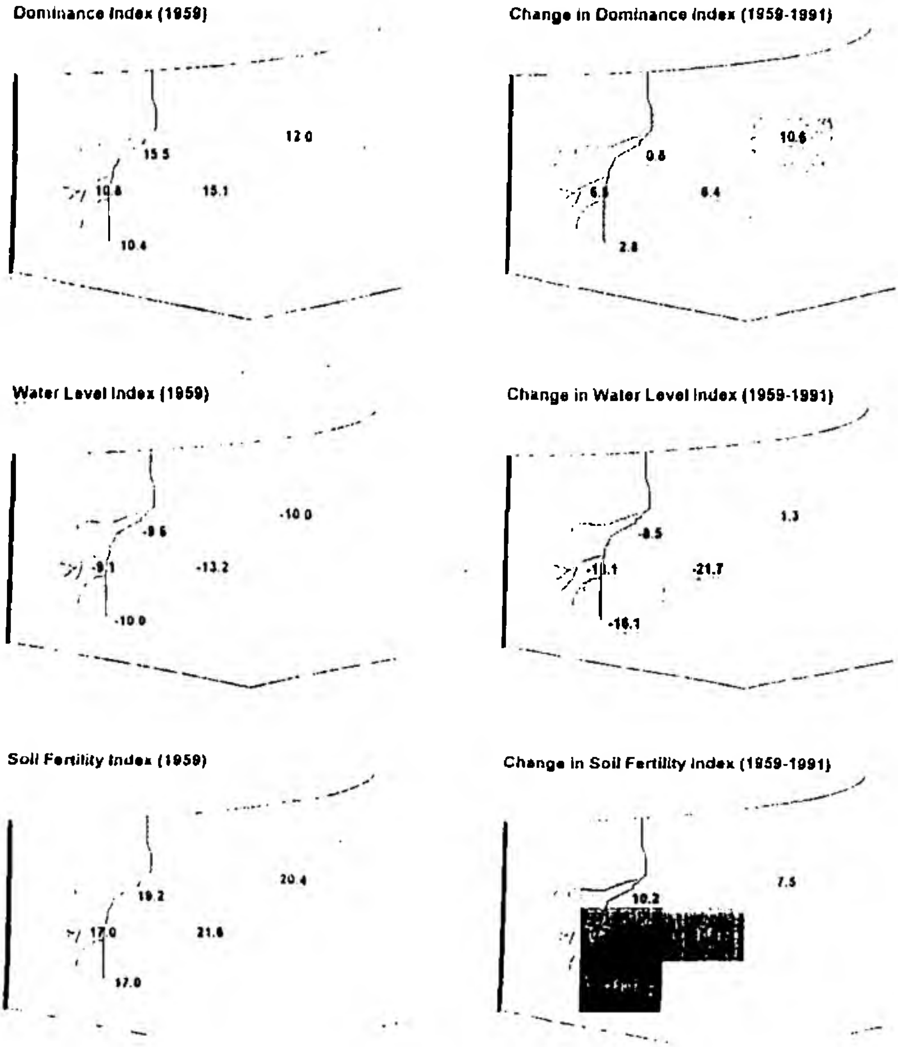
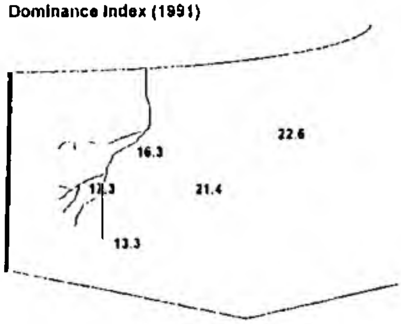


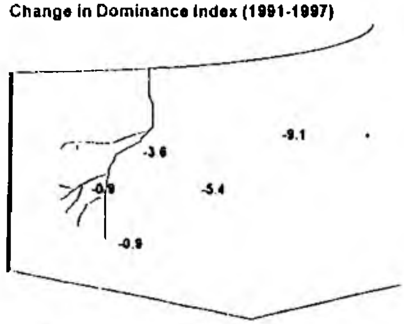
Figure 3H. FENSPEC analysis of Redgrave species data: frequency data, monitoring species (1959, 1991, 1997)



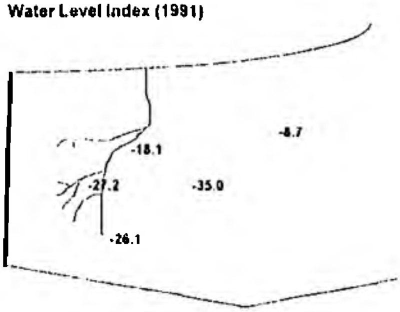
Dominance Index (1991)



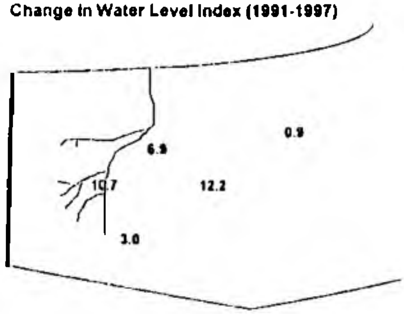
Change in Dominance Index (1991-1997)



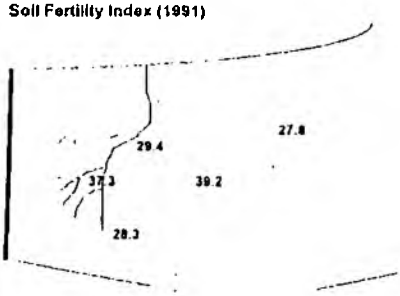
Water Level Index (1991)



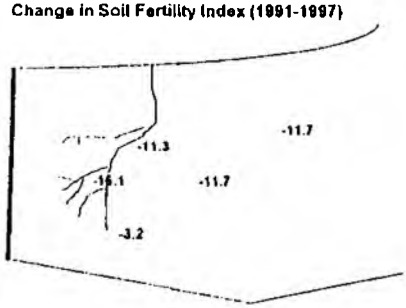
Change in Water Level Index (1991-1997)



Soil Fertility Index (1991)



Change in Soil Fertility Index (1991-1997)



4. FENSPEC (*Fen Species Prediction of Environmental Conditions*)

FENSPEC is a trait-based data processing procedure that forms part of the FENBASE database developed by B.D. Wheeler and held at the University of Sheffield. It is based on the measured environmental conditions associated with individual species (derived from FENBASE) together with measured 'functional' biological traits of species, derived from the FIBS database of the Unit of Comparative Plant Ecology (UCPE) (University of Sheffield). The principal use of the procedure is to predict the environmental conditions associated with particular species assemblages and to identify likely causes of changes in vegetation composition with time. It is essentially a development of the FIBS methodology developed by UCPE, expanded and refined with specific regard to the species of wetlands and to utilise the environmental data available within FENBASE.

Scope of FENSPEC

Various 'models' have been developed, especially in the Netherlands, to help predict environmental conditions in vegetation from species composition (e.g. the MOVE model; Latour *et al.*, 1993). FENSPEC has a broadly similar objective, but offers the following advantages over some, or all, other known approaches:

1. developed specifically for wetland species and habitats
2. based on large (UK-wide) environmental data set for wetland plant species
3. species ranges and 'preferences' can be analysed for specific regions of the UK
4. represents a unique combination of species environmental and trait data
5. based on measured environmental and trait values, not on 'expert assessment' (guesses)
6. based on continuous variables and thus permits more sensitive and accurate analyses to be made than is possible with 10 or 12 point scales (*e.g.* Ellenberg numbers)
7. can take account of the response curves of individual species to environmental conditions (*i.e.* is not just based on a single value for each species).

Development of FENSPEC

It is important to recognise that the development of FENSPEC has not been as a specific component of, or output from, the current project. Rather the procedure has been developed, in the context of this project, to provide a tool for assessing the effect of omitting species from monitoring on the interpretation of the results of the monitoring.

Nonetheless, as in many monitoring initiatives it is desirable to interpret the observed species changes in terms of changing environmental conditions, as has been illustrated above, it is likely that the FENSPEC approach has considerable application potential. However, further development of the protocols is required before such application can be made with full rigour. This is partly because there are some clear difficulties in using species to predict environmental conditions with precision, due mainly to the considerable variability in response of many species. One cause of such variability is the effect of interaction between different environmental conditions (for example, the summer water-level range tolerated by individual wetland plant species can be modified considerably by other environmental variables such as water flow, soil concentrations of Fe and Mn and nutrient availability, as well as by inter-specific interactions (Wheeler, 1999)). Further development of FenSPEC is needed *inter alia* to take account of such interactions.

In its present state FENSPEC is particularly well suited to identifying the causes of species change amongst successive data sets (the purpose for which it has been used in the current study) rather than predicting the environmental conditions associated with a species assemblage at one point in time. For this latter purpose, whilst FENSPEC is probably no worse than other 'models' currently in use – and appears to be better than many – further development is undoubtedly required to enhance its predictive accuracy.

5. References

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