PART B

THE VULNERABILITY OF PLANT SPECIES TO DEHYDRATION

INTRODUCTION

East Anglia has a larger concentration of fen ecosystems than any other part of lowland England of comparable area. Many of the sites are of great biological value and have been designated as Sites of Special Scientific Interest. Some of the sites, such as most of those in the Norfolk Broadland, are flood-plain mires, where proximity to sluggish rivers helps to maintain a high water table, year-round. Most of the others are sites which are thought to depend strongly upon water supply from the adjoining mineral ground, from deep-seated artesian sources or from more superficial seepages, overland flow and ditch drainage. Those sites which strongly depend on groundwater irrigation to maintain high water levels are (for convenience) here grouped under the broad heading of "valley fens", though they include spring fens, ground-water fed basin fens as well as valley fens *sensu stricto* (Wheeler, 1984) - i.e. they are those sites whose water level may be readily influenced by operations which help reduce the supply or retention of water, namely water abstraction and drainage.

Whereas abstraction of water from bore-holes in East Anglia is well known, its actual effects upon the valley fen ecosystems is not, though direct effects have been demonstrated for some sites. It is possible that the vegetation of a large number of valley fen sites in East Anglia may be being adversely effected by water abstraction, though, apart from anecdotal observations that some fen sites seem to be getting drier and that their vegetation is declining in quality, there is rather little direct information. This is because water levels of most sites has not been systematically monitored over a long period of time; because changes in the vegetation of the sites has not been systematically documented; and because other variables, such as soil fertility or vegetation dereliction may also have an important influence upon vegetation composition (Shaw & Wheeler, 1991), making it difficult to isolate the effects of a reduction in water supply.

There is clearly an urgent need to examine the condition of East Anglian fens; to determine whether there is evidence of vegetation deterioration, and to pin-point its cause; and to assess the vulnerability of individual species and sites to the threat, or reality, of dehydration.

This project forms the first phase of such a study. It is a desk-excercise which aims: to marshal existing information concerning the vegetation and 'condition' of the valley-fen sites; to assess past changes; to provide a base-line against which future changes can be assessed; and to characterise the vulnerability of species, communities and sites to desiccation.

In this preliminary report we present:

PART 1: an evaluation of the vulnerability of selected fen plant species and community-types to dehydration and an exploration of the potential use of some of them as biological indicators of dehydration.

[Much of this information is based upon a re-working of field data obtained by Wheeler & Shaw (1987) and Shaw & Wheeler (1990), with specific reference to the problems of habitat loss in East Anglian valley fens.]

PART 2: the potential use of plant species for monitoring water level conditions in East Anglian fens

Scope of the study

Mire-types

Essentially, the scope of the study was to encompass sites where direct supply of ground water is thought to be critical to maintaining the water table. This thus excludes the main flood-plain mire complexes of Broadland, but includes most other spring fens, valley fens (*sensu stricto*) and basin fens. For convenience, and to some extent following local practise, all of these systems are grouped under the generic title of "valley fens".

Vegetation-types

As defined above "valley fens" in East Anglia largely include rich-fen sites, but also a small, but select, group of poor-fens.

The East Anglian rich-fen "valley fens" are particularly important for a series of vegetation-types. These include:

Schoeno-Juncetum subnodulosi
Acrocladio-Caricetum diandrae
Rich-fen meadows

Of these the *Schoeno-Juncetum* stands are of especial importance, as they are nationally rare, support a range of nationally rare species and appear to be far better represented in East Anglia than elsewhere in Britain, or indeed, on the near-Continent. The loss, or degradation, of these community-types from the East Anglian fens would undoubtedly be a very major loss to conservation.

Geographical coverage

The area to be included in this survey was a relatively discrete area comprising most of East Anglia except for Essex. Counties to be included are those which contain (or contained) the bulk of the valley fens and which comprise a fairly discrete region. Using the Watsonian system of vice-counties[1] these are: v/c 25 East Suffolk; v/c 26 West Suffolk; v/c 27 East Norfolk; v/c 28 West Norfolk; v/c 29 Cambridge

1 Watsonian vice counties are used in this study as they form the organisational basis for most past recording of plant species.

PART I THE VULNERABILITY OF PLANT SPECIES TO DEHYDRATION OF VALLEY-FEN ECOSYSTEMS

Water table conditions in East Anglian fens and plant communities

Perhaps the most notable attribute of the wetland environment is that it is, to varying degrees, wet. Table 1 ranks the main degrees of water-table depth that have been recognised (Wheeler & Shaw, 1987; Shaw & Wheeler, 1990). The summer water-table conditions measured in Eastern England[2] valley fens can be compared with those from fen sites elsewhere in Britain (Table 2).

It is clear that although the maximum and minimum water tables measured in East Anglian valley fens were not more extreme than in sites elsewhere in lowland Britain, the mean summer water table recorded was about 5.5 cm below that of these latter sites.

Similarly, there was a tendency for the mean water tables associated with specific community-types to be somewhat lower in Eastern England valley fens compared to those elsewhere. This was particularly marked in the community-type that is perhaps most characteristic of, and important in, the East Anglian valley fens *(Schoeno-Juncetum)*, which had, on average, a water table some 6cm below that measured elsewhere. Thus particular attention attaches to the sensitivity of the characteristic species of this vegetation-type to a lowering of water tables.

Different fen plant community-types (Table 3) clearly occupy rather different ranges of water-table conditions. Dehydration of fen ecosystems may therefore be expected to lead to a changing character of the vegetation and, particularly to a loss of those communities, and component species that are dependent, either directly or indirectly, upon high water-table conditions. It should be noted that the data in Table 3 refer to stands that are recognizably referable to a particular community-type and as such may underestimate the potential effects of dehydration as in several (many ?) cases dehydration may have already led to the change of one community-type into another. There is little doubt that some examples of former *Schoeno-Juncetum* have changed into the (drier) *Cirsio-Molinietum* [evidence to be presented in some individual site accounts]. Likewise, the relatively high water tables associated with the wet-fen *Acrocladio-Caricetum* community even in Eastern England is probably because this vegetation-type has only been able to persist in sites with high water tables and may well have been lost from various other sites.

Dehydration of valley fens in Eastern England is, of course, only one of various processes that may cause vegetation change, such as nutrient enrichment and dereliction. The fertility data presented in

2 although this study is concerned specifically with valley fens in East Anglia, for comparison with national mean values environmental data specifically from East Anglian sites have been amalgamated with data from other vice-counties in Eastern England (e.g. SE Yorkshire) where there may be problems of dehydration similar those in East Anglia. These amalgamated data are referred to as being from "Eastern England"

Table 3 show that there is a tendency for Eastern England examples of the two fen meadow communities to be rather more fertile as well as drier than examples elsewhere. This may partly be a result of nutrient release consequent on dehydration, though enrichment may also occur independently of drying-out. However, it is notable that there is little evidence of enrichment in the two main mire communities, relative to mean values elsewhere.

An assessment of the sensitivity to dehydration of wetland plant species in East Anglian valley fens

The species that may be expected to be most vulnerable to a reduction of water-table in fens are those that are consistently, and largely exclusively, associated with high water tables. Using this assumption, here an attempt is made to identify those species that are at most risk in East Anglian valley fens.

Problems of assessing the susceptibility of fen plant species to dehydration

There are various problems inherent in assessing the sensitivity of fen plant species to dehydration:

1. The response of plant species to water conditions, or to changes in them, is very poorly known, and some of the information that is available is of rather little relevance.

   (a) screening of fen species response to water levels in controlled conditions has rarely been made (for example, it does not form part of the screening programme of the NERC Unit of Comparative Plant Ecology at Sheffield). In any case, many such data are probably of little value to the field situation as response to water-level flux is probably largely community-based (many fen vascular plant species grow as well, if not better, in normal garden soils as they do in undrained fens)[3].

   (b) there is very little detailed information on field changes of vegetation composition in response to dehydration (and even if there was it might be difficult to relate it confidently and unambiguously to the sole effects of dehydration).

   (c) there *are* field data relating the composition of fen vegetation (and hence the occurrence of particular species) to spot measurements of summer water level (Shaw & Wheeler, 1990), but these data are somewhat limited in their scope. Moreover, there are various assumptions and limitations implicit in the notion that the sensitivity of plant species to dehydration is necessarily reflected in the range of water table conditions in which they typically occur. These include the following:

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3 equally, the exclusion of many dryland plants from waterlogged soils is more a product of the conditions of anoxia associated with waterlogging than any direct effect of high water tables

2. Field data based on spot measurements of water tables may be an inadequate basis for use to relate to species tolerances, especially in fens subject to strong water-table flux. Yet, when complex, comprehensive time-series data of water levels are available it may be difficult to find effective ways of relating these to species occurrences.

3. Little is known about the speed of response of fen plants to changing water conditions, but it is likely *a priori* that established perennial plants will show substantial inertia against water level change[4].

4. Again little is *known* about the consistency of the response of species to water level change in different starting conditions. However, it is *likely* that the response of many species is strongly dependent on the starting conditions. For example, species loss from vegetation containing a potential strong dominant (e.g. *Cladium mariscus*) may occur much more rapidly than in vegetation without such a dominant (Wheeler & Shaw, 1987).

5. Species may be able to tolerate a wider range of water table conditions than they typically occupy in the field. Their field distribution may be truncated due to effects of other environmental variables (e.g. Fe^{2+}, S^-) which may vary in concentration amongst sites.

6. It is likely that the abundance of many species will be strongly affected by conditions other than just water level. In fens lack of management, nutrient enrichment, base-status and availability of toxic metals appear to help determine vegetation composition (Shaw & Wheeler, 1991). The implications of this are:

   (a) species changes may be controlled by lack of management and nutrient-enrichment as well as by water level. Moreover, there is no doubt that many valley fens in East Anglia have been subject to dereliction., Many have probably been subject also to nutrient enrichment, but there is generally rather little direct evidence for this (due to lack of appropriate study). (Nutrient enrichment may occur independently of, as well as being caused by, dehydration).

   (b) other environmental conditions may influence species responses. For example, the expansion of tall herb species (e.g. *Filipendula ulmaria* and *Epilobium hirsutum*) in drying-out fens is probably largely an indirect product of the changing water regime, in terms of both (i) greater nutrient availability; and (ii) reduction of concentrations of reduced toxins (Fe^{2+}, Mn^{2+}). However, both species, and especially *E. hirsutum*, can strongly dominate wetlands which are *not* subject to dehydration when nutrient concentrations are adequately high and concentrations of Fe^{2+} are naturally low (Wheeler, 1983).

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4 such a response permits survival of species in situations subject to periodic, short-term drought

Sources of information on water regime tolerances of individual species

Two main sources of information have been used to glean insights into the water regime tolerances of fen plant species.

1. Feuchtezahl *("Moisture value") (Ellenberg, 1974)*

Ellenberg (1974) gives "moisture values" for a very large number of vascular plant species, including the majority of those that occur in East Anglian fens. The evident value of this comprehensive survey is tempered by the following:

(a) some potentially-important species are not included; in particular, bryophytes are not considered.

(b) it is not clear how the values were derived (guessed ?[5]), nor the range of variation that individual species show (except insofar as species that characteristically occupy a broad moisture range are not assigned a value). [In general, many of the values given seem intuitively sensible].

(c) the 12-point scale is not very sensitive for specific moisture ranges. Thus many typical fen plants are accommodated just by points 8 and 9. [This coarseness probably helps explain why many of the rankings seem intuitively sensible.]

(d) the moisture tolerances of certain species in Central Europe may be rather different to those found in Britain. [This may go some way to explaining some problems with the scale.]

2. *Field water level ranges of fen species in Britain*

These are based on data collected by Wheeler & Shaw (1987) and Shaw & Wheeler, 1990) as part of a survey of the habitat conditions associated with specific fen plant community-types in lowland Britain. This comprehensive survey can be readily used to assess the water-level affinities of plant species, and is particularly valuable in indicating the range of water conditions associated with the species (i.e. their specificity as water-level indicator-species). However, it also has limitations:

(a) water level determinations are based just on spot measurements made during the summer months (though it may be argued that records made at this time may be most relevant to dehydration studies).

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5 despite its evident subjectivity, given the manifest problems of relating measured water level conditions to species tolerances, an inspired "guess" (or "informed judgement") of an experienced worker may be a quite reliable guide

(b) it cannot be assumed that the species-composition of the vegetation is necessarily in equilibrium with the environmental conditions. [In some situations, where there has been water-level flux, species-composition may not have re-equilibrated.]

(c) data were collected from throughout Britain, and some data, say from NW Scotland, may represent species-distribution / water-table interactions that are inapplicable to East Anglia[6].

(d) for some of the less common species, there are insufficient data from East Anglian fens alone to provide a secure basis for estimating moisture tolerances.

Despite these evident problems, there are few other data that can be used to assess vulnerability to dehydration.

Water level conditions associated with selected plant species of British fens

Table 4 summarises the summer water level environment typically associated with plant species in British fens, as recorded by Wheeler & Shaw (1987) and Shaw & Wheeler (1990). Ellenberg's *Feuchtezahlen* are also given. This list excludes all species with fewer than 4 records, but includes all of the species recorded (*i.e.* not just fen species).

For typical wetland plants there is generally quite good agreement between the mean water level recorded in lowland Britain and the *Feuchtezahlen*, though there are some notable exceptions, mainly relating to plants that occur both in fens and in other habitats. For example, the *Feuchtezahl* for *Polygonum amphibium* is 11 (i.e. *Wasserpflanze*), whereas the mean recorded summer water level was -32 cm! This is probably mainly because this plant was only recorded occasionally in fens, and in these it was typically in rather dry and disturbed sites, contrasting strongly with the open water habitat that it more usually occupies. This extreme may be compared instructively with *Leontodon autumnalis* (*Feuchtezahl* 5, *Frischezeiger*), mean summer water level -3.5 cm). Here, as with many plants that occur in dryland situations as well as in fens, the mean summer water level refers only to their preferences with respect to fens.

In other cases, disparity between the *Feuchtezahl* and mean summer water level may reflect genuine differences in range between Britain and Central Europe. For example, *Carex hostiana* (*Feuchtezahl* 9) is not restricted, in Britain, to such wet conditions as this rating implies (a values of 7 or 8 would seem more appropriate).

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6 though it may also be argued that if many of the East Anglian fens are becoming drier, and especially if conditions (b) applies, an estimation of species moisture tolerances from parts of Britain less influenced by dehydration may help give a more accurate indication of species optima and preferences

Selection of fen species "at-risk" from dehydration in East Anglian valley fens

Selection of fen species that may be particularly at risk from dehydration in East Anglian valley fens was made in two phases. Phase 1 selection was made with reference to water level data for fen sites throughout Britain (Table 4). These species were then subject to various secondary (Phase 2) selection procedures, made with specific reference to the more local conditions of Eastern England.

Phase 1 selection

The desirable properties of the species that formed a basis for Phase 1 selection were:
(1) that they occurred in East Anglian fens;
(2) that they were typical fen species;
(3) that they were herbaceous species; and
(4) that they typically occupied sites with a high water table.
Species that satisfied condition (4) were those that:
(a) were associated with a high overall summer water table in UK sites (mean > -4cm)
(b) occupied a fairly narrow range of high summer water tables in UK sites (>75% of occurrences within 10cm of surface)
(c) had *Feuchtezahl* > 7[7]

Table 5 lists the identity of the species that are eligible under these criteria. It also indicates the management status and the mean fertility of the sites in which they occurred (data again referring to fen sites throughout Britain).

Phase 2 selection

Poor-fen species

There are but few data available for water level conditions in poor-fen sites in East Anglia and it is considered that these are not sufficient to support statements on the specific water level conditions "preferred" by the relevant species. Thus the data presented for poor-fen species in East Anglia (Table 6) are based on values derived from sites throughout lowland Britain. However, a judgement has been made as to which species *may* be particularly sensitive to dehydration. This is based on casual observations on the distribution of the species in a wide range of UK sites (in addition to the poor-fen sites for which data are available) but it is clearly conjectural and must be interpreted accordingly.

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7 this criterion removed just 7 species from consideration: they were all species (Cardamine pratensis, Carex panicea, Lychnis flos-cuculi, Juncus effusus, Molinia caerulea, Pyrola rotundifolia, Succisa pratensis that would have been excluded in any case in the second phase of selection (from East Anglian data)

Note that a feature of many of the East Anglian poor-fen sites is that they also contain rich-fen elements, particularly along the main drainage axes. A consideration of the rich-fen species is thus also relevant to these sites.

Rich-fen species

1. *Selection of species based on summer water table conditions in Eastern England valley-fen sites*

A second selection procedure was performed using similar criteria to the Phase 1 selection, but based upon water table information derived exclusively from sites in Eastern England. [The rationale for this secondary selection phase was that it seemed possible that some species might be more closely associated with higher water tables in East Anglia than they were elsewhere in the UK: for example, it is possible that in western Britain some species typically grow in sites with a lower water table than in East Anglia as precipitation input may help maintain suitably moist conditions independently of the precise level of the water table].

As the water table conditions in the Eastern England valley fens were generally drier than the national data used in Phase 1 selection, the Phase 2 rich-fen selection criteria were slightly relaxed to include species that:

(a) had a high overall summer water table in EE sites (mean > -4cm)

or

(b) occupied a fairly narrow range of high summer water tables in UK sites (>75% of occurrences within 10cm of surface)

(c) had *Feuchtezahl* > 7

The species selected in the Phase 2 screening are listed in Table 7. It may be noted that very few additional species were added by the Phase 2 selection exercise, but that a number of species that occupied high mean water-table conditions in the national context have not been included. This is probably a reflection of the intrinsically lower water tables of valley fens in East Anglia than elsewhere and of the possibility that such populations are not in equilibrium with the current hydrological *status quo*, and may be declining. Such considerations epitomise the problems of extrapolating species "preferences" from mean values of measured environmental conditions, but at present there is little alternative information available. It is in any case possible to over-stress this problem: note that many of the East Anglian mean values are within 10% of the national mean value and are thus not highly deviant. Moreover, the differences in the species' water table relationships in Eastern England and the UK generally may give useful insights into the sensitivity of the species to dehydration and is considered in detail below.

2. Comparison of the occurrence of rich-fen plant species with respect to the water levels in sites of Eastern England and through lowland UK

This comparison has been made to supplement the data in Table 7, and has included *all* of the principal fen species that occur regularly in East Anglian valley fens (and for which more than 3 records are available) and not just those fen species that satisfied the Phase 1 and 2 selection criteria (above).

Table 8 includes fen species which, in Eastern England tend to occur in wetter situations than elsewhere (Eastern England mean water table is considerably (> 5cm) greater than UK mean). Those species that tend to occur in drier situations in Eastern England fens than elsewhere (EE mean water table is > 5cm less than UK mean) are given in Table 9. And species that tend to occupy situations of similar wetness in both Eastern England and elsewhere (EE mean water table is ± 5 cm of UK mean) are identified in Table 10.

A. *Species occurring in drier conditions in Eastern England than elsewhere in lowland Britain (Table 8)*

This category comprises an interesting array of species which can, broadly, be divided into several types, which include:

(a) species that occur widely in moist, or even dry, grassland as well as in fen (e.g. *Carex flacca, Cirsium dissectum, Juncus effusus, Luzula multiflora, Sagina nodosa*). These tend to occur in some of the driest EE sites. They are not at direct risk from dehydration, but as many of them are small, and are restricted to low fertility, low crop mass situations, they may be damaged by vegetational changes consequent upon dehydration.

(b) fen species that are tolerant of quite dry conditions. Perhaps the most notable examples of this are *Cladium mariscus*, which can persist for long periods in dry conditions, *Parnassia palustris* (which occupies moist limestone hillsides in N England) and *Schoenus nigricans* (which grows in *Rosmarinus* heaths in Bas Languedoc). These are also, to varying degrees, probably not at direct risk from dehydration, though many (*Cladium* is an exception) are likely to be strongly susceptible to any associated vegetation "overgrowth".

(c) wet fen species whose sites in Eastern England are drier than is typical elsewhere, but which are still associated with quite high water tables (e.g. *Carex diandra, Menyanthes trifoliata, Calliergon giganteum*). These species are characteristic of wet sites throughout the UK and, whilst they may accommodate slightly lower water tables in East Anglia, must be regarded as being "at risk". Several of them are typical components of *Acrocladio-Caricetum* communities [though it is notable that another typical species (*Potentilla palustris*) can occur in quite low water table environments in East Anglia.]

B. *Species occurring in similar water table conditions in Eastern England valley fens as elsewhere in lowland Britain (Table 9).*

These species may be divided into two broad types

(a) species that tend to occur in similarly dry(-ish) conditions in Eastern England and other valley fens. These include species that can sometimes rise to prominence in drained fens (e.g. *Calamagrostis canescens, Filipendula ulmaria*) and which will accommodate (and probably benefit from) any effects of nutrient-enrichment and dereliction. However, this group also includes various species typical of undrained and unproductive sites, but which tend to grow in somewhat drier conditions. These are exemplified by the three orchid species (*Epipactis palustris, Gymnadenia conopsea, Listera ovata*) which have all been recorded from dry chalk downland. Such species are unlikely to be at risk from the *direct* effects of dehydration

(b) species that are restricted to high water-table conditions in both Eastern England and other valley fens. These are the species that have a mean EE summer water table > -4 cm. They include some of the least common species of East Anglian valley fens, many of which (e.g. *Carex dioica, Dactylorhiza traunsteineri, Drosera anglica, Eriophorum latifolium, Philonotis calcarea*) are components of the highest quality *Schoeno-Junceta*. In many instances the EE mean summer water table for these species is slightly less than the UK mean, but the difference is small. This may be interpreted to suggest that these species typically have a dependence on high water levels. Indeed, the scarcity of low water-level minima amongst these species (Table 7) may be because such species have not occurred at, or have been lost from, the drier sites. Such species are clearly at high risk from dehydration.

Categories (a) and (b) are linked by a series of intermediates, many of which are relatively common fen species (*Mentha aquatica, Epilobium palustre, Caltha palustris*) that nonetheless most typically occupy wet sites. Several of these are species that were excluded from the Phase 1 screening, but which were included in the Phase 2 screening, based on Eastern England. In most cases this was because although the mean summer water table associated with these species was < - 4cm, more than 75% of the occurrences were in sites where the water table was less than 10cm below the soil surface.

C. *Species occurring in wetter conditions in Eastern England valley fens than elsewhere in lowland Britain (Table 10)*

It is a matter of considerable interest than any plant species tend to occur in wetter valley fens in Eastern England than elsewhere, even if they are few in number. It is also a matter that admits of considerable difficulty of explanation! One possibility, which may apply at least to *Epilobium hirsutum, Scrophularia aquatica* and *Solanum dulcamara*, is that these nutrient-demanding species, which are found widely in and alongside roadside ditches, drains etc., are occurring in wetter spring-fed EE sites than they tend to occupy elsewhere in lowland Britain because the waters are considerably enriched with agricultural nutrients. With the exception of *Carex elata*, none of these species are to be regarded as typical wetness-indicating species; they are common and not restricted to undrained fens and cannot be considered to be at risk from dehydration.

Table 11 has been derived from Tables 3 - 10, and the interpretation of their contents. It lists the East Anglian fen species selected as being probably "at risk" from dehydration. It must be re-iterated that these data need to be interpreted with caution, because:

(a) the association of a species with high water tables in fens does not mean that this species will *necessarily* decline in dehydrating fens. [It is notable that some species that are dryland species or fen species that are known to increase upon dehydration (e.g. *Calamagrostis canescens*) have high values of associated mean water tables in at least some of the data sets.

(b) some of those species associated with relatively low mean water tables may also be influenced detrimentally by dehydration.

(c) other environmental variables may also affect the populations of some of these species. It is, for example, notable that a number of the "at-risk" species are also typically associated with low-fertility soils or with managed vegetation (Table 4) and that their populations could be damaged by nutrient enrichment or dereliction.

PART II. USE OF FEN PLANT SPECIES AS "INDICATORS" OF WATER LEVEL CONDITIONS

Introduction

As different plant species can be seen to occupy distinctive environmental niches, it is not surprising that various workers have examined the potential use of plants as indicators of environmental conditions. Ellenberg (1974) has espoused this concept particularly systematically and has proposed "indicator values" for many Central European plants with regard to irradiance, climate, and soil water, pH, nitrogen, salt and heavy metals.

As water table conditions are undoubtedly of great importance with regard to the species composition of fen vegetation (Shaw & Wheeler, 1991), it is possible that the changing abundance and distribution of certain species may provide a useful tool for assessing past changes in the water environment of fens and for monitoring future changes.

Potential value of indicator species for assessing water level change.

The use of indicator species to assess water level change, compared to direct water-level monitoring has several potential advantages.

1. Some past records of species occurrences are available for many sites, whereas there is usually no good water level data.

2. Species presence can usually be assessed by 'spot measurements' - i.e, they can be determined on a single occasion - whilst repeated, and often frequent and long-term, water-level measurements may be needed to adequately quantify water level flux in fens.

3. The species record can help assess the significance of hydrological changes. It may be argued that the conservational significance of hydrological change in fens relates not so much to its *magnitude* as to its *impact* upon the biota.

4. The presence of indicator species effectively integrates the overall effects of water-level flux upon the ecosystem. The impact of dehydration on target species may not be mediated as much by a *direct* effect as by an *indirect* effect, operating upon other component species of the community, or upon other concomitant environmental changes (e.g. nutrient release).

5. The survival of indicator species effectively integrates the long term effects of water-level flux: many species may be able to survive periods of temporary dehydration (within certain limits); it is notoriously difficult to relate rigorously measured values of a strongly fluctuating variable such as water level to vegetation composition, especially when it is uncertain what time-period of flux needs to be considered.

Properties of an "ideal" water level indicator species

A sensitive species for monitoring water level change would have the following properties:

1. Responds in a defined and consistent manner to water-level flux (either direct or indirect effects).

2. Response is well synchronised with the salient biologically-significant parameter of water-level flux, 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.

5. Species is reasonably common - so that realistic determinations of abundance changes can be made, and to facilitate between-site comparisons.

6. Species is reasonably easy (a) to find; and (b) to identify

Problems of selecting water-level indicator-species.

The problems of selecting species as indicators of water level changes are comparable to those of assessing the susceptibility of fen species to dehydration. The "ideal" properties of a water-level indicator-species may be compared with the actual properties of potential indicator-species, insofar as they are known. On a point-by-point basis:

1. The response of plant species to water conditions, or to changes in them, is very poorly known.

2. Little is known about the speed of response of fen plants to changing water conditions, but it is likely *a priori* that established perennial plants will show substantial inertia against water level change[8].

3. Little is *known* about the consistency of the response of species to water level change in different starting conditions. However, it is *likely* that the response of many species is strongly dependent on the starting conditions. For example, species loss from vegetation containing a potential strong

8 such a response permits survival of species in situations subject to periodic, short-term drought

dominant (e.g. *Cladium mariscus*) may occur much more rapidly than in vegetation without such a dominant (Wheeler & Shaw, 1990).

4. It is likely that the abundance of many species will be strongly affected by conditions other than just water level. In fens lack of management, nutrient enrichment, base-status and availability of toxic metals appear to help determine vegetation composition (Shaw & Wheeler, 1991).

5 Several of the species that show a fairly clear relation to water level conditions are uncommon (see below).

6. Several of the species that show a fairly clear relation to water level conditions are *Cyperaceae* and *Bryophyta* (see below).

These considerations therefore suggest:

1 That there are several uncertainties surrounding the use of indicator-species to assess hydrological change.

2. That it is unlikely that a single indicator-species can be found. Rather, the observed responses of a number of species will be needed.

3. It may be difficult, in some cases, to disentangle vegetational effects of dehydration from the effects of some other forms of environmental change.

Subject to these various caveats, an attempt is made here to identify species that may be suitable as water-level monitors and to suggest a protocol for using them to monitor vegetation change.

Selection of indicator species for dehydration

Selection of species normally associated with high water tables

The plant species that may be expected to decline in abundance with a decrease in water-tables are essentially those that have already been identified as potentially "at risk" (Table 11). These do not have equal suitability as monitoring species, as assessed by the "ideal "specifications (above).

(a) several species that are closely associated with consistently high water tables are rare (i.e. uncommon within some sites and quite absent from others)

(b) some of the most eligible species are also more "difficult" taxonomically (i.e. they are graminoid monocotyledons or bryophytes)

(c) many of the most eligible species are also typically associated with low-fertility soils and presence of management.

Species that may be particularly suitable as indicator species are listed in Table 12. An attempt has been made to include as many common species as possible, but it should be recognised that, in general, these are less precise indicators of water-table conditions.

Selection of species normally associated with low water tables

An alternative approach to using indicator species as measures of dehydration is to monitor possible increases in those taxa that are most usually associated with low water levels. The potential of this approach requires more evaluation than it has been possible to make here, but initial observations suggest that it may be even more problematic than attempts to monitor changes in dehydration-sensitive species. This is because:

(a) it often difficult to predict which species are likely to expand. This is because there is a large assemblage of fen and dryland species that can potentially expand within drying out fens. Those that actually expand are likely to be determined *inter alia* by:

- those species present initially
- degree of dehydration
- other constraints (grazing, fertility, etc.)

(b) in general, individual fen species are less clearly confined to dry conditions than others are to wet ones. Most species, including taxa that are thought to typically increase upon dehydration, can also grow readily in very wet conditions. This applies, for example, to such species as *Molinia caerulea* which is well known to spread in drying-out fens but which, on the basis of its high national mean water table (Table 8) could be regarded as desiccation-sensitive!

(c) one reason for this lack of sensitivity is that the water level mean data are based on all species records and take no account of abundance. This is because, in general, there are few clear relationships between species abundance and water table in the data sets of Wheeler & Shaw (1987) and Shaw & Wheeler (1990), though this may be as much a reflection of insufficient data for most species as of a genuine lack of relationships.

(d) many of the species that are mostly likely to expand are taxa of moist grassland rather than fens. Comprehensive synoptic data of water table 'preferences' are not available for most of these species.

Despite these evident limitations, the use, as indicators, of species that may expand upon dehydration may merit further study. In Table 12 a list is provided of some species that are thought to expand consequent on dehydration, based on field observations. This list does, however, require more objective verification, especially as the abundance of many of the species may be controlled by variables other than water levels.

Monitoring change with water-table indicator species

The primary requirements of a monitoring protocol using "indicator species" are:

1. that the species are carefully and rigorously recorded

2. that some estimate of abundance is made

3. that this is done is such a way that the exercise can be repeated

In general, except perhaps for at the simplest sites, there seems little to be gained in attempting to monitor change over an entire site. Heterogeneity of vegetation cover and sheer size can mean that composite site monitoring may have little value in detecting long-term change. Monitoring is thus best focussed on specific communities or other appropriate units.

Whilst it may seem desirable to monitor a wide range of communities at any given site, this may not be practicable. In most cases it will probably be necessary to select certain areas that require monitoring, either on account of exceptional species interest or representativity. Thus, rather than attempts at whole-site monitoring, in most cases it seems preferable to:

a) target *and delimit* specific areas for monitoring
b) monitor within (rather than across) "uniform" stands of vegetation, or other patches
c) monitor areas thoroughly, so that changes can be readily identified (this may demand the use of relatively small monitoring areas, depending upon resources).

These considerations suggest that:

1. for each site a list of "indicator species" is established [the same list may be used for many sites]

2. that *discrete* and *identifiable* sections of the site are monitored and that these sections are *known* and *locatable* and are *used* for subsequent monitoring

3. that some supplementary information is recorded relevant to the site outside of the main monitoring areas.

4. in particular, the following is desirable:

   a) some estimate of the area and boundaries of the stands that are being monitored

   b) brief notes on other parts of the site

Monitoring protocols

In most cases the objective of monitoring will be to make some assessment of the abundance (often frequency) of indicator species within the vegetation. The exact monitoring protocol that should be adopted will depend upon:

1. resources available
2. nature (and area) of the vegetation

Objective assessments

Frequency of indicator species is perhaps one of the most readily-measured estimates of abundance. This may be recorded in permanent plots or by randomly-located samples. Permanent plots give valuable information of vegetation change at a fixed point, but this may not be representative of the site/community as a whole, especially as repeated sampling may cause some modification to the vegetation. Random plots lack continuity but may better represent changes in the stand as a whole.

The number and size of random plots is partly determined by the nature of the vegetation. In a large, uniform stand of vegetation an adequate number (30) of quite large plots (0.25 $m^2 \rightarrow 4$ m^2) (Wheeler & Shaw, 1991) is appropriate. But such an approach is not well suited to small flush areas of only a few square metres area. In this situation gridded permanent plots, which may be sampled randomly internally may provide an acceptable approach, though in this situation considerable attention needs to be given to damage inflicted upon the (often sensitive) vegetation as well as to the niceties of sampling theory.

Subjective assessments

Although subjective assessments of species abundance (such as DAFOR guesstimates) lack the precision of more objective procedures, they are usually made much more quickly and can be applied fairly consistently, at least as far as the more conspicuous species are concerned and when the areas involved are not too great. They may be particularly well-suited to recording small flushes etc. in situations where objective approaches may be more difficult to apply. Moreover, subjective assessment of species abundance may be the only realistic method, given limited resources, if widescale monitoring of a large number of sites is envisaged.