ASPECTS OF THE PLANT ECOLOGY OF A FLOOD-PLAIN MIRE IN BROADLAND, NORFOLK.

By

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ASPECTS OF THE PLANT ECOLOGY OF A FLOOD-PLAIN MIRE IN BROADLAND, NORFOLK.

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SUMMARY

The vegetation of a particularly diverse area of undrained flood-plain mire is described. Factors and processes important in determining the distribution of community-types within the study area have been investigated.

Investigation of the alluvial stratigraphy has revealed the presence of a complex pattern of peat cuttings. Succcession within the peat cuttings, with appropriate vegetation management, has led to the formation of *Cladium mariscus*-, *Phragmites communis*- and *Juncus subnodulosus*-dominated fen vegetation and, in some areas, poor-fen communities with much *Sphagnum*. In areas not cut for peat, management has also sustained various rich-fen herbaceous communities (different to those of the cuttings); in its absence, fen carr develops. The differences in successional development in peat cutting areas and those not cut for peat is mainly due to difference in hydrological status.

Long term experiments established to examine effects of different management techniques are described.

Studies of peat and peat water chemistry in a representative selection of community-types has demonstrated local areas of high salinity, caused by incursions of brackish water due to exceptionally high tides and, particularly, the influence of underlying estuarine deposits. Although large areas are flooded by river water there is little evidence for eutrophication, except very locally. Indeed, 'seral oligotrophication' is occurring in isolated areas. This may preceed, but is not a pre-requisite for, *Sphagnum* invasion. The most species-rich communities are developed in non-saline areas with a fairly stable water level; they may, however, be dependent upon flooding by river water for maintenance of their base status.

Possible directions of future succession are discussed.

PLATE 1. A small turf-pond (Fenside Inner Broad) July 1978

PLATE 2. The central part of Great Fen during sedge mowing July 1977.

ACKNOWLEDGEMENTS

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TERMINOLOGY AND DEFINITIONS

Species nomenclature follows Dandy (1958) for vascular plants, Smith (1978) for mosses and Paton (1965) for hepatics.

Utricularia vulgaris, *Rosa canina* and *Rubus fruticosus aggregates* have not been separated, nor has *Salix cinerea* been separated from *Salix atrocinerea*. *Chara* spp. have not been identified.

Swamp: areas with a summer water level above the peat surface (Tansley 1939).

Rich-Fen: with relatively base-rich water, pH c. 6.0 or more (cf. Du Rietz 1949).

Poor-Fen: with relatively base-poor water, pH c. 6.0 or less (cf. Du Rietz 1949).

Marsh: used as an equivalent term for fen.

Rond: a bank or wall running alongside a dyke (Norfolk Reedgrowers Association 1972).

Nodum: an abstract vegetation unit of undetermined rank or status (Poore 1955).

Eutrophic: enriched with nitrogen and phosphorus.

Oligotrophic: nutrient poor.

Abbreviations commonly used in the text:

Cladium, *Cladium mariscus*; *Phragmites*, *Phragmites communis*; *Betulo-Myricetum*, *Betulo-Myricetum peucedanetosum Sphagnum* var, *P.-P.*, *Peucedano-Phragmitetum*; *Osmundo-Alnetum*, *Osmundo-Alnetum glutinosae lycopetosum*; *Potentillo-Caricetum*, *Potentillo-Caricetum rostratae lysimachetosum*.

CHAPTER 1

INTRODUCTION

1.1 PERSPECTIVE

'Exploring these fens is by no means without its excitement. Many of them ... consist of a mass of vegetation floating on an unknown depth of water and mud. The floating carpet yields at every step; the surface for yards round becomes tremulous; and one may be walking over the middle of a deep pool, with the knowledge that should the thin covering break it would be impossible to swim, almost impossible for a rescuer to approach, and the nearest help may be a mile distant. Unpleasant, though not dangerous, is the effect of new and old peat workings, which occur on most of the fens. Walking carefully in nine inches of water, the depth of which is hidden by the vegetation, a sudden drop of two feet or more into an older peat working is apt to interrupt botanical investigation for a time. Further troubles are caused by the sharp edges of the sedge and the saw-like teeth of *Cladium*, the stumps of reed below the water, the slipperiness of the putrid mud, and the falls from the narrow ridges that intersect the peat workings. Happily, however, these drawbacks preserve *Liparis* and other Norfolk rarities from the ravages of the collector' (Clarke 1915).

Perhaps this early description of botanical forays into the Norfolk fens provides an explanation for the scarcity of information on the ecology of one of the most important areas of rich-fen in Britain.

1.2. BROADLAND

Broadland is the name given to the part of East Anglia between Norwich and Great Yarmouth which contains the lower reaches of five main river valleys; the Yare, Bure, Ant, Thurne and Waveney. Situated only slightly above sea level the valleys have negligible gradient, are poorly drained and contain considerable accumulations of peat which are intercalated with an increasing thickness of estuarine clay towards the sea (Jennings 1952; Lambert *et al.* 1960). Much of the former wetland has been reclaimed for agriculture but large areas of undrained mire remain, particularly around shallow lakes - the Broads.

The mechanism of formation of the Broads was a subject of controversy until comparatively recently when very detailed investigations of the alluvial stratigraphy of the main river valleys, together with some complementary evidence, demonstrated that they are the flooded remains of medieval turbary (Lambert *et al.* 1960). Fen vegetation occurs today both in areas of uncut, undrained peat and as part of a primary hydrosere over peat cuttings.

Altogether the rich-fen systems of Broadland fens cover an area of c. 3500 ha, jointly forming the largest area of rich-fen in lowland Britain. The fens are developed on the flat, waterlogged flood plains of the Broadland rivers (i.e. flood plain mires (Goode 1972)) and are of high conservation importance (Ellis 1965; Ratcliffe 1977). The wide range of wetland plant species which occur in these flood plain mires include several nationally rare species (Ellis 1965; Perring & Farrell 1977). The most diverse wetland vegetation (both in terms of communities and species) is today found in one of the smaller river valleys, that of the River Ant (Wheeler 1978).

1.3. RATIONALE

1.3.1. Broadland Research

Recent ecological research in Broadland has mostly involved studies of limnology (e.g. Phillips 1977; Moss 1977); investigations of primary reedswamp (Mason & Bryant 1975; Boorman & Fuller 1981) and observations of coypu (*Myocastor coypu*) activity (Gosling 1974, 1976).

Since the early work of Pallis (1911a) investigations of the ecology of fen vegetation have been conducted in the Thurne valley (Godwin & Turner 1933), the Yare valley (Lambert 1946, 1948; Buttery & Lambert 1965; Buttery, Williams & Lambert 1965) and the Bure valley (Lambert 1951) but little in the way of research has been performed in the Ant valley.

There is evidence to suggest that the most species-rich herbaceous fen communities were formerly more widespread and extensive but are now restricted to a few areas of the Ant valley (Wheeler 1975). Many areas which were occupied by such vegetation now support species-poor herbaceous fen or fen carr.

An understanding of the factors and processes which have led to the development of the present floristic diversity of the Ant valley fens was considered essential for future maintenance of the characteristic herbaceous fen of Broadland.

1.3.2. Factors and Processes in mire ecology

Factors and processes which appear to be important in determining the distribution of vegetation types within and between mire systems are hydrology (Kulczynski 1949; Ingram 1967), chemistry (Du Rietz 1949; Sjörs 1950), successional status (Tansley 1939; Walker 1970) and management interference (Godwin 1929; Lambert 1951).

Little information on the importance of such factors and processes in the control and development of the varied vegetation-types of the Broadland fens is available. The present study was designed to rectify this lack of information for a particular very diverse area of mire (1.4). Many features highlighted as important here will require further detailed investigations to clarify specific issues. It is hoped that the study will provide a baseline for such work in the future. In particular, the lack of autecological studies on the habitat requirements of many wetland species prevents definite conclusions from being drawn on the importance of factors in controlling species distribution.

1.4. THE STUDY AREA

The flood plain mire complex investigated here is situated in the middle reaches of the River Ant valley, to the south-east of Barton Broad, and will be referred to as the Catfield and Irstead Fens. To the west the study area is bordered by the River Ant which drains from Barton Broad along the land margin at the village of Irstead. To the north and east the edge of the study area is marked by the boundary of the peat deposits with the upland. The underlying bedrock of Norwich Crag is covered by drift deposits of Norwich Brickearth - often a decalcified weathered boulder clay deposit (Chatwin 1961) - over which the peat deposits of the study area have formed.

The Catfield and Irstead Fens comprise an area of c. 150 ha and the present mire surface is only slightly above sea level (< 1 m O.D.). The former course of the river winds through the centre of the study area, marked by the Catfield-Barton Turf parish boundary (Jennings 1952). The River Ant was diverted through Barton Broad before the middle of the eighteenth century. Formerly the western part of the study area lay in the parish of Irstead which is now amalgamated with Barton Turf parish. A complex network of dykes, dug partly to allow the passage of boats, dissect the marshes of the study area. These, together with the presence of raised peat strips in some places, serve to divide the Catfield and Irstead Fens into compartments which are named in Fig. 1.1. The names in many cases are those used by local landowners and marshmen and in general, these are the same names as given on the Tithe maps of 1839-40.

At the time of the Tithe Maps the pattern of leasehold and ownership was very complicated but many of the fen compartment limits are similar to those of the present day. This is not true of part of the study area within Catfield parish (Fig. 1.2) where the marsh was divided into a complex area of smaller units by many dykes. The windmill marked in the centre of this map (the ruins of which can still be seen) is shown standing on a strip of ground with a dyke running either side of it. The fact that there were no connections between these dykes, and the presence of a roadway leading into compartment 161 suggests that the windmill was used to lower the water level in the area of marsh contained by the strip of ground (or rond). Subsequently the part of the study area within this rond is referred to as the 'internal system' and the rest of the study area as the 'external system'. Unfortunately there is little information given on the maps as to the land use at that time. All of the present day marsh of the study area is described as 'pasture' in the Tithe Award.

The marsh compartments which lie in Catfield parish but are not enclosed within the rond - Great Fen and Little Fen - were (and in fact still are) Poor's allotment. In the former parish of Irstead there are still large areas of Poor's Fen

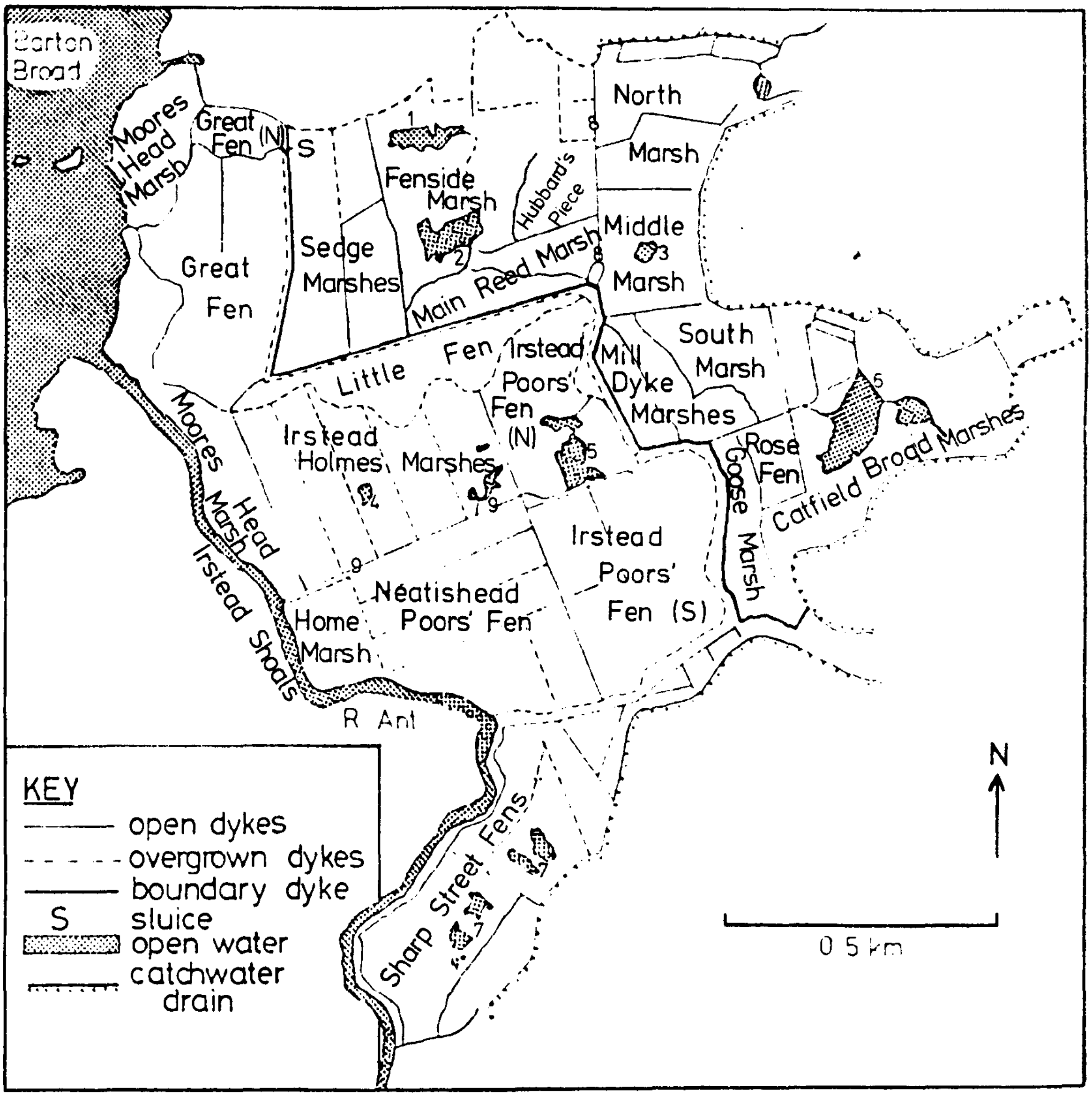

Fig. 1.1. Names of fen compartments in the study area (1, Fenside Outer Broad; 2, Fenside Inner Broad; 3, Middle Marsh decoy; 4, Monsey's Decoy; 5, Irstead Holmes Broad; 6, Catfield Broad; 7, Sharp Street turf ponds; 8, Commissioners Drain; 9, East-West dyke).

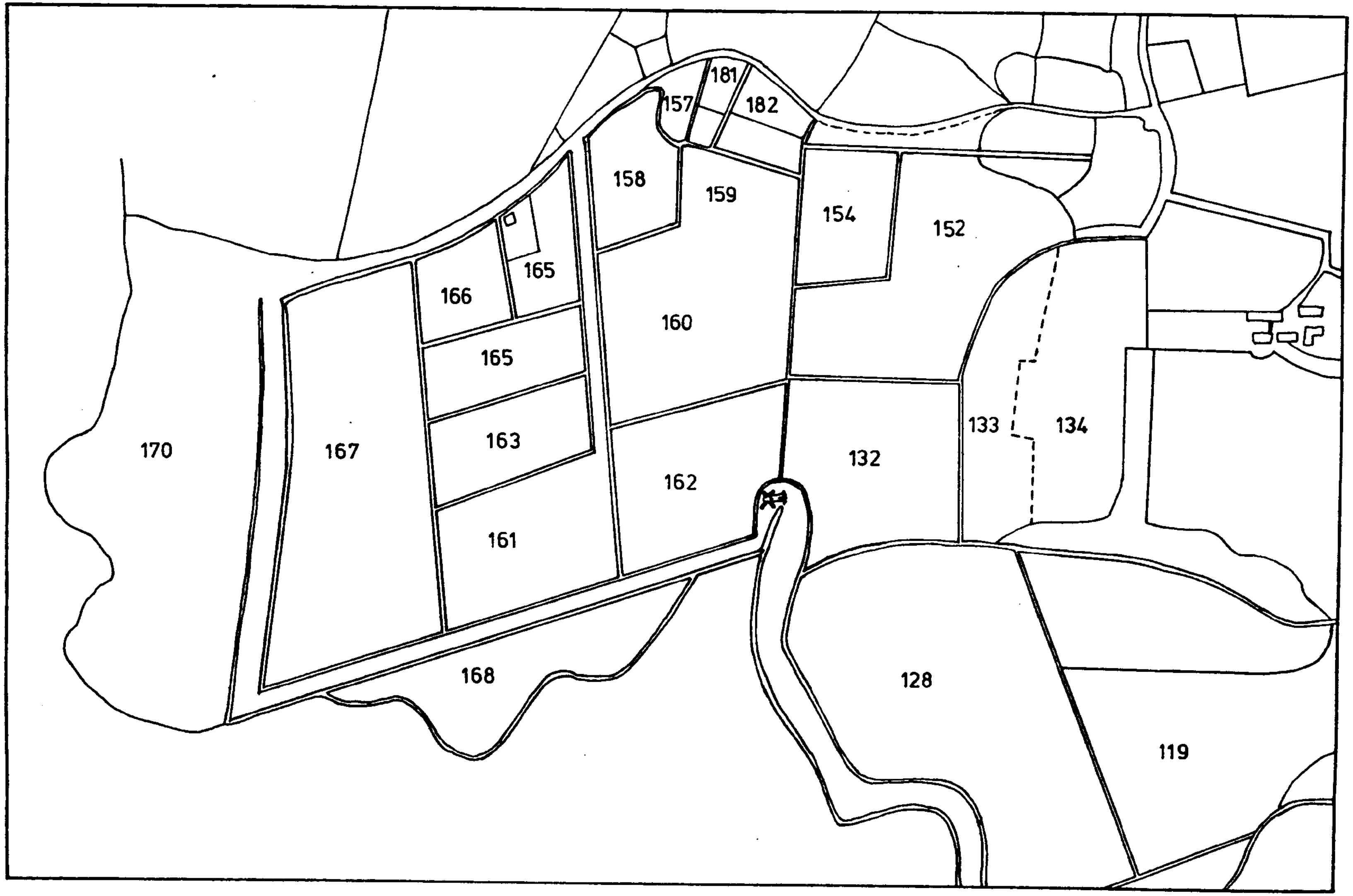

Fig. 1.2. A reproduction of part of the map of Catfield Parish produced by the Tithe Redemption Commission in 1840.

belonging to the Trustees for the Poor of Irstead and Neatishead parishes, even though no part of the study area lies in Neatishead parish. (Neatishead parish contains only a small area of marsh, in fact only part of the Alder Fen Broad and Burnt Fen Broad basins).

The first edition 1" Ordnance Survey map (1838-40) of the Catfield and Irstead Fens shows little detail of the marshes, but the North Marsh, Middle Marsh, Goose Marsh, Rose Fen, Catfield Broad Marshes and Sharp Street Fen areas are not marked as fen. Another windmill is marked at the eastern end of the East-West dyke on this map. The 1885 6" Ordnance Survey map denoted the vegetation of the study area using four separate symbols (Fig. 1.3). North Marsh is shown here as rough pasture and woodland is marked around Catfield Broad. Large parts of the study area are shown as open water/swamp (coloured blue), indicating that they were much wetter than other areas marked as fen. Many of the dykes shown on the Tithe maps are not marked on this map, but there are several new dykes, in particular a broad dyke in the centre of Sedge Marshes.

A rough sketch map in the diaries of Robert Gurney, dating from 1903 shows a portion of the study area within Catfield Parish (Fig. 1.4). On this the roadway marked on the Tithe map, leading into the centre of the marshes, petres out into a 'large reed hole' passing by an area of flooded meadow.

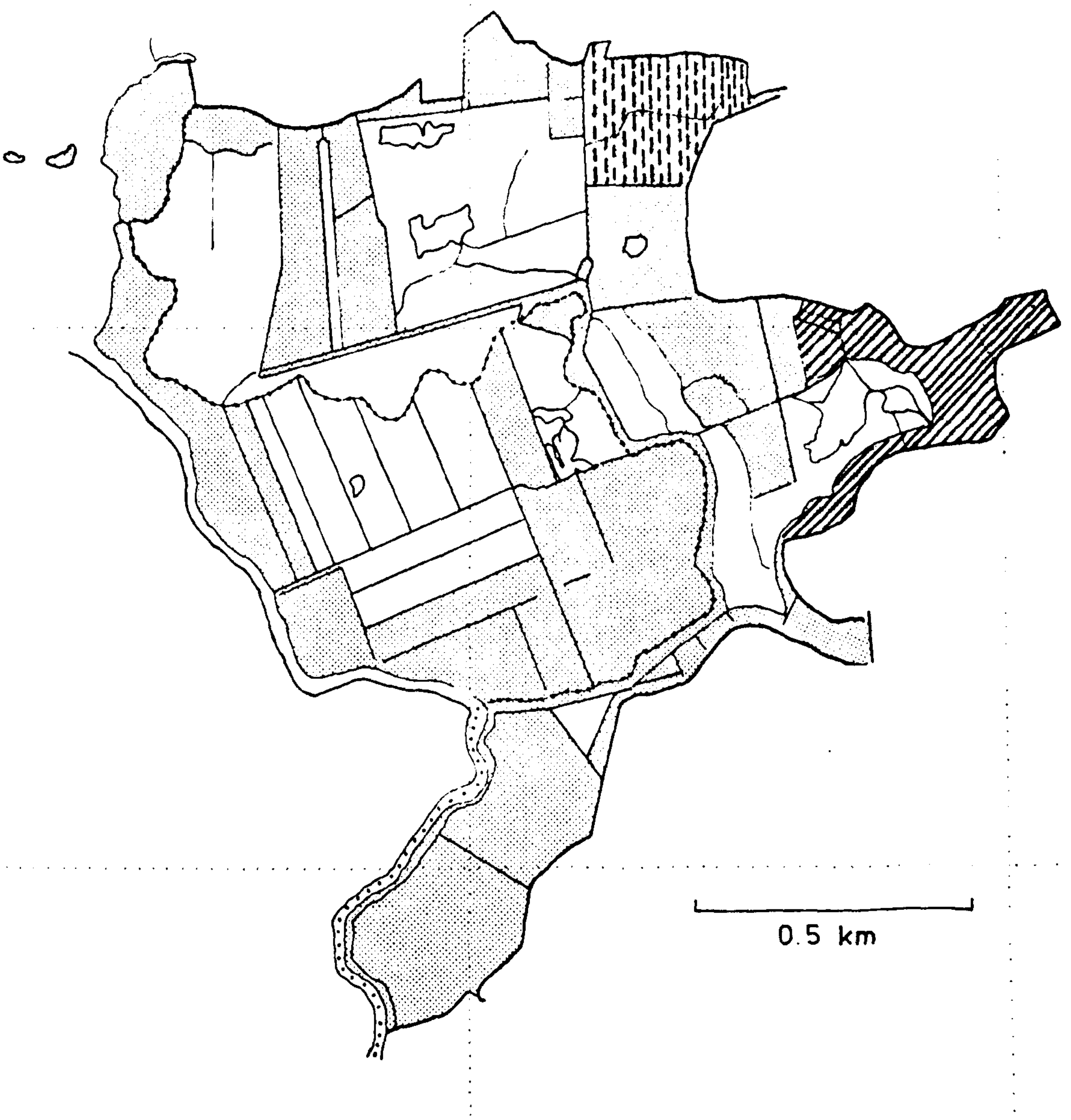

Fig 1.3. Swamp (□), Marsh (▨), rough grassland (▥) and woodland (▨) as shown on the 1885, 6" Ordnance Survey map.

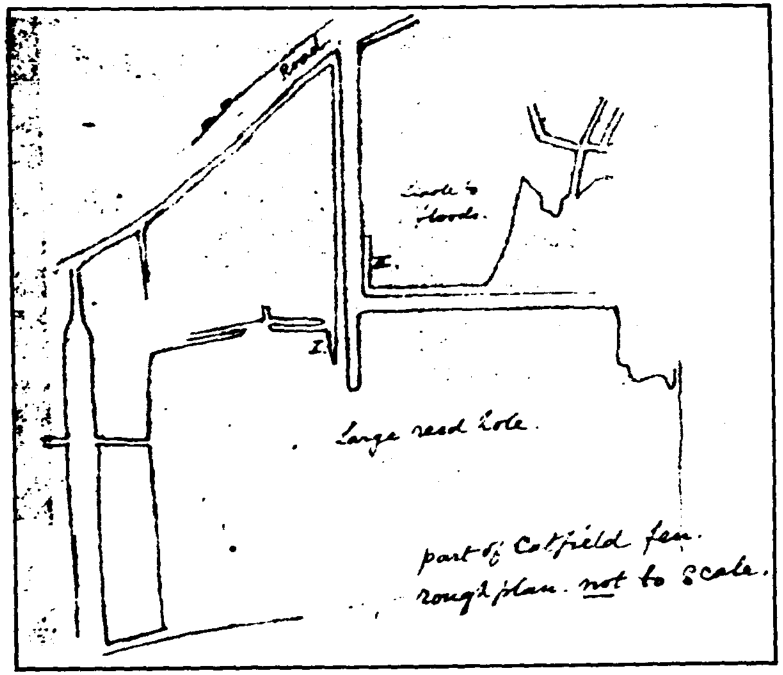

Fig. 1.4. Sketch map of part of the internal system from the field notebooks of Robert Gurney for 1903. (Held at the Castle Museum, Norwich).

Together, the evidence of these maps suggests that the windmill shown on the Tithe map was used for pumping water out of the internal system, possibly to allow grazing in North Marsh and some of the other marginal marshes.

Later maps give little further information on the study area; Catfield Broad and other pools were not subsequently marked until the 1977 1:25000 Ordnance Survey maps were produced. Additional information is available from aerial photographs and local people. On aerial photographs from 1946, open water can be seen only in those places where pools are now present. The duck decoy in Middle Marsh was excavated in 1947, and between 1967 and 1974 the dykes of the internal system and Catfield Broad were redredged (D.S.A. McDougall pers. comm.). In a few places new dykes were cut, for instance the dyke dissecting North Marsh (Fig. 1.1). A sluice was installed between the dykes of the internal and external systems in 1967 but it is not clear what connection (if any) between the two dyke systems was present before that time. The remains of an old sluice are present in the rond to the north of Little Fen.

1.5. RESEARCH APPROACH

The Catfield and Irstead Fens were chosen for detailed investigation due to the great diversity of vegetation types within a well defined area - no other area of comparable size in Broadland contains such a diversity.

A detailed vegetation map was prepared to highlight areas of interest and examine the spatial distribution of communities. Examples of various communities were then selected for detailed investigations of hydrology and peat and peat water chemistry. Features highlighted in these studies were further investigated with both broader and more specific studies. Investigations of the alluvial stratigraphy were conducted along four transects which linked many of the sites, with additional borings being made in other areas. Some long term management experiments have also been established, the preliminary results of which are presented here. Overall the study was designed to provide a basic understanding of the main factors influencing the distribution of vegetation types.

CHAPTER 2

THE PRESENT VEGETATION

2.1. INTRODUCTION

The first detailed descriptions of the vegetation in the flood-plain mires of Broadland are those of Nicholson (1909) and Pallis (1911a). Pallis distinguished two main types of 'fen formation', the Yare valley type and the Bure valley type. The Yare valley type was distinguished by the occurrence of more 'eutrophic' vegetation with much *Glyceria maxima* and *Thalictrum flavum* which were uncommon in the Bure valley type. The vegetation of the Ant and Thurne valleys was included in the Bure valley type. Pallis also distinguished two main types of carr; fen carr and swamp carr.

Lambert (1951) expanded this classification of different seral vegetation types and a fuller description of the Broadland vegetation was given by Lambert (1965). A more comprehensive account of the plant communities of the Ant valley fens was published by Wheeler (1978).

A detailed vegetation survey of the study area was essential to provide information on areas of particular interest, to examine the spatial distribution of the plant communities and to provide a baseline for future observations of vegetation succession.

2.2 METHODS

The vegetation of the study area was surveyed during the summer of 1978, although further records have been made during the subsequent period of study. A preliminary reconnaisance of the whole area was made to gain familiarity with the phyto-sociological units of Wheeler (1978, 1980a, c). Species lists were made and compared with the community descriptions of Wheeler (1978). The species lists were recorded using a cover-abundance scale (Table 2.1) modified from that of Braun Blanquet (1964) over a homogeneous area (100 m^2) of vegetation.

Table 2.1. Cover/abundance scale used in vegetation recording

Symbol	Degree of cover/abundance
5	80 - 100%
4	60 - 80%
3	40 - 60%
2	20 - 40%
1	5 - 20%
+	< 5%
-	very rare

It was also necessary to recognize two further categories of fen vegetation to encompass the full range of variation of the vegetation types (2.3).

Once a working knowledge of the classification had been established the study area was examined in detail to determine the phytosociological identity of each stand of vegetation and the boundaries between the stands. This information was marked onto large scale (1:25000) maps in the field. Aerial photographs (K. St. Joseph, Cambridge 1975) were used extensively to relate the vegetation to the maps. The only definite landmarks were dykes, paths and mature trees, although the transitions between adjacent communities could usually be detected on the aerial photographs. The community boundaries were often indistinct and broad transitional areas were present in many cases. Here the boundary was marked as close to the centre of such a transition zone as possible. Full species lists were made for areas which provided a good or unusual expression of a community type.

The results of the initial vegetation survey are shown in Plate 3 and have been presented in detail by Giller (1978). The present description will be confined to the spatial distribution of the plant communities over the study area. The phytosociological nomenclature follows Wheeler (1978, 1980a, c) and list numbers in brackets refer to the number of the species list in Table 2.2 for herbaceous vegetation and Table 2.3 for fen woodland vegetation.

2.3. ADDITIONAL VEGETATION CATEGORIES

The species-poor communities described by Wheeler (1980a) did not encompass some examples of species-poor vegetation found within the study area. Two further categories were recognized as physiognomic units based on dominance (c.f. Wheeler 1980a).

2.3.1. *Phragmites-Potentilla palustris* community

Potentilla palustris forms a dense carpet among *Phragmites* stands with few associates, mainly species of the *Peucedano-Phragmitetum* e.g. *Peucedanum palustre, Lythrum salicaria, Epilobium palustre.*

2.3.2. *Phragmites-Typha angustifolia* community

A species-poor community typically composed of a dense mat of *Agrostis stolonifera* with sparse shoots of *Typha angustifolia* and *Phragmites* which apparently lack vigour and are usually co-dominant. *Oenanthe lachenalii, Stellaria palustris, Scirpus tabernaemontani* and charophytes are often present.

PLATE 3. A vegetation map of the Catfield and Irstead Fens 1978. The key to the community-types is given on the following page.

Swamp

Scirpo-Phragmitetum

Cladietum marisci

Cicuto-Phragmitetum

Herbaceous Fen

Potentillo-Caricetum rostratae

Peucedano-Phragmitetum typicum

P.-P. typicum Phalaris var.

P.-P. typicum Carex paniculata var.

P.-P. myricetosum

P.-P. cicutetosum

P.-P. schoenetosum

P.-P. caricetosum

Phragmites sociation

Phragmites-Sium latifolium community

Phragmites-Typha angustifolia community

Phragmites-Agrostis stolonifera community

Phragmites-Potentilla palustris community

Phragmites-Thelypteris palustris community

Cladium-Thelypteris palustris community

Cladium-Carex elata community

Fen Woodland

Myricetum gale peucedanetosum

Betulo-Dryopteridetum cristatae

Betulo-Myricetum peucedanetosum

B.-M. peucedanetosum Sphagnum var.

Salix cincerea carr

Osmundo-Alnetum glutinosae lycopetosum

O.-A. glutinosae lycopetosum Sphagnum var.

Fen Grassland

Cirsio-Molinietum

Marginal Vegetation

herbaceous

woodland

2.4. SWAMP AND FEN VEGETATION

2.4.1. Swamp Vegetation

Communities of the *Phragmition* alliance

Scirpo-Phragmitetum Koch 1926

This association is very restricted in distribution being found only along the edges of Barton Broad, small turf ponds and overgrown dykes and dyke edges. All of the *Phragmites* swamps are referable to the species-poor *typicum* subassociation, containing only few associates such as *Lemna minor* and *Utricularia vulgaris*. The most extensive areas occur around the turf ponds of the Sharp Street Fens (Lists 45, 46).

Typha angustifolia society Wheeler 1978

Small areas of open mono-dominant *Typha angustifolia* fringing Barton Broad.

Cladietum marisci Zöbrist 1933 em. Pfeiffer 1961

These *Cladium* dominated swamps are infrequent, usually found fringing small turf ponds. All stands are referable to the *Utricularetosum* subassociation, although a single plant of *Carex lasiocarpa* has been found in one area (List 48). *Utricularia vulgaris* is an ubiquitous species, often being found with *Chara* spp. and occasionally *Nymphaea alba, Hydrocharis morsus-ranae* and *Carex pseudocyperus*. The most extensive area of *Cladietum marisci* is on the northern side of Fenside Inner Broad where *Veronica scutellata* occurs sporadically.

Cicuto-Phragmitetum Wheeler 1978

The large areas of the actively managed *Phragmites* beds of the Catfield Hall Estate are mainly composed of this community. Abundant species include *Typha angustifolia, Cicuta virosa, Sium latifolium* and *Ranunculus lingua* but aquatic macrophytes are generally absent. The substratum is quite firm and there is substantial invasion of *Salix cinerea* throughout the reedbeds. Such areas seem to represent a species-poor expression of the *Peucedano-Phragmitetum cicutetosum* usually lacking in most of the characterising species of this association but having many floristic similarities to it (Lists 39-42). A more characteristic example of this community occurs as a fringing reedswamp to the south-west of the inner Fenside Broad, where *Scirpus lacustris, Utricularia vulgaris* and *Fontinalis antipyretrica* are present (List 38).

2.4.2. Herbaceous Fen Vegetation

Communities of the *Magnocaricion* alliance

Potentillo-Caricetum rostratae Wheeler 1980

All stands of the *Potentillo-Caricetum* belong to the *lysimachetosum* subassociation (a broader subunit including the *peucedanetosum* suggested by Giller (1978)). It is a community of marginal areas in which the dominant species varies considerably between stands. The *Potentillo-Caricetum* areas of the Sharp Street fens are dominated by *Phragmites communis* and *Juncus effusus* with much *Eriophorum angustifolium, Potentilla palustris* and *Agrostis stolonifera* (Lists 36, 37), while the more typical examples in Middle Marsh (List 34) and the southern half of North Marsh (List 33) are dominated by *Juncus effusus, Carex rostrata* and *Eriophorum angustifolium*. *Carex lasiocarpa* and *Menyanthes trifoliata* are abundant in the stands in Middle Marsh where *Typha latifolia* and *Stellaria palustris* are also frequent, as in the *Potentillo-Caricetum* areas at the north of Fenside Marsh (Lists 28-30).

An interesting variant of this community occurs to the north-west of North Marsh where there is a continuous carpet of *Sphagnum squarrosum* and *S. fimbriatum* with *Carex nigra* and the more characteristic species (e.g. *Juncus effusus, Potentilla palustris* etc). There are also patches containing *Dryopteris cristata, D. carthusiana* and *Osmunda regalis* (List 31) which may represent a transitional stage in succession to the *Betulo-Dryopteridetum cristatae* Wheeler 1975.

Peucedano-Phragmitetum Wheeler 1978

This community encompasses the majority of the herbaceous fen vegetation of the study area, five of the seven subassociations being well represented.

typicum subassociation

This subassociation is usually dominated by *Phragmites*, *Cladium* or *Juncus subnodulosus* and covers quite large areas of derelict mowing marsh. While it is characterized by the absence of differential species of other subassociations some of these occur sporadically e.g. *Carex appropinquata*, *Ranunculus lingua*, *Epipactis palustris*. The more species-rich areas are usually *Juncus subnodulosus* dominated (e.g. List 5) and the recurrent occurrence of *Lotus uliginosus* and *Galium uliginosum* (Lists 6,7) suggests the phytosociological affinity of these areas to 'fen meadow'. Most areas of the *typicum* subassociation are extensively invaded by *Salix cinerea* and *Myrica gale*.

While nearly all of the *Peucedano-Phragmitetum typicum* subassociation belongs to the *typical* variant (as described above), the *Carex paniculata* var. and the *Phalaris* var. (Wheeler 1978) do occur. The *Carex paniculata* var. is restricted to a few small areas adjacent to Barton Broad, while the *Phalaris* var. is also found in one area at the margin of Irstead Poors Fen (List 11). *Phragmites communis* and *Phalaris arundinacea* are co-dominant here and *Sonchus palustris* (otherwise restricted to the river banks) occurs in the open fen.

myricetosum subassociation

There is usually a dense development of *Myrica gale* (up to 1 m tall) in the *myricetosum* which is often associated with the *schoenetosum* subassociation. Other areas where the *myricetosum* is common are generally in marshes where management has been neglected or abandoned. *Thelypteris palustris* is often abundant (List 13). This community type also occurs as linear strips along the boundaries between fen compartments in the external system.

cicutetosum subassociation

The *cicutetosum* subassociation has many similarities with the *Cicuto-Phragmitetum* (containing many 'swamp' species), but contains most of the characterising species of the *Peucedano-Phragmitetum* (*Calamagrostis canescens* and *Eupatorium cannabinum* are uncommon). The most species-rich reed beds belong to this subassociation, most examples being of limited extent. In some expressions of this community in the external system there is a dense carpet of *Agrostis stolonifera* (List 18). As suggested by Wheeler (1980a) some of the wetter stands of the *caricetosum* subassociation are transitional to the *cicutetosum* (see below).

schoenetosum subassociation

Within the study area, as most commonly elsewhere in Broadland this community is dominated by *Cladium mariscus* (Wheeler 1980a). The substratum is characteristically solid and *Schoenus nigricans* and *Molinia caerulea* are usually abundant, although in some areas they are difficult to find. More species-rich 'islands' are found in the south-western part of Sedge Marshes with *Pedicularis palustris, Valeriana dioica, Epipactis palustris, Cirsium dissectum* and *Potentilla erecta* occurring in small areas (1-2 m across) of lower plant growth.

In a wetter area of the eastern edge of Sedge Marshes *Carex lasiocarpa* and *Potamogeton polygonifolius* are abundant and *Menyanthes trifoliata* also occurs. After the unusually wet summers of 1980 and 1981 (4.4.3.) *Utricularia minor* and *Scorpidium scorpioides* expanded dramatically in this part of the marsh. Most examples of the *schoenetosum* contain much *Myrica gale* and *Salix repens*. While Sedge Marshes appears to contain the most species-rich example of the *schoenetosum* (List 21), other examples do contain species such as *Osmunda regalis, Epipactis palustris* and *Scorpidium scorpioides*. The most common bryophytes of the *schoenetosum* are *Campylium stellatum* and *Calliergon cuspidatum*.

As with the *cicutetosum* subassociation, some areas of *schoenetosum* in Great Fen are transitional to the *caricetosum* subassociation.

caricetosum subassociation

This subassociation is a rare community, the expressions found within the study area being species-rich. The community occurs in two areas of Great Fen and is dominated by *Cladium mariscus*. All of the characterising species of the subassociation are present and the two areas are different sub-varietal forms of the *Menyanthes* variant (Wheeler 1978). The *Ranunculus lingua* sub. var. occupies a large part of the central, eastern area of Great Fen (List 26). This is a complex area with many wetter hollows, the deeper of which are transitional to the *cicutetosum* subassociation (Lists 24, 25), with *Typha angustifolia, Carex pseudocyperus* and *Cicuta virosa* and an abundance of aquatic species including *Baldellia ranunculoides, Hydrocharis morsus-ranae, Nymphaea alba, Potamogeton coloratus, Potamogeton polygonifolius, Utricularia vulgaris*[1] and *Chara* spp.[2].

Most of the area has a dense bryophyte carpet of *Scorpidium scorpioides* and *Calliergon giganteum* with many other species including *Cinclidium stygium, Campylium elodes* and *Drepanocladus vernicosus*. This bryophyte carpet forms the substrate on which shallow rooted species such as *Drosera anglica* and *Anagallis tenella* are found. *Utricularia intermedia* and *U. minor* are also common species in this area growing intertwined with the mosses. The fine-leaved sedges *Carex diandra, C. lasiocarpa* and *C. appropinquata* are abundant throughout the

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[1]*Utricularia neglecta* was recorded here by Dr. F. Rose 1975.

[2]*C. delicatula, C. aculeolata* recorded by J. Moore 1975.

community as are *Schoenus nigricans* and *Carex elata; C. limosa*[1], *C. lepidocarpa, C. rostrata, C. nigra* and *Carex acutiformis* occurring with less frequency. *Epipactis palustris, Dactylorchis praetermissa, D. incarnata, D. incarnata* subsp. *ochroleuca* and *D. traunsteineri* occur sporadically in more elevated areas of the fen. There are some areas which lack many of the characterising species of the *caricetosum* subassociation e.g. *C. diandra, C. lasiocarpa* etc. and are probably transitional to the *schoenetosum* subassociation.

The *Molinia* sub-variant of the *Menyanthes* var. covers the majority of the northern compartment of Great Fen (List 27). Here *Molinia caerulea, Cirsium dissectum, Anagallis tenella, Samolus valerandi* and *Menyanthes trifoliata* are much more common than in the *caricetosum* of central Great Fen, and aquatic and swamp species are virtually absent. The bryophyte carpet is composed mainly of *Calliergon giganteum, C. cuspidatum* and *Campylium stellatum* and *Epipactis palustris, Dactylorchis incarnata* and *D. praetermissa* are all present but less common than in central Great Fen. *Parnassia palustris* also occurs in this compartment which is extensively invaded by *Salix cinerea, S. repens, Myrica gale* and *Betula pubescens*.

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1 A single plant was recorded by Dr B.D. Wheeler in 1972.

Species poor communities dominated by *Phragmites communis*.

Phragmites sociation Wheeler 1980

The most dense *Phragmites* stands belong to this community, the eastern edge of North Marsh providing a good example (List 51). Here the *Phragmites* grows to approximately 2.5 m tall with *Urtica dioica*, *Epilobium hirsutum* and *Peucedanum palustre* sparsely scattered through the stand. Other examples cover much larger areas of actively managed reed beds (e.g. Goose Marsh, Irstead Poor's Fen) where the reed is less tall and less dense with associates such as *Typha angustifolia*, *Lycopus europaeus* and *Scirpus lacustris* sparsely present (List 52).

Phragmites-Sium latifolium community Wheeler 1980

This slightly richer community covers quite large areas of Mill Dyke Marsh, Irstead Holmes Marshes and Irstead Poor's Fen (N). Common associates are *Rumex hydrolapathum*, *Stellaria palustris* and in the examples in Irstead Poors Fen there is often a densely developed carpet of *Agrostis stolonifera* (List 54).

Phragmites-Typha angustifolia community

Characteristically both *Phragmites* and *Typha angustifolia* have sparse, scattered shoots of only 1-1.5 m in height and the peat surface is covered with a dense mat of *Agrostis stolonifera*. This community covers large areas of the Neatishead Poor's Fen, Irstead Holmes Marshes and the Sharp Street Fens, *Scirpus* *tabernaemontani* and *Stellaris palustris* being common associates (Lists 55, 56). Ruderal species (e.g. *Atriplex hastata*) occur frequently and in Neatishead Poor's Fen *Chara aculeolata*[1] is abundant covering quite large areas. Small *Cladium mariscus* dominated patches (2-3 m across) occur within many areas of this community (List 57).

Phragmites-Agrostis stolonifera community Wheeler 1980

A very similar community to the *Phragmites-Typha angustifolia* community but lacking the abundance of *Typha* (Lists 59, 60), this community is much more widely distributed but covers less area than the former.

Phragmites-Potentilla palustris community

These sparse *Phragmites* stands with a dense understorey of *Potentilla palustris* are often fragmentary but form quite extensive areas in Goose Marsh and North Marsh. In North Marsh this community appears to be a species-poor variant of the *Potentillo-Caricetum rostratae* with *Juncus effusus* and *Eriophorum angustifolium* present. It is generally found in marginal situations, for example around Catfield Broad (Lists 62, 63).

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1 det. J. Moore

Phragmites-Theylpteris palustris community
Wheeler 1980

A rare community in the study area, the *Phragmites-Theylpteris* community covers a few small areas in the Irstead Holmes Marshes, Irstead Poor's Fen and Neatishead Poor's Fen (List 64).

Species-poor communities dominated by *Cladium mariscus*

Cladium-Carex elata community Wheeler 1980

Only one small area of this community occurs to the north of Fenside Marsh (List 66). *Peucedanum palustre* and *Epilobium palustre* are present.

Cladium-Thelypteris palustris community
Wheeler 1980

Again this community occupies only one area of Fenside Marsh (List 65). *Cladium mariscus* and *Thelypteris palustris* grow very densely with some *Phragmites communis* and *Juncus subnodulosus*.

N.B. As these above communities are so species-poor it is possible that the species complement may alter very quickly. For example the occurrence of *Sium latifolium* in a *Phragmites-Typha angustifolia* or *Phragmites-Agrostis stolonifera* community would change the status of these communities to a *Phragmites-Sium latifolium* community.

2.4.3. Fen Woodland Vegetation

Communities of the *Salicion cinereae* alliance

Myricetum gale (Gadecean 1909) Jonas 1935
peucedanetosum Fischer 1967

These species-poor, dense stands of *Myrica gale* are infrequent but widely distributed in the study area. A very typical example of this community is a marginal area at the north of Fenside Marsh where the *Myrica gale* grows up to 1.5 m tall with few associates scattered through the stand including *Calamagrostis canescens*, *Peucedanum palustre*, *Phragmites communis*, *Solanum dulcamara* and *Rumex hydrolapathum* (List 1).

Betulo-Dryopteridetum cristatae Wheeler 1975

Typically a community of immature birch scrub, the *Betulo-Dryopteridetum cristatae* occurs widely distributed in the study area both as small, open 'islands' (sometimes only 1-2 m across) and as more extensive areas where it is often adjacent to more mature birch woodland. *Dryopteris cristata* is a ubiquitous plant of this community but is most abundant and grows most vigourously when the shrub is very young and sparse (Lists 5, 7, 8). Many species more typical of open herbaceous fen (e.g. *Lysimachia vulgaris*, *Juncus subnodulosus*) persist growing through the dense *Sphagnum* carpet which is usually composed of *Sphagnum subnitens*, *S. squarrosum* and *S. fimbriatum*, although in richer examples other species of *Sphagnum* do occur. In an example

Table 2.3. Species lists of fen woodland vegetation. Abbreviations are: *M.g.*, *Myricetum gale*; *B.D.c.*, *Betulo-Dryopteridetum cristatae*; *B.M.*, *Betulo-Myricetum peucedanetosum*; *S.c.c.*, *Salix cinerea* carr; *O.A.*, *Osmundo-Alnetum glutinosae lycopetosum*; M.W., Marginal Woodland, *S*; *Sphagnum* var; T., Typical var. For interpretation of cover-abundance values see Table 2.1. Locations of species lists are given in Appendix 1.

	COMMUNITY TYPE																										
	M.g.		*B.D.c.*							*B.M.*						*S.c.c.*				*O.A.*					M.W.		
										S				T										*S*			
List No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Betula pubescens		+	+	+	+	2	1	1	3	4	3	4	2	4	4	1	1	+		1	1	+	+	1		+	2
Myrica gale	5	5	+		+			+	2	+	1	2	2	2	3										+	+	
Frangula alnus										+		+								+				+	+	+	
Alnus glutinosa								+		1	3	1	+	1				2	1	4	4	4	4	4	3	2	
Salix cinerea					+	+		+	+	1	2	+			1	4	4	4	4	2	+	1	2	+	+		
Quercus robur			+							+												+	+		4	4	3
Crataegus monogyna										+				+					+	+		+				+	+
Sorbus aucuparia												+							+			+		+		1	+
Rosa canina		+												+				+			+						
Rubus fruticosus					+		+	+		2	+	+	2		+			+	+	+			+	+	+	+	+
Lonicera periclymenum										+	+		+		+	+				+	+		+	+	+	+	
Ribes nigrum																+				+	+		+				
Phragmites communis	1	2	+	2	2	3	4	3	2	+	2	1	+	+	2	+	2	+	+		+				2		
Calamagrostis canescens	1	+	+		3	1	3	2	1			+	+	3	+	+	3	3	2	+	1	+	+			+	
Peucedanum palustre	+		+		2	1	+	1	+	+		+	+	+			+	+		+	+	+	+	+	+		
Lysimachia vulgaris			+	+	+		+	+	+			+		+	+	+	+	+						+			
Lythrum salicaria					+		+			+	+	+				+	+			+	+		+				
Eupatorium cannabinum	+	+		+		+		+			+	+		+				+	1	+	+	+		+			
Iris pseudacorus					+		+									+			+	+	+	+	+	+	+		
Carex elata					+				+	+		+				+	+	+	+	+	+	+	+	+	+		
Thelypteris palustris		+			+	2		1	1	+	+	+		+	+			1	+	+	+	+	+				
Juncus subnodulosus			+	+	+	+		1	2			+					1	+									
Cladium mariscus			+			+	3		3	1	+	+				+	+										
Agrostis stolonifera			+	+	+						+					+						+		+			
Valeriana officinalis				+												+	+			+							
Cirsium palustre				+	+			+				+		+			+	+		+							
Potentilla palustris				+		+		+	+	+							+										
Epilobium palustre			+	+	+			+																+			
Dryopteris carthusiana			+	+	1	+	2	+	+			+	+														
D. cristata			+	+	2	1	2	2	+			+															
D. dilatata			+	+	+		1	+		+	+	+	2									+				+	3
Athyrium filix-femina					+					+		+															
Osmunda regalis					+	1			+														+				
Hydrocotyle vulgaris			3					+					+				+	+									
Eriophorum angustifolium			+								1													+			
Carex pseudocyperus					+							+															
Typha angustifolia					2			+																			
Filipendula ulmaria											+			+			+	+	+								

Table 2.3 (Continued)

	COMMUNITY TYPE																										
	M.g.		B.D.c.							B.M.						S.c.c.				O.A.					M.W.		
										S				T										S			
List No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Carex paniculata											+									1							
Pyrola rotundifolia											3						+			+				+			
Lycopus europaeus								+				+				+			+								
Galium palustre													+			+	+	+		+	+	+	+	+			
Mentha aquatica																+	+			+		+	+				
Cardamine pratensis																+				+	+	+	+				
Solanum dulcamara	+													+		+		+	+	+	+	+	+				+
Urtica dioica																+				+	+	+					
Carex acutiformis																		+	+	+	+	+		+			
Carex remota																				+	+	+	+				
Myosotis scorpioides																				+		+		+			
Phalaris arundinacea																				+	+						
Juncus effusus			+		+																				+	+	+
Calluna vulgaris																										2	1
Molinia caerulea									+	+																3	2
Poa trivialis																					+			+		+	+
Brachythecium rutabulum		+					+						+	+	+			1	+	+	+	+					+
Eurhynchium praelongum							+						+			+		+	+	+	+	+	+	+			
Mnium hornum					+	+	+			+		+	+		+					+	+		+	+	+	+	+
Sphagnum subnitens			2		1		2	4	4		1		+														
S. squarrosum				4	1			1	1			1	+											2			
S. fimbriatum				+	1	1		+		3	3	3	2														
S. palustre					+			+		+		2															
S. recurvum						1				+			2														
Calliergon cuspidatum	+					+												+		+							
Polytrichum commune							+	+				+															
Aulacomnium palustre					+			+	+		+		+														
Plagiothecium denticulatum					+			+					+														
P. undulatum							+			+			+														
Calypogeia muellerana					+			+		+	+																
Lophocolea bidentata								+					+														

Additional species: 2. *Salix repens*; 3. *Drosera rotundifolia, Holcus lanatus, Juncus articulatus*; 4. *Calliergon giganteum, Rhytidiadelphus squarrosus*; 5. *Chamaenerion angustifolium, Potentilla erecta, Campylopus pyriformis, Hypnum cupressiforme, Pellia epiphylla, Sphagnum magellanicum*; 7. *Blechnum spicant, Campylium stellatum, Dicranum scoparium, Pseudoscleropodium purum*; 8. *Bryum pseudotriquetrum, Calypogeia fissa, Polytrichum alpestre, Sphagnum teres*; 9. *Drosera rotundifolia, Salix repens*; 10. *Isothecium myosuroides, Thuidium tamariscinum*; 12. *Acer pseudoplatanus, Hottonia palustris, Lemna minor*; 13. *Campylopus introflexus, Dicranum scoparium, Hypnum cupressiforme, Pohlia nutans*; 20. *Calystegia sepium, Carex riparia, Humulus lupulus, Lychnis flos-cuculi*; 21. *Impatiens capensis, Stellaria media*; 22. *Berula erecta, Stachys sylvatica*; 24. *Epilobium montanum*; 25. *Ilex aquifolium, Polypodium vulgare, Polytrichum formosum*; 26. *Hedera helix, Ilex aquifolium, Luzula multiflora, Ribes sylvestre*; 27. *Glechoma hederacea, Holcus lanatus*.

of the *Betulo-Dryopteridetum cristatae* in Fenside Marsh, *Sphagnum capillaceum, S. palustre, S. magellanicum* and *S. teres* are all present. Other bryophytes commonly found in this community include *Aulacommium palustre, Polytrichum commune, P. alpestre, Plagiothecium undulatum* and *Calypogeia muellerana.*

Drosera rotundifolia and *Pyrola rotundifolia* occur in a few stands of this community-type in Fenside Marsh and Great Fen and *Calluna vulgaris* is also present in one place. Less floristically rich examples tend to have densely packed saplings of *Betula pubescens* and *Dryopteris cristata* is usually present only in sterile form in such places. Whilst many examples of the *Betulo-Dryopteridetum cristatae* border more mature birch carr many of the more open examples are adjacent to quite wet fen and in some cases, fen pools (List 6).

Betulo-Myricetum peucedanetosum Wheeler 1980

All of the mature birch woods in the study area are referable to this subassociation. Those examples on more solid peat belong to the *typical* variant (Wheeler 1978) and include the most mature examples. There is generally an understorey of *Myrica gale* with *Salix cinerea, Rubus fruticosus* and *Lonicera periclymenum.Calamagrostis canescens* usually dominating the ground flora of open glades (Lists 14, 15).

The *Sphagnum* variant (Wheeler 1978) is more frequent. In this there is usually a continuous carpet of *Sphagnum fimbriatum, S. subnitens, S. squarrosum* and *S. palustre.*

In some examples for instance in the centre of Great Fen, *Pyrola rotundifolia* is abundant sometimes forming patches of up to 3 m in diameter. A large population of *Eriophorum angustifolium* also occurs in one area (List 11). *Cladium mariscus* and *Phragmites communis* are frequent components of the ground flora as is *Dryopteris dilatata* and more rarely *Athyrium filix-femina* and *Blechnum spicant*. Other frequent bryophytes include *Aulacomnium palustre*, *Plagiothecium denticulatum*, *Eurhynchium praelongum* and *Lophocolea bidentata*.

Salix cinerea carr

There are many extensive examples of this willow carr in the study area, the largest developments being in the western part of Great Fen and Irstead Poors Fen. As described by Wheeler (1978) this community often forms a narrow band around the edges of fen compartments, often with *Alnus glutinosa* and *Betula pubescens* and forms an almost continuous band along the Catfield-Barton Turf parish boundary (which marks the former course of the River Ant (Jennings 1952)). The community also occurs more extensively over areas of derelict fen, for example in Irstead Poors Fen, and stands of the *Peucedano-Phragmitetum typicum* appear transitional to *Salix cinerea* carr in some cases (Table 2.2., Lists 1, 2). There are often few associated species, especially in younger, denser examples of the community, although most of the common fen species (e.g. *Lycopus europaeus*, *Mentha aquatica*, *Cardamine pratensis*) occur in some places. *Galium* *uliginosum*, an uncommon species in these marshes, is often found associated with more mature willow carr while *Pyrola rotundifolia* is generally associated with younger examples (List 17). The bryophyte flora is poorly developed, the commoner species being *Calliergon cuspidatum*, *Brachythecium rutabulum* and *Mnium punctatum*.

Osmundo-Alnetum glutinosae lycopetosum Klötzli 1970

All of the alder carr in the study area belongs to the *Peucedanum palustre* variant (Wheeler 1980) of this subassociation *Salix cinerea* is usually frequent and *Betula pubescens* occurs in some stands. There is often a distinct shrub layer with *Ribes nigrum*, *R. sylvestre*, *Viburnum opulus*, *Rosa canina*, *Rubus fruticosus* and occasionally *Frangula alnus*. Climbing plants such as *Solanum dulcamara*, *Lonicera periclymenum* and *Humulus lupulus* occur frequently although *Humulus* is less common here than in many of the Broadland alder carrs. The ground layer is most frequently dominated by *Carex acutiformis*; *Phragmites communis*, *Carex elata*, *C. remota* and *Calamagrostis canescens* also being important species. Other common species include *Myosotis scorpioides*, *Iris pseudacorus*, *Peucedanum palustre*, *Filipendula ulmaria* and *Eupatorium cannabinum*. *Osmunda regalis* occurs in several places and *Urtica dioica* is common alongside dykes. The community is most extensive in marginal areas around Catfield Broad and Fenside Marsh, also forming a wide band along the margin of Barton Broad.

An unusual sub-variant of the *Peucedanum palustre* var. transitional to the *Sphagnetosum* subassociation Wheeler 1975 occurs in North Marsh (List 24). *Alnus glutinosa* dominates the tree layer with an understorey of *Salix cinerea, Sorbus aucuparia* and *Frangula alnus*. There is a virtually continuous carpet of *Sphagnum squarrosum,* with some *Sphagnum fimbriatum,* the herb layer being sparsely developed with *Scutellaria galericulata, Peucedanum palustre, Carex pseudocyperus* and *Thelypteris palustris* among the species present.

2.4.4. Marginal Vegetation

Fen Grassland

There is little fen grassland adjacent to these marshes as most suitable areas are either overgrown by carr or have been used for agriculture. Some small areas do remain but only one of these in Middle Marsh is of any significant size. This grassland with much *Molinia caerulea* is included within the *Junco (subuliflori)-Molinion* alliance.

Cirsio-Molinietum Sissingh et De Vries 1942

The south-eastern corner of Middle Marsh contains a fine example of the *nardetosum* subassociation of this community. *Cirsium dissectum, Dactylorchis maculata* subsp. *ericetorum* and *Luzula multiflora* are abundant with *Molinia caerulea, Nardus stricta* and *Agrostis tenuis* as the main grass species.

Sieglingia decumbens and *Festuca ovina* are also present. Further towards the centre and at the western side of the marsh are areas which contain more species of the *Peucedano-Phragmitetum* (e.g. *Juncus subnodulosus, Calamagrostis canescens, Lysimachia vulgaris*). These areas are examples of the *eupatoretosum* sub-association Wheeler 1980. There are also two small pockets of fen grassland in North and South Marshes which appear to be species-poor examples of the *Cirsio-Molinietum*. *Dryopteris cristata* is present in this grassland in South Marsh.

Other marginal grassland areas such as those of the north-eastern corner of Fenside Marsh have some affinity to the *Cirsio-Molinietum* but are much more species-poor. These areas seem to have been extensively disturbed at some time and contain much *Carex nigra, Juncus effusus* and *Holcus lanatus*.

Fen Meadow

An area of fen meadow is present at the southern tip of the study area which probably falls within the *Juncus subnodulosus-Iris pseudacorus* nodum Wheeler (1980c) of the *Calthion palustris* alliance. The meadow is periodically grazed by cattle and contains many fen species including *Schoenus nigricans*. The dominant species varies across the area *Juncus effusus* being most common with much *Juncus subnodulosus, J. articulatus* and *Phragmites communis* in parts.

Marginal Woodland

A narrow band of quite dry woodland with much *Quercus robur* skirts most of the landward margins of the marshes. *Betula pubescens* is also common, the understorey usually being composed of *Ilex aquifolium*, *Crataegus monogyna*, *Frangula alnus* and *Myrica gale*. Along the northern edge of Sedge Marshes and Fenside Marsh there is an interesting ground flora with *Molinia caerulea*, *Calluna vulgaris* and *Luzula multiflora* although the woodland floor is usually virtually bare in most places (Lists 25, 26).

Disturbed Vegetation

The vegetation which has colonized the dredgings from the dykes and river is usually of little interest with much *Calamagrostis canescens*, *Pteridium aquilinum*, *Rubus fruticosus* and *Betula pubescens*. Alongside some stretches of the River Ant *Sonchus palustris* and *Conium maculatum* occur on the river banks.

2.5. VEGETATION OF THE DYKES AND POOLS

Three main categories (noda) of aquatic macrophyte vegetation have been identified from the dykes and turf ponds of the Catfield and Irstead Fens by Wheeler and Giller (1982b). Examples of each of these categories are given in Table 2.4. There is very poor development of aquatic macrophyte vegetation in the dykes of the external system. *Nuphar lutea* and *Lemna minor* are the only species recorded in the initial vegetation survey from dykes with a free connection to the River Ant. In 1981 *Ceratophyllum demersum* was quite abundant in the East-West dyke and *Enteromorpha* sp., *Chara* sp. and *Potamogeton pusillus* agg. were recorded from this area. Some small pools in Irstead Poor's Fen which are probably isolated remnants of former dykes contain *Utricularia vulgaris* and charophytes.

The open waters of the internal system support a very rich and varied flora.

The *Elodea-Potamogeton crispus* nodum is confined to dykes at the very margins of the study site around Poplar Marsh and Catfield Broad Woods. There is usually a luxuriant development of vegetation with much *Ceratophyllum demersum, Elodea canadensis* and locally *Oenanthe aquatica*. Other associated species include *Potamogeton natans, P. crispus, Ranunculus aquatilis* and emergents such as *Alisma plantago-aquatica, Sparganium erectum, S. emersum* and *Glyceria maxima*. *Juncus bulbosus* and *Scirpus fluitans* have been recorded from this vegetation nodum. In the summer months

Table 2.4. Species composition of some stands of aquatic vegetation of the Catfield & Irstead Fens, July 1978. Values are subjective cover estimates: + = 0-5%; 1 = 6-20%; 2 = 21-40%; 3 = 41-60%.

	Utricularia nodum					*Ceratophyllum-Stratiotes* nodum							*Elodea-Potamogeton* nodum			
List No:	3	5	8	9	4	1	2	6	7	10	11	12	13	14	15	16
Hydrocharis morsus-ranae	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Lemna minor	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
L. trisulca	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Callitriche platycarpa	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+
Polygonum amphibium	+	+	+			+	+	+	+		+	+	+	+	+	
Utricularia vulgaris	3	3	+	+	+	3	+	1	3	3	+	3				
Myriophyllum verticillatum	+	+	+	+	3	+	+	+	+							
Potamogeton obtusifolius	+		+	+	+	+	+	+			2					
Nuphar lutea	+	+	+		+	+	+	1		+						
Stratiotes aloides			+			+	+	3	2	+	+	2				
Ceratophyllum demersum					+	+	+	+	2	2	3	2	+	+	2	
Rhizoclonium sp.							+	1	+	1	2	2	3	2	3	3
Sparganium erectum							+	+			+		+		+	+
Rorippa nasturtium-aq. agg.					+		+				+			+	1	2
Elodea canadensis								+	+		+	+	3	+	3	
Potagmogeton crispus											+		+	+	+	
Enteromorpha sp.													2	2	3	2
Glyceria maxima													+	+	+	+
Potentilla palustris		+			+	+			+	+						
Hottonia palustris		+			+		+	+	+							
Berula erecta			+			+	+				+	+				
Oenanthe aquatica							+		+		+	+				
Ceratophyllum submersum		2			+				+		+					
Sium latifolium						+				+	+					
Alisma plantago-aquatica		+									+			+	+	+
Nymphaea alba	+						+									
Ranunculus lingua						+				+						
Sagittaria sagittifolia							+	+								
Hypericum elodes	1															

the surface is often covered with a thick scum composed mainly of Enteromorpha sp. and Rhizoctonium sp..

The *Ceratophyllum-Stratiotes* nodum is also found at the margins of the study site but is more frequent than the *Elodea-Potamogeton* nodum. In dykes where the *Elodea-Potamogeton* nodum is present it often occupies the (often extensive) transition zone between this and the more central areas of the study site. *Ceratophyllum demersum* is normally the dominant species often forming dense, tangled stands. *C. submersum* is the dominant species in an example of this nodum in the marginal reaches of the dyke between Great Fen and Sedge Marshes. *Stratiotes aloides* is not abundant in most examples but is dominant in a few places, for instance in the dyke between Middle and North Marshes where in some years it forms quite dense rafts. *Utricularia vulgaris* is also quite abundant in some examples of this nodum.

The *Utricularia* nodum is almost exclusively confined to the more central areas of the internal system where it occupies long stretches of the dykes. An exception to this is found in the small side pools of Catfield Broad where *Polygonum amphibium* is also abundant. This nodum is well developed in Fenside Inner Broad with much *Nymphaea alba* and beds of charophytes. *Hydrocharis morsus-ranae* and *Potentilla palustris* are common alongside the dyke edges in the *Utricularia* nodum and *Hypericum elodes*, *Stratiotes aloides* and *Fontinalis antipyretica* occur occasionally.

In a number of small pools adjacent to Fenside Inner Broad an unusual vegetation is present with many emergent and aquatic species. *Lythrum salicaria* is the dominant species and common associates include *Ranunculus lingua*, *Cicuta virosa*, *Veronica scutellata* and *Utricularia vulgaris*. An example of this contained the following species:

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3 *Lythrum salicaria*	+ *Ranunculus lingua*
+ *Carex pseudocyperus*	+ *Cicuta virosa*
1 *Juncus subnodulosus*	+ *Sium latifolium*
+ *Veronica scutellata*	+ *Juncus effusus*
+ *Epilobium parviflorum*	+ *Juncus articulatus*
+ *Galium palustre*	
+ *Potentilla palustris*	+ *Lemna minor*
+ *Cladium mariscus*	+ *Hydrocharis morsus-ranae*
1 *Mentha aquatica*	+ *Callitriche platycarpa*
+ *Phragmites communis*	+ *Utricularia vulgaris*

Ellis (1963) described similar areas from Broadland with much *Lythrum salicaria* as hollows created by intense grazing by the coypu (*Myocastèr coypus*).

2.6. DISCUSSION

There was little documentation of the vegetation of the study area until the description of the plant communities of the Ant valley by Wheeler (1978), although a few plant records probably relating to the Catfield Fens have been found (Table 2.5).

All of these species still occur within the study area. The occurrence of *Sphagnum* spp. in the region of Barton Broad has also been described by Pallis (1911a), Poore (1956) and Ellis (1965).

As previously suggested (1.3) the study area contains a great diversity of plant species and communities. *Lathyrus palustris* is the only apparent absentee from the study area of the Broadland rarities. The primary fen communities of the *Carex paniculata* sere (Lambert 1951) are largely absent from the study area but are abundant in the marginal vegetation on the western side of Barton Broad. The scarcity of such communities in the study area is probably due to the lack of much primary fen at the broad margin.

If the distribution of the plant communities within the study area (Plate 3) is compared with the distribution of open water/swamp on the 1885 Ordance Survey map it can be seen that many community types are apparently restricted to or from such areas. Most present-day swamp communities, the *Cladietum marisci*, *Scirpo-Phragmitetum* and *Cicuto-Phragmitetum* are found

Table 2.5. Some plants records from the study area

Species	Date	Location	Recorder	Source
Carex lasiocarpa	1911	Catfield	Miss Cator	Nicholson (1914)
Carex paradoxa (= *C. appropinquata*)	1902	Great Fen between Catfield and Barton Broad	C.E. Salmon	Bennet (1904)
Liparis loeselii	1895	Catfield Fen	Rev. M.C.H. Bird	Bennet (1912)
	1905	Catfield Fen	Mr & Mrs Nicholson	Bennet (1912)
Peucedanum palustre	1903	Great Fen near Barton Broad	C.E. Salmon	Bennet (1912)
Scirpus fluitans (with *Nasturtium officinale* (= *Rorippa nasturtium-aquaticum*) *Potentilla palustris* and *Juncus subnodulosus* (= *J. articulatus*))	?	Dyke at Fenside, Catfield	Nicholson	Nicholson (1909)

in areas shown as open water in 1885, as are the *Peucedano-Phragmitetum cicutetosum* communities and communities with much *Sphagnum*, the *Betulo-Dryopteridetum cristatae* and *Betulo-Myricetum (Sphagnum* variant) (Fig. 2.1). The only exception to this is in the southern part of Irstead Poor's Fen, but here there is evidence of former dykes and pools.

The *Peucedano-Phragmitetum schoenetosum* and *P.-P. myricetosum* communities are restricted to areas marked as fen on the Ordance Survey map (Fig. 2.2). *Osmundo-Alnetum* communities are likewise distributed in the study area but this is not the case elsewhere in Broadland. Other communities for example the *Peucedano-Phragmitetum typicum*, do not exhibit such restricted distributions.

The *Potentillo-Caricetum rostratae* communities are all found in very marginal areas which may well have been drained in the last century (1.2). Pallis (1911a) describes a *Potentilla palustris* society with much *Carex inflata (= C. rostrata*) in a marginal area near Barton Broad. The presence of many species characteristic of acidic heathland (e.g. *Nardus stricta*, *Calluna vulgaris*, *Ulex europaeus*) in the marginal communities (2.4) may represent a relict of the former vegetation of the adjacent mineral ground (cf. Pallis 1911a). In other marginal areas of the Ant and Thurne valley fens *Erica tetralix*, *Erica cinerea* and *Ulex gallii* can also be found, supporting this suggestion.

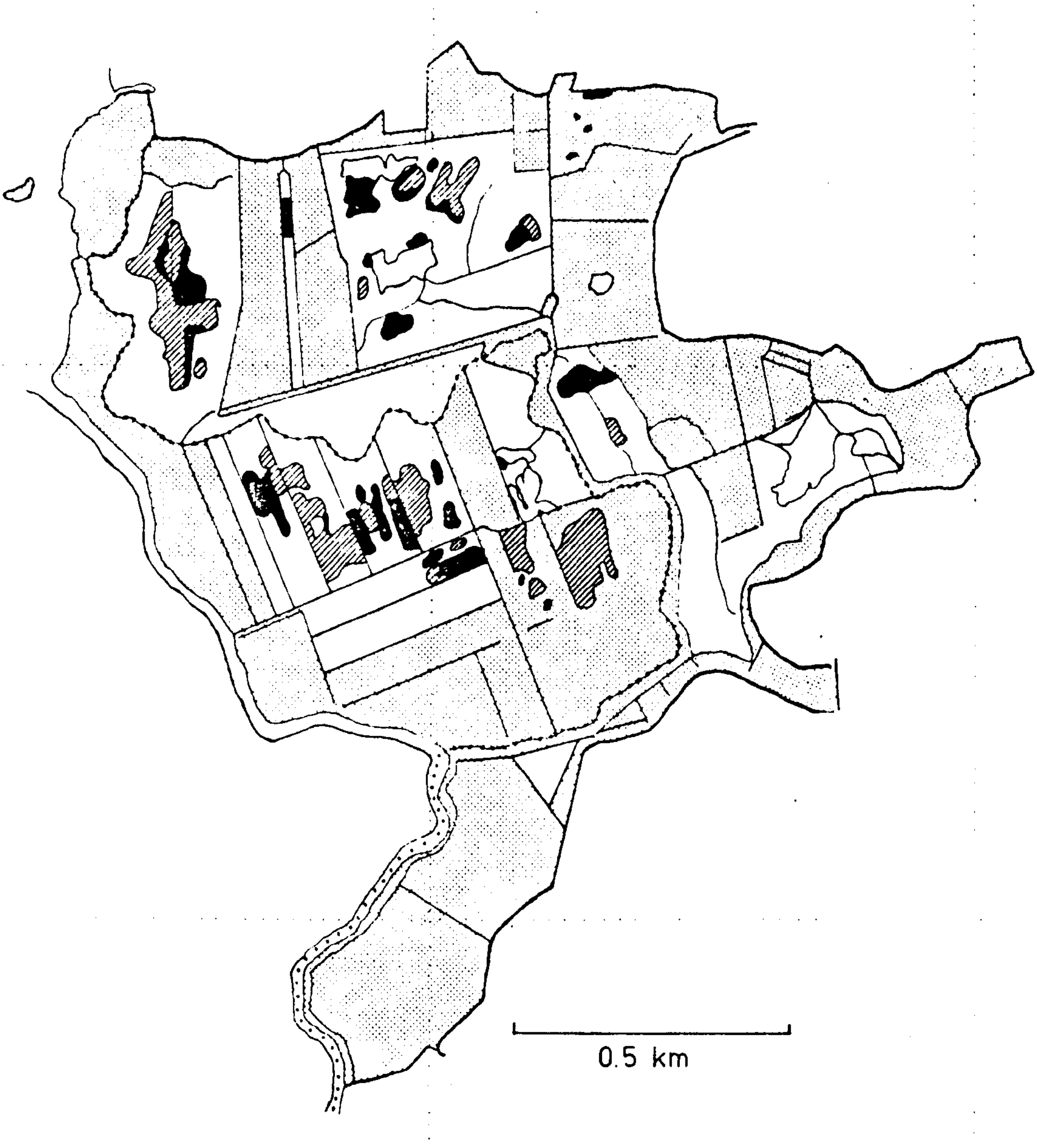

Fig. 2.1. Map showing the distribution of *Betulo-Dryopteridetum cristatae* (■) and *Betulo-Myricetum* (▨) communities. Stippled areas not shown as swamp on the 1885 6" O.S. map.

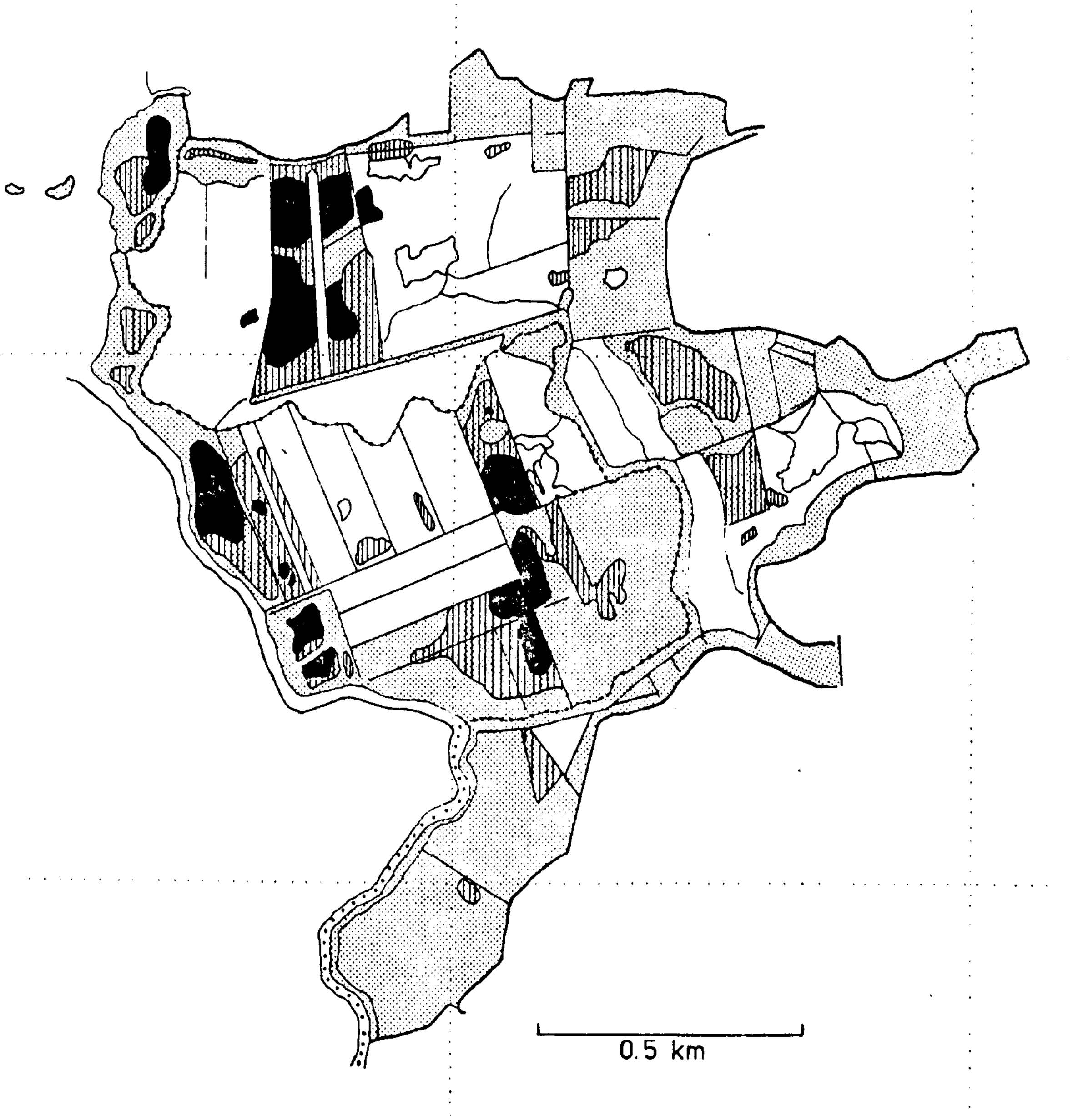

Fig. 2.2. Map showing the distribution of *Peucedano-Phragmitetum schoenetosum* (■) and *Peucedano-Phragmitetum myricetosum* (▨) communities stippled areas not shown as swamp on the 1885 6" O.S. map.

CHAPTER 3

ALLUVIAL STRATIGRAPHY AND VEGETATION SUCCESSION

3.1. INTRODUCTION

The alluvial stratigraphy of the broadland river valleys has been extensively studied, both with respect to the origin of the broads (Jennings & Lambert 1951; Jennings 1952; Lambert & Jennings 1960) and to examine evidence for hydroseral succession (Lambert 1951; Lambert & Jennings 1951). Most of the studies of vegetation succession have been made in the Bure valley (Lambert 1951). Comparatively little attention has been paid to the alluvial stratigraphy of the Ant valley around Barton Broad (Jennings 1952) and this provides no discussion of the relationship of the present vegetation to the stratigraphy of the peat deposits.

An investigation of the alluvial stratigraphy of the study area was undertaken to examine how the present vegetation of the study area had developed. As the underlying layers of peat had been shown to be mainly brushwood peat of some considerable antiquity throughout the Broadland river valleys (Jennings 1952), the present investigation was restricted to an examination of the stratigraphy of the deposits above the brushwood peat.

3.2. METHODS

The surface stratigraphy of the peat deposits was examined by cross- sections constructed along four levelled transects. Peat sampling was carried out using a Hiller peat borer in most cases. The surface peat in many areas was too fresh and fibrous or too loose to be sampled by Hiller or 'Russian' design peat borers. In such cases the peat was excavated using a sharpened spade and by hand, but often there was 10-20 cm of the peat which could not be sampled using such methods (c.f. Lambert & Jennings 1951). Borings were made at intervals of 30 m normally and at smaller intervals where topographical or vegetational changes were noted on the surface. The analysis of the major components of the peat samples obtained was conducted mainly in the field but critical samples were returned to the laboratory to be compared with a collection of preserved material. In some cases monoliths of the surface peat (0-60 cm below the peat surface) were examined in detail in the laboratory.

Levelling of transects was initially carried out using a Quickset Level but difficulties were encountered due to the dense vegetation (especially young birch carr). To overcome these difficulties the transects were marked with canes at measured intervals and each transect was subsequently levelled during a period of very high water levels in the winter when the surface was almost completely flooded (in January 1981) by measuring the height of standing water above the peat surface. In a few cases (notably ronds and *Sphagnum* communities) the water level was below the peat surface and here estimations were made in shallow pits. This method of levelling may be slightly inaccurate in such cases where the water level is below the peat surface (Jennings 1952). The differences in the height of the peat surface may be greater than that shown on the transects at times of lower water levels when lowering of the peat surface may occur in some areas (4.4.3). Transects were selected which crossed many different vegetation types in both the external and internal systems and linked many areas selected for further detailed studies (4.2.2). Additional peat borings were made in other areas of the external system to supplement the information provided by the main transects.

3.3. THE PEAT STRATIGRAPHY DIAGRAMS

The locations of the transects are shown in Fig. 3.1. The symbols used to identify peat types are those of Jennings and Lambert (1951) with some additional symbols (Fig. 3.2.). The surface vegetation types of the areas in which the peat borings were made can be found by comparison of Fig. 3.1 and Plate 3. The water levels shown on the diagrams are estimated 'typical' summer water levels.

3.3.1. Sedge Marshes-Fenside Marsh Section (Fig. 3.2)

The peat beneath the *Peucedano-Phragmitetum schoenetosum* of Sedge Marshes was underlain by dark humified peat predominantly composed of black *Cladium* roots with some *Cladium* and *Phragmites* rhizomes. Beneath this was a grey-green mud with many *Phragmites* rhizomes which extended into the surface horizons of the brush-wood peat. In the central overgrown dyke which dissects the two parts of Sedge Marshes the peat was much less humified.

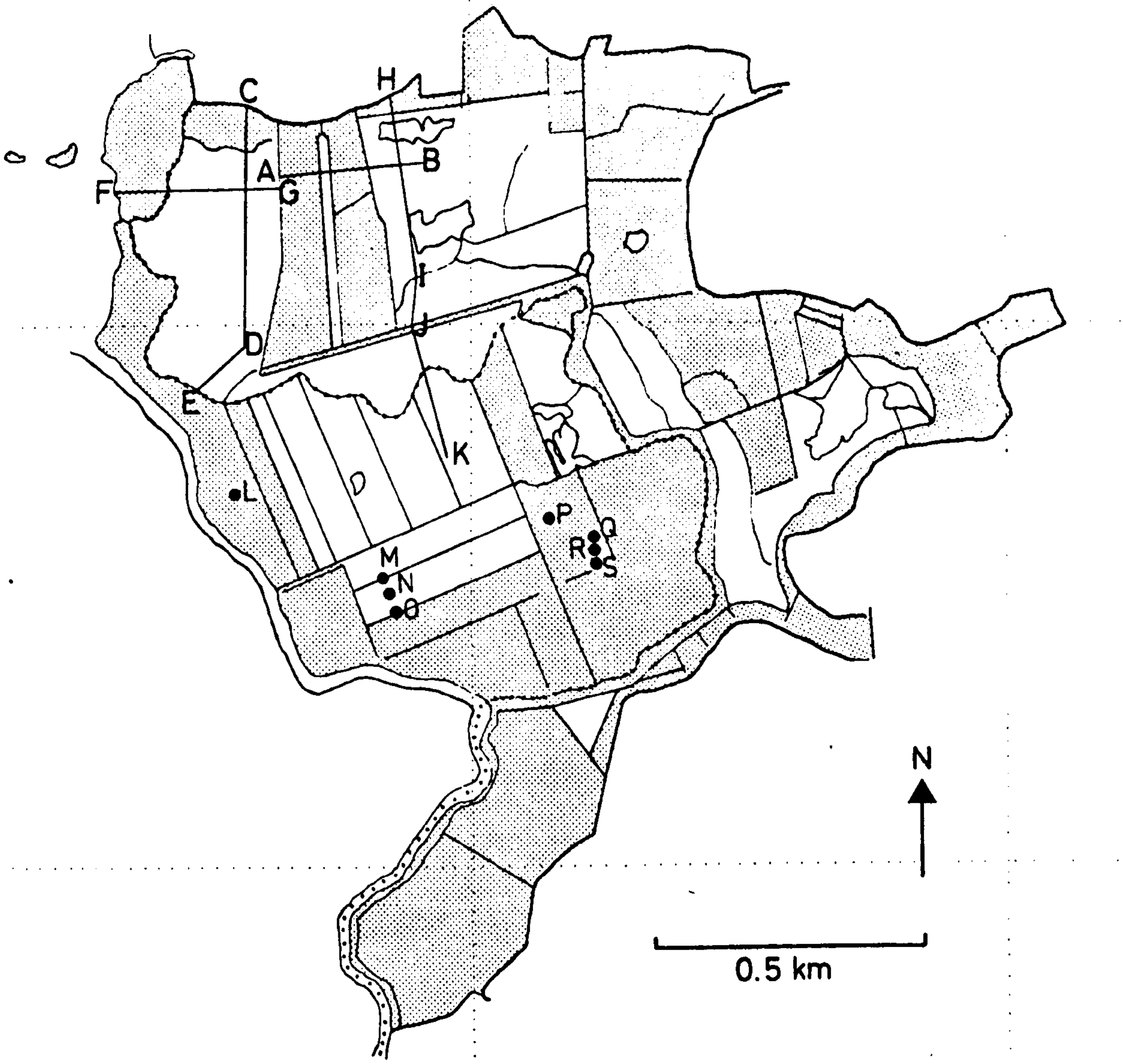

Fig. 3.1. Locations of the transects and additional sites selected for stratigraphical investigation. Stippled areas not marked as swamp on the 1885 6" Ordnance survey map.

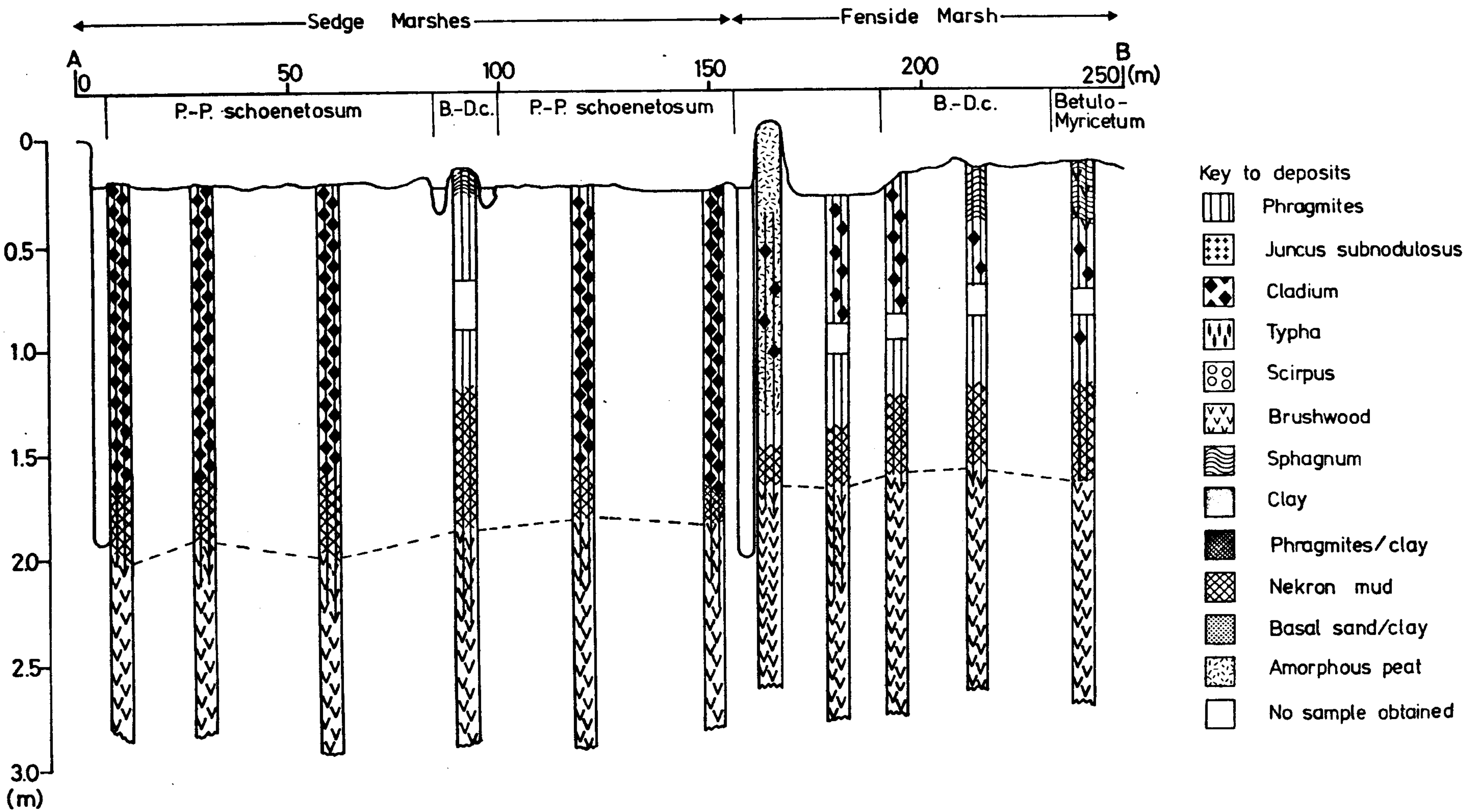

Fig. 3.2. Sedge Marshes-Fenside Section.

The *Phragmites*/brushwood peat gave way to a much wider band of grey nekron mud with *Phragmites*, underneath quite pure fresh *Phragmites* peat. The *Phragmites* peat was capped with 15 cm of *Sphagnum* peat where a small island of *Betulo-Dryopteridetum cristatae* was present.

The surface amorphous peat on the eastern edge of the dyke between Sedge Marshes and Fenside Marsh is the result of peat deposited when the dyke was cut in 1968 (D.S.A. McDougall, pers. comm.). The metre of peat directly beneath this is quite amorphous, perhaps due to compaction of the peat, but some *Cladium* and *Phragmites* remains were identifiable. In the area to the east of this dyke the level at which the brushwood peat was found is generally slightly higher than that found in Sedge Marshes. The surface peat layers in this area were quite fresh and unhumified. The *Cladium*/*Phragmites* peat was covered by a thin layer of *Sphagnum* and *Sphagnum*/brushwood peat under the areas of the *Betulo-Dryopteridetum cristatae* and *Betulo-Myricetum* respectively.

The macrofossil composition of a peat monolith from beneath the *Betulo-Dryopteridetum cristatae* community in Fenside Marsh is described below.

Depth	Main components	Other macrofossils
0-10	Fresh *Sphagnum* peat (*S. fimbriatum, S. subnitens*)	Birch leaves, wood fragments.
10-20	more humified *Sphagnum* peat (*S. fimbriatum, S.* sect. *Acutifolia*)	*Juncus subnodulosus* rhizomes and stems. *Thelypteris palustris* rhizomes. *Phragmites* leaves. *Carex pseudocyperus* seed.
20-30	humified *Sphagnum* peat (*Sphagnum fimbriatum, S. squarrosum, S.* sect. *Acutifolia*)	*Phragmites* rhizome. *Cladium* seed, leaves, rhizomes.
30-40	*Cladium/Phragmites* rhizomes	Few *Sphagnum* leaves (c.f. *squarrosum*) at 30-32 cm depth.
40-50	*Cladium/Phragmites* rhizomes	*Typha angustifolia* rhizomes.
50-60	"	"

A mixed *Cladium/Phragmites* peat with some *Typha* rhizomes was present in the peat 30 cm below the surface. *Sphagnum* remains were present above 32 cm and predominated the surface 30 cm of peat. *Sphagnum squarrosum* branches and leaves were important below 20 cm and *Sphagnum fimbriatum* and *Sphagnum subnitens* were the main peat forming species in the upper 20 cm.

3.3.2. Great Fen Section (Fig. 3.3)

The *Salix* carr bordering the dyke at the northern margin of Great Fen had a shallow deposit (50 cm) of very humified structureless peat over a coarse sand-clay mixture.

In the peat borings taken between 20 and 300 m along the transect a similar sequence of peat types was observed from the underlying brushwood peat through brushwood/*Phragmites* and *Phragmites*/nekron mud to *Cladium* peat, although the depth at which the transitions from one peat type to another cccurred did vary. There was a greater depth of *Cladium* peat in the northern compartment of Great Fen which had a more humified character than that from the central area (200-250 m). The upper level at which brushwood peat was found also varied being relatively lower in Great Fen (North) and variable but higher in the central part of Great Fen. The level of the peat surface was also quite variable in the central part of the fen, demonstrating some correspondence with the upper limit of the brushwood peat.

At the southern end of the section is an overgrown channel which marks the Catfield-Irstead parish boundary, indicating the former course of the River Ant (Jennings 1952). This is known as the Hundred Stream. The two borings close to this dyke had a deep band of pure blue-grey clay beneath very amorphous peat in which only a few *Phragmites* rhizomes could be identified. Further away from the dyke the brushwood peat was found less than two metres below the peat surface beneath a clay with a quite different character. This clay was sticky but with much organic material resembling a *Phragmites*/nekron mud/clay mixture. Jennings (1952) examined the stratigraphy of a section quite close to this and termed the deposit in the corresponding horizons a *Phragmites*/clay. This name will be adopted here.

The *Phragmites*/clay band extends to roughly 200 m from the Hundred Stream. The *Phragmites*/clay is overlain in most cases by *Phragmites*/nekron mud over which *Phragmites*/*Cladium*/*Juncus*, *Phragmites*/*Juncus* and *Phragmites*/*Typha* peats were found. The *Phragmites*/*Typha* peat at 450 m on the section had a semi-floating character underfoot and was a mixture of fresh *Phragmites*/*Typha* rhizomes and living rhizomes.

Monoliths of surface peat which underlay *Peucedano-Phragmitetum caricetosum* communities in Great Fen (North) and central Great Fen were examined in detail. The main macrofossil components in monoliths from both of these areas were *Cladium* rhizomes, black *Cladium* roots being more abundant in the peat from Great Fen (North). An example of the macrofossils found in the surface peat from Great Fen (North) is given below.

Depth (m)	Main components	Other Macrofossils present
0-10	*Cladium* rhizomes and roots	*Carex elata* leaves, *Calliergon giganteum* branches.
10-20	"	*Carex* c.f. *elata* seed. *Menyanthes* rhizomes. *Calliergon giganteum*, *Campylium stellatum* branches.
20-30	"	*C. elata* leaf bases, *Campylium* sp. leaves. *Phragmites* rhizomes.
30-40	"	*Juncus subnodulosus* rhizomes, *Schoenus* leaf bases.
40-50	"	*Scorpidium scorpioides* v. abundant. *Phragmites* rhizomes.
50-60	"	*Schoenus* leaf bases. Few *Scorpidium scorpioides* and *Calliergon* c.f. *giganteum* leaves.

The macrofossils present in the surface 40 cm of peat indicate the presence of a similar vegetation to that found in this area at present. *Carex elata, Juncus subnodulosus, Phragmites, Menyanthes* and *Schoenus* remains were present in these surface layers with *Calliergon* and *Campylium* shoots; all species which grow here at present. In the peat from 40-50 cm below the surface *Scorpidium* branches were very abundant perhaps indicating that much wetter conditions were prevalent at this time, *Scorpidium scorpioides* has not been recorded here recently.

In the central area of Great Fen, *Scorpidium scorpioides* is today very abundant and many remains were found in the surface peats:

Depth (m)	Main components	Other macrofossils present
0-10	*Cladium* rhizomes	*Juncus subnodulosus* rhizomes and shoots. Complete shoots of *Scorpidium scorpioides*. *Phragmites* rhizomes, *Schoenus* leaf bases.
10-20	"	*Carex* c.f. *elata* leaf bases. *Phragmites* rhizomes. *Schoenus* leaf bases. *Scorpidium scorpioides* branches.
20-30	"	*Carex elata* seed. Abundant leaves of *Scorpidium scorpioides*. *Schoenus* leaf bases.
30-40	"	*Phragmites* rhizomes, *Carex elata* leaf bases, *Scorpidium scorpioides* branches.
40-50	"	*Carex elata* leaf bases, *Phragmites* rhizomes, *Scorpidium scorpioides* branches.
50-60	"	Fine gritty mud with many snail shells. Few *Scorpidium* leaves.

All of the other species recorded in the surface peats from the central area of Great Fen are found in the surface vegetation at present. In the lower horizons described above (50-60 cm depth) a fine nekron mud with many *Cladium* rhizomes and many snail shells was found. It is likely that this deposit indicates very open swamp vegetation was present at the time it was formed.

3.3.3. Great Fen-Barton Broad Section (Fig. 3.4).

Again a blue-grey clay deposit was found close to the course of the Hundred Stream. The distribution of clay is unusual and does not seem to be centralised around the exact location of the Catfield/Irstead parish boundary. This was probably as the line of transect was quite close to some marked bends in the former course of the River Ant.

The stratigraphy of the section at the eastern end was similar to that found in the north-south Great Fen section. Shallow *Sphagnum* peat (c. 10 cm) is found further west overlying similar deposits on the edge of much deeper *Sphagnum* peat (c. 50 cm). Further towards Barton Broad a *Phragmites*/brushwood peat is found underneath *Salix* carr and very humified brushwood peat underneath the *Osmundo-Alnetum glutinosae*. In the open fen close to the broad *Phragmites* peats extend from the surface to the clay below.

A peat monolith was taken from beneath the *Betulo-Myricetum* community for detailed examination.

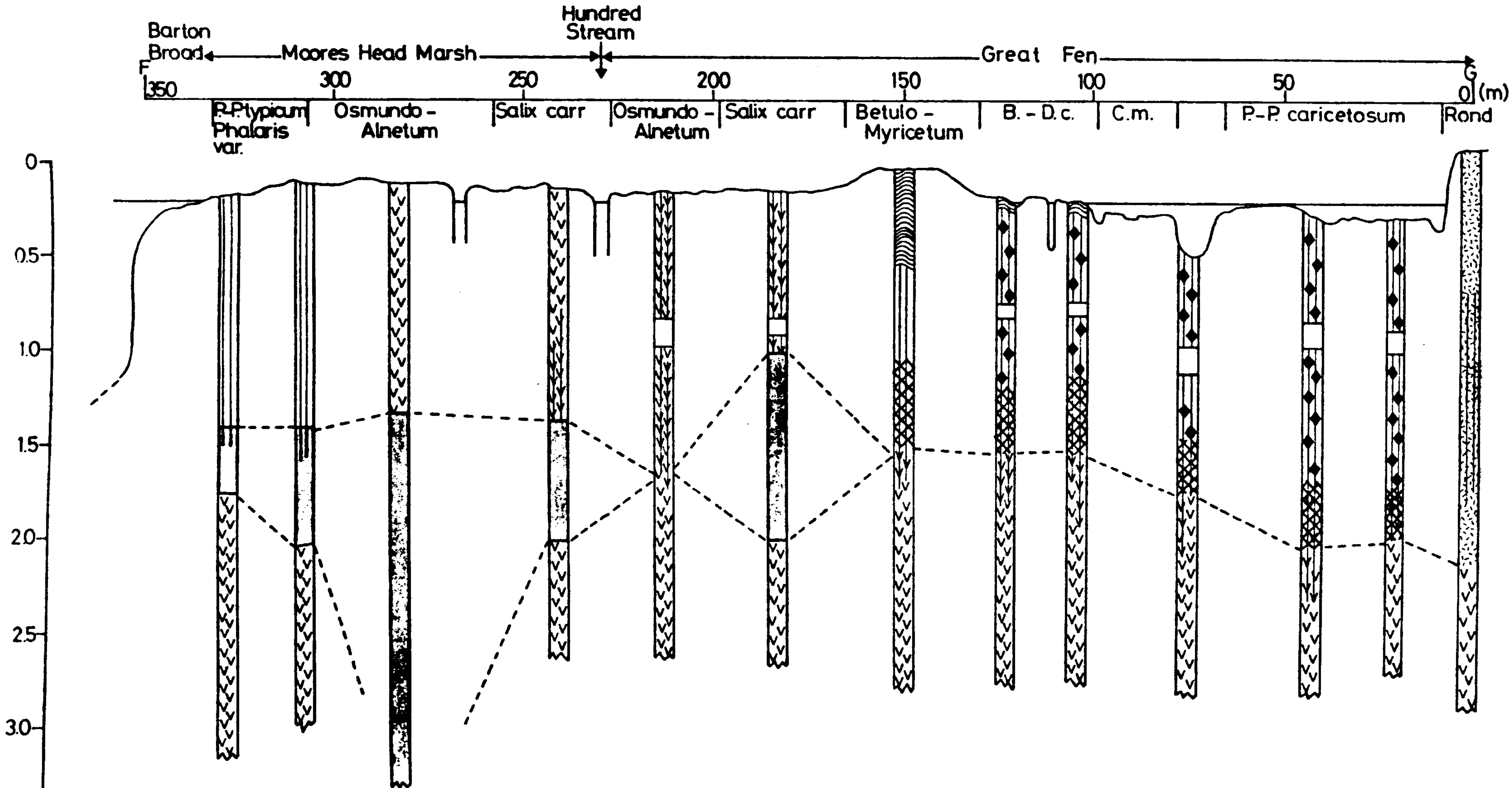

Fig. 3.4. Great Fen-Barton Broad section (A key to the symbols is given in Fig. 3.2.).

Depth (m)	Main components	Other macrofossils present
0-10	*Sphagnum*	Birch leaves, wood fragments abundant
10-20	*Sphagnum* (*S. fimbriatum*)	Birch leaves, wood fragments abundant.
20-30	*Sphagnum* (*S. fimbriatum*)	*Phragmites* rhizomes, Birch leaves.
30-40	*Phragmites* rhizomes/*Sphagnum* (*S. squarrosum*, *S. fimbriatum*)	*Betula* leaves, wood fragments
40-50	*Phragmites* rhizomes & stems	*Sphagnum squarrosum*, *S. fimbriatum* fragments
50-60	*Phragmites* rhizomes	*Ranunculus* c f. *lingua* seed. *Sphagnum* leaves at 50-55 cm.
60-65	*Phragmites* rhizomes & stems	*Drepanocladus* c f. *revolvens*.

In this monolith *Phragmites* peat is overlain with a peat containing some wood fragments but predominantly composed of *Sphagnum* remains. The greatest depth at which *Sphagnum* remains were found was 50-55 cm and the lowest positively identified *Sphagnum* fragments were of *Sphagnum squarrosum* and *S. fimbriatum*. Wood fragments and leaves of *Betula pubescens* were more common in the surface 20 cm of peat where *Sphagnum* sect. *Acutifolia* (probably *Sphagnum subnitens*) remains were abundant.

3.3.4. Fenside-Irstead Holmes Section (Fig. 3.5)

An obvious feature of this section is the broad wedge of pure blue-grey clay on either side of the Hundred Stream. In the boring made at the edge of this overgrown channel clay was detected at a depth of 280 cm while it occurred at 120-130 cm depth in the borings at either side. This is probably due to the removal of the clay to form a dyke at some time which has subsequently become filled in with detritus. Some wood fragments are identifiable in the amorphous peat found in this boring above the clay perhaps suggesting that trees have been present along the Hundred Stream for a long time. This clay deposit was not found in any borings made in the internal system but was detected as a band roughly 40 cm wide in the wide rond separating the two systems.

In the borings in the southern part of Main Reed Marsh a distinct band of a *Phragmites*/clay is found. This *Phragmites*/clay overlies *Phragmites*/nekron muds and has a much more sticky, mineral character than the latter. In the horizons above this *Phragmites*/clay band roots of *Scirpus* were found in all the borings made in Main Reed Marsh.

The peat near the mineral margin of Fenside Marsh was very humified and structureless overlying a coarse sand/clay. Amorphous peat was also found in the boring made on an island in the outer Fenside Broad, overlying brushwood peat.

In virtually all the borings where amorphous peat was not found the underlying brushwood peat gave way to a *Phragmites*/nekron mud, often with *Typha* remains. In different cases this was covered with *Phragmites*, *Phragmites/Typha* or *Cladium* peat. The open fen of the external system had much *Phragmites* peat underneath relatively superficial deposits of *Juncus* peat in Little Fen and *Cladium* peat in the Irstead Holmes area. A peat monolith from below the *Juncus subnodulosus/Phragmites* dominated *Peucedano-Phragmitetum typicum* community in Little Fen is described below.

Depth (m)	Main components	Other macrofossils present
0-10	*Juncus subnodulosus* shoots and rhizomes	*Thelypteris* rhizomes. *Phragmites* rhizomes. *Carex elata* seed.
10-20	*Juncus subnodulosus* rhizomes. Some *Phragmites* rhizomes	*Phragmites* spikelets. *Carex pseudocyperus* seed. *Carex nigra* seed.
20-30	"	
30-40	Predominantly *Phragmites* *Juncus subnodulosus* rhizomes	*Calliergon cuspidatum* branch.
40-50	*Phragmites* rhizomes *Juncus subnodulosus* rhizomes	*Equisetum fluviatile* stem, *Carex nigra* seed, *Carex pseudocyperus* seed
50-60	Predominantly *Phragmites* rhizomes	*Juncus subnodulosus* rhizomes.

Abundant macrofossils of the peat in this monolith were of *Phragmites* and *Juncus subnodulosus*. *Phragmites* rhizomes were predominant between 30 and 60 cm below the peat surface. *Juncus subnodulosus* remains became increasingly important towards the surface from 50 cm depth. Macrofossils of *Carex nigra*, *C. pseudocyperus* and *Equisetum fluviatile* were present in the peat monolith but have not been recorded in the surface vegetation from this area (Table 2.2., List 5). Quite shallow *Sphagnum* peat was found in a few areas along the section where the relative level of the brushwood peat to *Phragmites*/nekron mud transition was usually higher than that underneath the surrounding fen communities.

A peat monolith from the *Betulo-Dryopteridetum cristatae* community was examined:

Depth (cm)	Main components	Other macrofossils present
0-10	*Sphagnum*/*Phragmites* rhizomes (*S. fimbriatum*)	*Potentilla palustris*, *Lycopus europaeus*, *Cicuta virosa* seeds.
10-20	*Phragmites* rhizomes & stems/*Sphagnum* (*S. fimbriatum*, *S. squarrosum*)	*Typha angustifolia* rhizomes, *Carex elata* seed.
20-30	*Phragmites* rhizomes	*Sphagnum fimbriatum*. *S.* sect. *Acutifolia*. *S. squarrosum* stem fragments.
30-40	*Phragmites*/*Typha* rhizomes	*Sphagnum fimbriatum*, *S.* sect. *Acutifolia* few fragments.
40-50	"	
50-60	"	

Here the *Sphagnum* peat (mainly *Sphagnum fimbriatum*) was shallow (≃ 20 cm) although some *Sphagnum* leaves and fragments were found up to 40 cm below the surface. *Phragmites* and *Typha* rhizomes were predominant in the lower parts of the monolith.

3.3.5. Additional Peat Borings (Fig. 3.6)

Two additional peat borings were made under *Peucedano-Phragmitetum schoenetosum* communities. The boring from the southern area of Moores Head Marsh (Fig. 3.6., L) revealed that there was a shallow deposit (165 cm) of solid humified *Cladium* peat present which was directly above the coarse sand/clay of the subsoil. This deposit was very uniform but had a slightly muddy texture towards the base. The core from the *P.-P. schoenetosum* area of Irstead Poor's Fen (Fig. 3.6., P) had a much deeper peat deposit (620 cm) and had stratigraphy very similar to that found in Sedge Marshes (Fig. 3.2). The brushwood peat to nekron mud transition occurred at 170 cm below the peat surface.

Three borings were made in Neatishead Poor's Fen, one in the centre of the fen (Fig. 3.6., N) and two through the more elevated compartment boundaries at either side (M & O). All of these had a quite thick (70-90 cm) band of *Phragmites*/clay (similar in texture to that found at the southern end of Great Fen) overlying the brushwood peat. The deposits above the *Phragmites*/clay were quite similar in the borings from the two compartment boundaries being composed of dark humified amorphous peat in

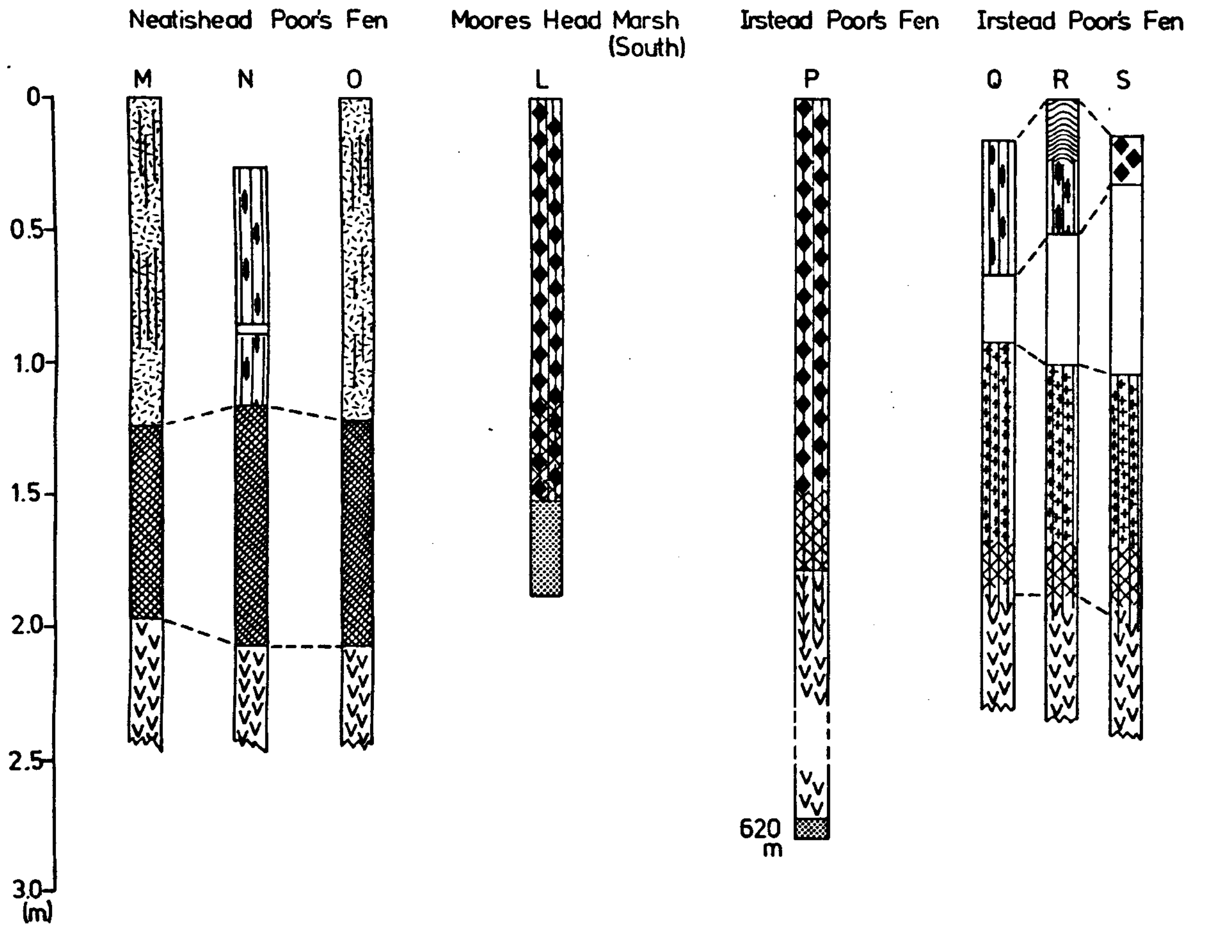

Fig. 3.6. Additional peat borings (A key to the symbols is given in Fig. 3.2.).

which only a few *Phragmites* rhizomes could be identified. The peat from the central area of the fen was much less humified, the surface layers (0-60 cm) being almost completely undecomposed while the lower band of *Phragmites/Typha*/nekron mud was slightly more humified.

Further borings were made on the line of a short transect(5.5.3) in Irstead Poor's Fen. The peat surface in this area has a semi-quaking nature underfoot and the peat stratigraphy revealed a wide (25-70 cm) gap beneath the peat surface from which samples could not be obtained. Investigations by hand to c. 60 cm below the very fresh unhumified surface peats detected the presence of a coarse meshwork of living rhizomes of *Typha angustifolia* within a very liquid slurry of fine organic material. The peat deposits below this gap consisted of a moderately humified *Juncus/Phragmites* peat separated from the brushwood peat below by a band of *Phragmites*/nekron mud.

3.4. AN INTERPRETATION OF THE PEAT STRATIGRAPHY

The interpretation of peat stratigraphy in which species such as *Phragmites communis* and *Cladium mariscus* are found is complicated, as both these species have roots and rhizomes which can penetrate deep into the substratum. It may not always be clear whether roots and rhizomes found at a certain depth in a peat deposit are a record of the vegetation growing on the peat surface at that time, or a later addition to the peat. In cases where plant remains are found of a species beneath surface vegetation in which that species is no longer found, or if considering remains of small plants, such as *Sphagnum*, it is probably reasonable to assume that the plant remains form a record of the vegetation growing on the peat surface at a time close to the formation of the peat layer. In the cases of the larger rhizomatous species care must be taken when drawing conclusions.

3.4.1. Brushwood peat, clays and peat cuttings

Brushwood peat only occurred in the surface metre of peat beneath fen carr communities, but was present beneath the surface layers of peat in most parts of the study area investigated. In some places a band of pure blue-grey clay, probably laid down during the Romano-British marine transgression (Jennings 1952) separated the brushwood peat from the surface peat layers. *Phragmites*/clay deposits were found in similar horizons to the pure clay deposits in the southern part of Great Fen (Fig. 3.3.), Main Reed Marsh (Fig. 3.5) and Neatishead Poor's Fen (Fig. 3.6). The thickness of this deposit decreased with distance away from the Hundred Stream in Great Fen and is likely that it was formed beneath *Phragmites* vegetation which bordered the main river channel at the time of the marine transgression (Jennings 1952). In the borings made in Main Reed Marsh the *Phragmites*/clay was separated from the brushwood peat by a less sticky *Phragmites*/nekron mud (Fig. 3.5). In this case perhaps increasing water levels caused the replacement of fen carr by *Phragmites* dominated vegetation before water levels rose high enough to cause the deposition of clay.

In the northern part of Moores Head Marsh close to Barton Broad, brushwood/*Phragmites* peat was found directly above the clay deposits and over this humified brushwood peat occurred continuing to the present peat surface (Fig. 3.4). This perhaps indicates that fen woodland was established almost directly over the clay and has persisted to the present day. In most areas the brushwood peat or clay deposits were replaced by *Phragmites*/nekron mud, but the depth at which this transition occurred is variable usually being between 120 and 200 cm below the present surface.

The depth at which the brushwood peat to *Phragmites*/nekron mud transition occurred beneath the *Peucedano-Phragmitetum schoenetosum* community in Sedge Marshes was very constant (≃ 170 cm below the surface). Humified *Cladium* peat was found over the *Phragmites*/ nekron mud. The boring made underneath the *Peucedano-Phragmitetum schoenetosum* community in Irstead Poor's Fen (Fig. 3.6) had very similar stratigraphical features to Sedge Marshes. The humified *Cladium* peat under the *Peucedano-Phragmitetum schoenetosum* community in the southern part of Moores Head Marsh (Fig. 3.6) was separated from the mineral subsoil by a *Cladium*/mud, again occurring at a similar depth (155 cm below the present surface) to the lowest layers of *Cladium* peat in Sedge Marshes.

The level of the mud deposits beneath these *Cladium* dominated communities was very similar to the levels at which the clay deposits described above were found. It is likely that the rising water levels associated with the marine transgression caused the disappearance of fen carr communities in Sedge Marshes and Irstead Poor's Fen and the spread of fen vegetation over the adjacent mineral ground in the southern part of Moores Head Marsh.

In many of the areas investigated the surface peat was much less humified than in those described above, suggesting that peat cutting must have taken place at some time. The amorphous peat found in the narrow linear island in Fenside Outer Broad (Fig. 3.5) probably represents a baulk left untouched at the time of cutting (c f. Jennings & Lambert 1960). Similar features can be seen in Irstead Holmes Broad (Plate 3). The distribution of areas with unhumified surface peat found in the sections is almost identical to the distribution of areas marked as open swamp on the 1885 Ordnance Survey Map (Fig. 3.1). An exception to this is the northern compartment of Great Fen where the surface peat is of moderate humification (not as humified as that in Sedge Marshes) suggesting that peat cutting may have taken place here at an earlier date than in the other areas with less humified surface peats. On this map the boundaries of the areas marked as swamp are linear, or follow the Catfield-Irstead parish boundary, suggesting that they mark the limits of peat cuttings.

3.4.2. The depth and timing of the peat cutting

While there seems to be good correlative evidence that peat cutting has occurred in some parts of the study area it is not clear to what depth the peat was dug or when the peat cutting took place. The maximum depth to which the peat may have been dug since the Romano-British marine transgression is indicated by the upper limit of the brushwood peat, or clay deposits where they occur. That the peat was removed to this surface is suggested by the quite large variation in the level of the upper surface of the brushwood peat in some sections, notably the Great Fen Section (Fig. 3.3). The upper surface of the brushwood peat is found more than 50 cm lower in the northern compartment of Great Fen than in some parts of the central area of the fen. The highest samples of brushwood peat taken in some borings from Great Fen and Fenside Marsh had an unusual loose granular character perhaps representing the re-deposition of the peat in open water which could have happened subsequent to digging into the brushwood peat.

There is also evidence that peat was dug to a shallower level in many areas. It is known that shallow peat cuttings were made in the fens of Broadland, although documentary evidence is sparse. Carrodus (1949) in a work concerning the recent history of Horning describes peat cutting on a large scale of '3,000 turves a year for each cottage'. The peat cutting was carried out in spring using a 'becket', the turves measuring 3½" square and two to three feet long. The description of turf cutting given by Carrodus suggests that the cuttings were made into herbaceous peat, referring to the regrowth of reedbeds over the cuttings as being '... like a rotational change of crops'. Carrodus also describes peat cutting alongside the River Bure on the Woodbastwick Marshes. The stratigraphy of these marshes was investigated by Lambert and Jennings (1951) who detected evidence of peat cuttings occurring in *Phragmites* peat in a similar area to that described by Carrodus. Lambert and Jennings found the cuttings to be 90 cm deep (roughly equivalent to the length of one turf) and the depth of the peat cutting was marked by an abrupt transition to more humified peat which could be sampled with a borer. This is not very different from the depth at which peat is able to be sampled in the Catfield and Irstead Fens where the highest samples were usually obtained at 75-80 cm below the surface. The detailed examination of monoliths in the central part of Great Fen supports the view that this level marks the depth to which peat was cut. A very fine mud with many fresh-water snail shells was found between 50 and 60 cm below the peat surface, suggesting that this might have been formed in a flooded peat cutting. This point will hopefully soon be clarified by further attempts to retrieve samples from between 60 and 80 cm below the surface, which appears to be a very critical horizon. In two of the borings from Irstead Poor's Fen the depth at which samples were obtained by the borer were lower, being roughly 1 m below the peat surface. The stratigraphy in this case indicates that a cutting was dug from herbaceous peat; the lower peat contained much *Juncus subnodulosus* which was absent from the upper layers.

Hearsay evidence also indicates the presence of shallow peat cuttings, a process locally known as 'turfing out' of reedbeds, where the surface peat was removed to favour the growth of reed in deeper water (P. Neave pers. comm.). An area where this appears to have occurred quite recently is Neatishead Poor's Fen (Fig. 3.6., N) where the surface peat is very fresh and unhumified. Here there is evidence that the peat has been cut both to the level of the *Phragmites*/clay and to a higher level marked by a distinct change in humification, when compared with the humified peat found above the *Phragmites*/ clay in the two borings from the compartment boundaries (Fig. 3.6., M & O). It seems likely that these compartment boundaries which are obvious raised strips in the fens, often covered with a dense growth of *Myrica gale* (2.4.3.), may be relicts of baulks used to stack the peat for drying. Whether the presence of amorphous peat can be used as an indication that peat cutting has not taken place is questionable as the deposition of dyke dredgings at the edge of Fenside Marsh in 1968 seems to have led to compaction of the peat giving it an amorphous character. However, some *Cladium* and *Phragmites* rhizomes could be indentified in this peat from Fenside Marsh, especially in lower layers (below 140 cm), whereas only very few *Phragmites* remains were found in the amorphous peats in Neatishead Poor's Fen.

Overall the evidence available suggests that peat cutting in the study area has occurred both to the upper limit of the brushwood peat (130-200 cm below the present surface), at least in some areas, and that further much shallower peat cuttings were dug at a much later date. No areas of open water are marked on the Tithe maps of 1842 but open water is marked on the 1885 Ordnance Survey Map in the areas where the stratigraphy indicates shallow peat cuttings. It seems likely that shallow peat cuttings (70-80 cm deep) were dug over large areas in the nineteenth century between 1842 and 1885. That some correspondence of the height of the peat surface with the upper limit of the underlying brushwood peat occurs in some areas (e.g. Fig. 3.3) could be due to the removal of single turves of roughly equal length beneath a previously undulating peat surface.

It seems probable that areas with a continuous humified peat above the marine clay (Fig. 3.4) or above the brushwood peat to *Phragmites*/nekron mud transition (Fig. 3.2 and 3.6.) have not been cut for peat. Complementary evidence that conditions during peat formation in areas such as Sedge Marshes, (where peat cutting does not seem to have taken place) were drier than those prevailing in the peat cuttings in Great Fen and Fenside Marsh recolonised by *Cladium*, comes from the nature of the *Cladium* macrofossils. In the *Cladium* peat in Sedge Marshes the predominant macrofossils are black *Cladium* roots normally produced in well-aerated conditions, while in the *Cladium* peats of Great Fen these black roots are uncommon and the predominant macrofossils are thick reddish roots which are normally produced in submerged peat (Conway 1936).

3.5. INFERRED SUCCESSIONAL CHANGES IN THE PAST VEGETATION

3.5.1. Succession in the peat cuttings

In most areas where peat cutting seems to have occurred (3.2.4.) the first stages of colonisation appear to be by an open reedswamp of *Phragmites* (and *Typha angustifolia* in some cases) leading to the formation of a *Phragmites*/nekron mud. *Scirpus lacustris* may also have been important in these early stages of colonisation of the peat cuttings in some places (Fig. 3.4.). The *Phragmites* seems to have persisted in the vegetation in virtually all of the areas to the present day, although other species become the dominant peat formers in some areas. *Cladium* appears to have been an early invader of *Phragmites* and *Phragmites-Typha* reedswamp in many cases or possibly may have directly invaded open water for example in Great Fen and Fenside Marsh (Figs. 3.3., 3.5). Once *Cladium* had established it appeared to maintain its dominance in these areas. Where shallower peat cuttings have been dug into the *Cladium* peats of Fenside Marsh and Great Fen then these seem to have been recolonized by a similar vegetation of *Cladium* and *Phragmites*. *Juncus subnodulosus* appears to have become an important peat forming species at quite a late time (Figs. 3.3., 3.4) and is found only over *Phragmites* peats.

The recolonization of the shallower peat cutting in an area of Irstead Poor's Fen (Fig. 3.6) has been by the formation of a semi-floating raft of peat and living rhizomes of *Phragmites* and *Typha*. Similar formation of *Phragmites* rafts over open water has been described from Wybunbury Moss, Cheshire by Poore and Walker (1959), and from the Woodbastwick Marshes in the Bure valley by Lambert and Jennings (1951).

The *Sphagnum* peats form only quite shallow, superficial deposits in all cases the deepest being found under the *Betulo-Myricetum* community in Great Fen where the *Sphagnum* remains are found 55 cm below the peat surface. Generally *Sphagnum* peats were only found in areas where there was evidence that peat cutting had taken place, but there was no restriction of *Sphagnum* peat to a particular peat type (i.e. *Sphagnum* had invaded vegetation in which *Cladium*, *Phragmites*, *Typha angustifolia* and *Juncus subnodulosus* were all abundant). Lambert and Jennings (1960) describe some similar peat deposits with abundant *Sphagnum* remains from the Buckenham and Hassingham area of the Yare valley and the Barnby area of the Waveney valley, often intercalated with hypnoid moss peat. These deposits were all overlain with fen peats and appear to have been formed before the Romano-British transgression.

3.5.2. Succession in areas not cut for peat

In some areas where the peat has probably not been cut the brushwood peat is covered by a layer of *Phragmites*/nekron mud which in turn is covered by dense humified *Cladium* peat (Figs. 3.2., 3.6). It seems likely that in these areas the

Phragmites mud was formed at the time of the marine transgression, as it is found at similar horizons as the marine clay in other areas. The subsequent invasion of *Cladium* appears to have happened at quite an early date, and *Cladium* is still the dominant peat forming species.

In the northern peat of Moores Head Marsh (Fig. 3.4) the clay is overlain by a mixed *Phragmites*/brushwood peat which is covered by humified brushwood peat. This indicates that fen carr was established at an early date and has persisted to the present day as an *Osmundo-Alnetum glutinosae* community now occupies this area. The relatively lower height of the peat surface in Sedge Marshes to that in this alder carr community (4.2.2) may be related to the maintenance of an open fen community in Sedge Marshes by anthropogenic influences removing potential peat forming material (Lambert 1951).

3.5.3. Discussion

Lambert (1951) identified very similar successional sequences to those described above from stratigraphical studies in the Bure valley. She also identified additional hydroseral pathways involving the colonisation of *Phragmites* fen by *Carex paniculata* and *C. acutiformis* two species which are uncommon in the study area. These species are abundant in the primary fen to the west of Barton Broad where similar communities to those described by Lambert can be found, leading to the formation of swamp carr and semi-swamp carr. Most of the woodland of the study area is what she described as fen carr (2.6) and is formed over solid peat. Little primary fen is present along the Barton Broad margin of the study area today and this, perhaps combined with active management of the marshes which tends to exclude *Carex paniculata* and *C. acutiformis* may explain the lack of *Carex* and swamp carr peats in the study area.

The succession from open water to fen and fen carr communities in the areas which were cut for peat has taken place very rapidly. Walker (1970) suggests that reedswamp stages in hydroseres are short lived, often lasting less than 500 years, but that peat accumulation rates were usually less than 100 cm per 1000 years. The peat in areas subject to peat cutting is very fresh and unhumified and will perhaps be subject to some compaction in the future. Nevertheless the rates of peat accumulation and vegetational change in these areas has been very rapid. Some small turf ponds still remain in the areas which were cut for peat. It seems likely from examination of aerial photographs that these turf ponds once supported a swamp vegetation but it has since been removed, probably due to coypu activity (Lambert 1965; Boorman & Fuller 1981).

Lambert (1951) found no difference between the structure and composition of the fen communities developed over peat cuttings or managed fen communities developed upon solid, uncut peat except in the abundance and vigour of *Phragmites*. This is certainly not the case in the study area as the differences in the vegetation between areas of cut and uncut peat are very pronounced. Many community-types are almost completely restricted to areas of recent peat cutting (e.g. *Cicuto-Phragmitetum*, *Betulo-Dryopteridetum cristatae*) and some to areas apparently not cut for peat (e.g. the *schoenetosum* and *myricetosum* sub-associations of the *Peucedano-Phragmitetum*). The distribution of the vegetation types is described in more detail in 2.6.

3.6. CONCLUSIONS

While obviously further stratigraphical studies are necessary to clarify specific issues (e.g. the nature of deposits not sampled in the present study) several conclusions can be made:

1) The former work of Jennings (1952) is generally confirmed.

2) Extensive peat cutting has occurred within certain areas of the study area, certainly some recent peat cuttings have been dug in the nineteenth century between 1842 and 1885.

3) These peat cuttings have become revegetated within the past century although a few remnant turf ponds remain.

4) The distribution of the nineteenth century peat cuttings correlates very well with the distribution of many vegetation types; some

community-types being restricted to uncut peat surfaces and some to cut surfaces. In particular swamp communities and communities with much *Sphagnum* are restricted to areas which were cut for peat in the last century.

5) The hydroseral pathways found here agree closely with some described by Lambert (1951) but there is also evidence for additional processes.

CHAPTER 4

INVESTIGATIONS OF ENVIRONMENTAL PARAMETERS IN SELECTED STUDY SITES

4.1. INTRODUCTION

The differences in hydrology and chemical composition of the peats and waters of mires have been used to generate classifications of mire types (Kulczynski 1949, Sjörs 1950, Bellamy 1972). Other investigations have examined the relationships between hydrology and peat and peat water chemistry and the vegetation within mire systems (e.g. Malmer 1962, Proctor 1974, Daniels & Pearson 1974). There is comparatively little information available on the annual variations in the chemical composition of mire waters (McColl 1969, Daniels & Pearson 1974).

While the chemistry of the lakes and rivers of Broadland has been extensively studied (e.g. Innes 1912, Osborne & Moss 1977, Phillips 1977) little attention has been paid to the chemical status of the surrounding mire systems. Some measurements have been made by Bellamy (1967) and Buttery, Williams and Lambert 91965).

It was decided to undertake an investigation of the differences in hydrology and peat and peat water chemistry between several study sites which were considered to be representative of the main vegetation types found within the study area. This study was also designed to provide information on the relationship between the chemical composition of the peats and peat waters and the variation in the levels of various chemical constituents at different times of the year.

4.2. THE RATIONALE FOR SAMPLE COLLECTION AND THE STUDY SITES

4.2.1. Rationale for peat and water sampling

The majority of research on the composition of mire waters has been based on analyses of open surface waters (e.g. Sjörs 1950; Tolonen & Hosiaisluoma 1978) or of water expressed from the surface peat (e.g. Gorham 1956; Bellamy 1967; Daniels & Pearson 1974; O'Connell 1981). Sjörs (1950) indicated that it is not legitimate to compare chemical characteristics of open waters with those of peat waters as the latter will generally contain 'much greater quantities of minerals'. This point is recognized by Gorham and Pearsall (1956a) who identified if samples were taken from open water. Summerfield (1974) emphasises the need to collect water samples from precise rooting depth of a particular species under investigation and to specify the time of year of collection.

Proctor (1974) suggests that 'Measurements of cation concentrations of surface water are less useful than measurements on peat samples for elucidating the detailed relation between vegetation and cation availability, if only because sampling points are limited in number'. The use of tubes inserted into the peat not only allows the sampling of water when the water level is up to 50 cm below the peat surface, but should also bear a closer relationship to the interstitial water of the peat matrix than waters collected at the surface of the peat, as the holes in the tube walls will allow equilibration between water in the tube and that within the peat. This is especially desirable when, as in several of the sites examined, the substratum is composed almost completely of living roots and rhizomes of the plants growing there (3.3.).

The need for small samples when sampling surface mire waters due to their stratification was emphasized by Sjörs (1950), and the peat waters in the sites studied also exhibit marked stratification (5.5). In gaining an estimate of the ionic concentrations of the peat waters in different study sites a single large sample (500 ml) was taken from each tube, mixed, and used to gain a 'bulk mean' estimate of ionic concentrations in the peat water within 50 cm below the peat surface, five such samples being used to provide an overall estimate of the mean ionic concentrations in each study site.

The sampling method described above has disadvantages when examining areas in which there is a superficial stratigraphical change in the character of the peat. This is especially apparent in areas with a shallow surface layer of *Sphagnum* peat, where such water samples would include water from both the *Sphagnum* peat and the deeper peat layers. As many species which grow in the community types with much *Sphagnum* root in the lower peat layers (e.g. *Cladium mariscus*, *Phragmites communis*) it was deemed worthwhile to gain an overall estimate of the ionic concentrations prevailing in the surface 50 cm to allow comparison of the study sites. The chemical stratification of the peat waters formed part of a separate investigation (5.5).

The chemical differences between the peats of the different study sites were investigated on one occasion in the autumn of 1979. This time of sampling was chosen as uptake into the vegetation should be minimal at this time of year as little active growth is taking place. Peat samples were not taken on a regular basis both due to practical constraints and the destructive impact on the study site, in terms of excavation of peat and the extensive trampling involved. This was especially undesirable in the communities of high conservational value.

4.2.2. Selection of Study Sites

Fourteen main study sites were chosen for detailed investigation. Sites were selected to represent a wide range of vegetation types, dominance and presumed successional status, and to examine spatial variation within the study area. A brief description of each study site is given in Table 4.1 and complete species lists can be found by reference to Tables 2.2 and 2.3. Each site was chosen as a representative expression of a community-type, except sites 3. GFS and 6. IPF which were unusual examples. Two sub-sites 1 a). GFNP and 2 a). GFCL were included to examine whether these particularly species-rich areas of *Peucedano-Phragmitetum caricetosum* had different environmental characteristics from the main sites 1. GFN and 2. GFC. Water samples for chemical analysis were also collected from Barton Broad and from the River Ant at Irstead Shoals to allow comparison with the mire chemistry to be made.

Table 4.1. The Study Sites. Full Species Lists can be found by reference to the relevant table. Abbreviations are: *P.-P.*, *Peucedano-Phragmitetum*

Site No.	Compartment Name	Abbreviation	Table No.	Species List No.	Community Type	Main Species	Description
1	Great Fen (North)	GFN	2.2	27	*P.-P. caricetosum Menyanthes* var. *Molinia* sub-var.	*Cladium mariscus*	Highly species-rich, intermittently managed. Extensively invaded by *Salix cinerea*, *Myrica gale* & *Betula pubescens*.
1 a)	Great Fen (North)	GFNP	-		*P.-P. caricetosum Menyanthes* var. *Molinia* sub-var.	*Cladium mariscus*	As 1 with *Dactylorchis incarnata*, *D. praetermissa*, *Epipactis palustris* and *Parnassia palustris*.
2	Great Fen (Central)	GFC	2.2.	26	*P.-P. caricetosum Menyanthes* var. *R. lingua* sub-var.	*Cladium mariscus*	Highly species-rich. Many aquatic and swamp species present.
2 a)	Great Fen (Central)	GFCL	-		*P.-P. caricetosum Menyanthes* var. *R. lingua* sub-var.	*Cladium mariscus*	As 2 with more extensive bryophyte carpet of *Scorpidium scorpioides* and *Cinclidium stygium* with *Epipactis palustris*, *Drosera anglica*.
3	Great Fen (South)	GFS	2.2	16	*P.-P. cicutetosum*	*Phragmites/Typha angustifolia*	Many associated species e.g. *Cicuta virosa*, *Sium latifolium*. Poor reed growth.
4	Little Fen	LF	2.2	5	*P.-P. typicum*	*Juncus subnodulosus/ Phragmites*	Overgrown 'litter' fen. Many associated species. Invaded by *Myrica gale*, *Salix cinerea*, *Alnus glutinosa*.
5	Neatishead Poors' Fen	NPF	2.2	56	*Phragmites-Typha angustifolia* community	*Phragmites/Typha angustifolia*	Species-poor with a dense carpet of *Agrostis stolonifera*. Poor reed growth.
6	Irstead Poors' Fen	IPF	2.2	58	*Phragmites-Typha angustifolia* community	*Phragmites/Typha angustifolia*	Species-poor with no *Agrostis stolonifera*. Poor reed growth.
7	Moores Head Marsh	MHM	2.2	23	*P.-P. schoenetosum*	*Cladium mariscus*	Much *Schoenus nigricans*, *Juncus subnodulosus* and *Molinia caerulea*. *Oenanthe lachenalii* present.
8	Sedge Marshes	SM	2.2	21	*P.-P. schoenetosum*	*Cladium mariscus*	Much *Schoenus nigricans*, *Carex elata*, *Juncus subnodulosus*, *Molinia caerulea*.
9	Moores Head Marsh	OA	2.3	21	*Osmundo-Alnetum glutinosae lycopetosum*	*Alnus glutinosa*	Ground flora composed mainly of *Carex acutiformis Phalaris arundinacea*.
10	Fenside Marsh	FBR	2.2	38	*Cicuto-Phragmitetum*	*Phragmites communis*	Tall reed swamp with *Scirpus lacustris*, *Utricularia vulgaris*.
11	Fenside Marsh	FBC	2.2	48	*Cladietum marisci utricularetosum*	*Cladium mariscus*	Very pure stands of *Cladium mariscus* with few associated species.
12	Fenside Marsh	FBDC	2.3	9	*Betulo-Dryopteridetum cristatae*	*Sphagnum* spp.	Much young *Betula pubescens*. Herbaceous plants include *Cladium*, *Phragmites*, *Juncus subnodulosus*.
13	Main Reed Marsh	MRM	2.2	8	*Betulo-Dryopteridetum cristatae*	*Sphagnum* spp.	Little *Betula pubescens*. *Phragmites*, *Juncus subnodulosus* abundant.
14	Great Fen (Central)	BM	2.3	11	*Betulo-Myricetum gale peucedanetosum Sphagnum* var.	*Betula pubescens*	Continuous carpet of *Sphagnum fimbriatum* and *S. subnitens*. *Eriophorum angustifolium* present, *Pyrola rotundifolia* abundant.
15	River Ant (Irstead Shoals)	RIV	-		-	-	*Nuphar lutea*, *Potamogeton pusillus* agg. present.
16	Barton Broad	BRD	-		-	-	Samples taken adjacent to *Phragmites* reedswamp. No aquatic macrophytes present.

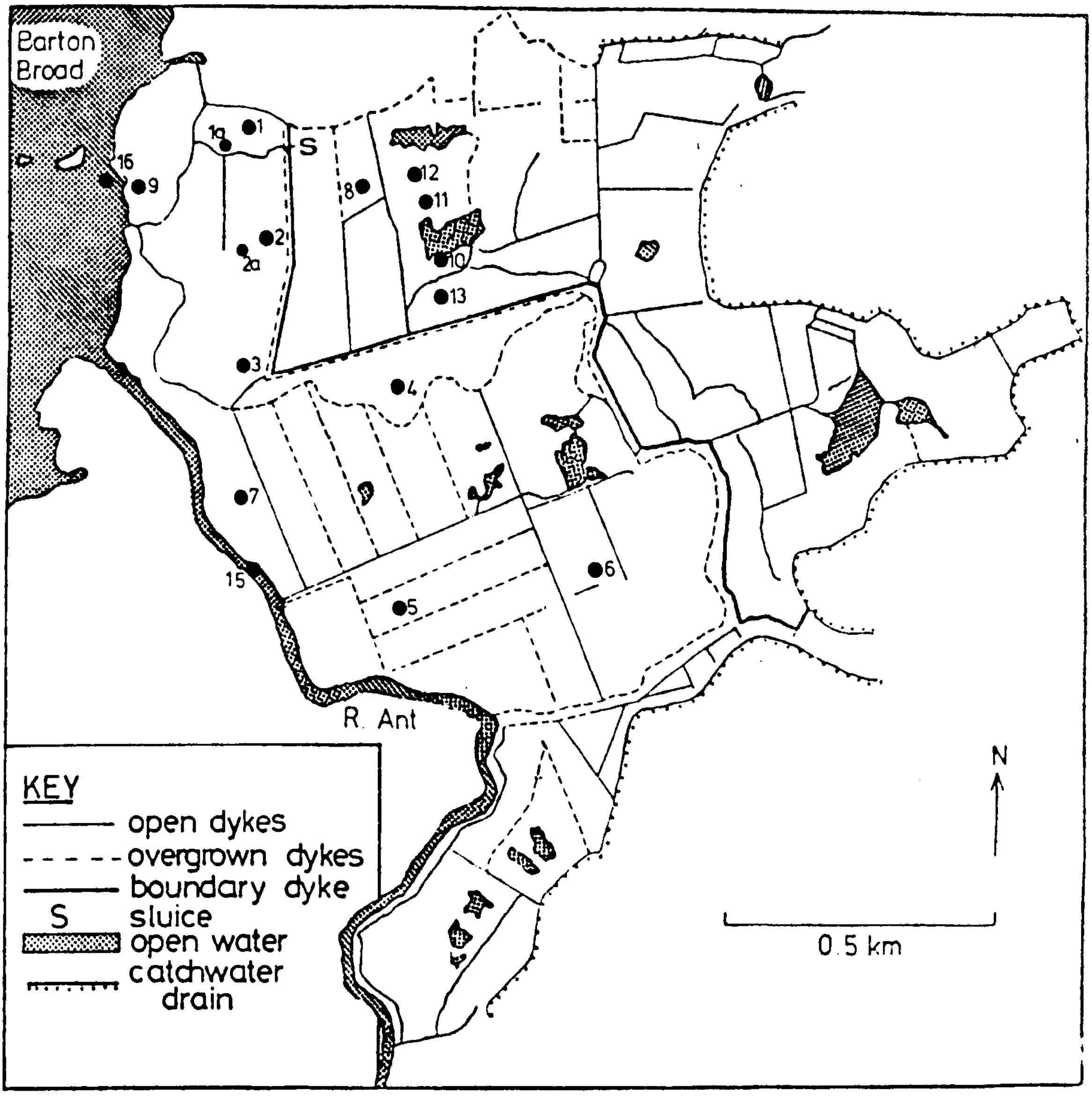

Fig. 4.1. Locations of the study sites described in Table 4.1.

In addition to the study sites mentioned above investigations were in some cases extended to other areas to investigate specific issues. These study sites are described in the text where they occur.

4.3. MATERIALS AND METHODS

4.3.1. Water Sampling

A floristically and physiognomically 'uniform' area of approximately 100 m^2 was selected within each study site. Five sampling points were located in the central 25 m^2 of this area using random number tables and a sampling tube installed at each point. The sampling tubes (Fig. 3.2) were 50 cm lengths of ABS soil pipe (4" diameter) with numerous holes drilled through the sides and were buried to within 5 cm of their length.

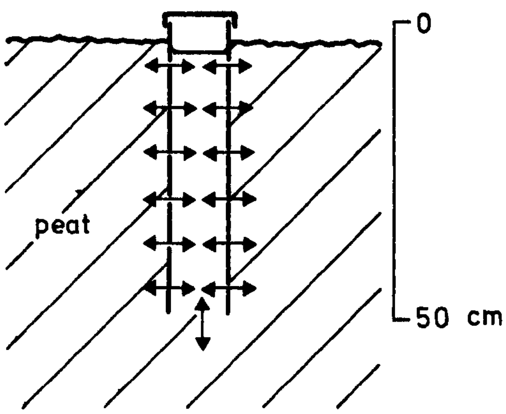

Fig. 3.2. A sampling tube *in situ*

The tubes were inserted into the peat as carefully as possible to minimise disturbance of the substratum, in the case of fresh *Phragmites* peats this simply involved making a cut through the surface with a spade after which the tube could be easily pushed in, while more humified peats required more excavation to allow the tube to be buried. Any debris within the pipe was removed by hand before the pipes were covered with a PVC lid. The lids were found to be necessary as previous trials had proved the tubes to be effective traps for small animals[1].

The sampling tubes were installed two months before samples were taken for chemical analysis to allow the surrounding environment to re-equilibrate. During this period the portion of the tube below the peat surface became permanently darkly stained, presumably due to adsorption of organic compounds. Samples were taken from the tubes for chemical analysis at roughly 2 monthly intervals over the period from September 1979 to September 1980. A single sample of water was taken from each tube on each sampling occasion in a 500 ml polyethylene bottle. The bottles were completely filled with water which was filtered and stored at $5^{o}C$ within 24 hours of collection. All subsequent analysis was completed within ten days.

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[1] In fact during the subsequent study it was found that small mammals could still enter the tubes by forcing up the lid which caused loss of several samples through contamination.

4.3.2. Water Level Measurement

The height of the water level was measured from the top of the five sampling tubes inserted for collection of water samples. The distance from the top of the tube to the peat surface[1] was also measured and the water level in relation to the peat surface was calculated from these two measurements. Measurements were taken at roughly monthly intervals over a period of 2 years from September 1979 to September 1981.

The measurement of water level in wide pipes (4" diameter) may not reflect the exact water table within the peat when the water level is below the surface of the peat, as it will underestimate the effects of capillarity. Such measurements are more comparable to those taken in soil pits (Godwin 1931; Kassas 1951) and will provide an indication of the fluctuations of water level in relation to the peat surface. These measurements may not reflect the movement of the true water level in relation to the subsoil (2-7 m below peat surface) as the sampling tubes are held at the peat surface and should therefore move with the peat surface if expansion or contraction of the peat takes place. Indeed an estimate of the water level in relation to the peat surface was considered to be more useful in elucidating the effect of water levels on the composition of the vegetation in the study sites.

Measurements of water level in the internal dyke system over the past thirteen years have been provided by Mr D.S.A. McDougal of Catfield Hall. To allow a comparison of water levels in the

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1 The peat surface was taken to be the level at which a 50 cm perspex rule would rest under its own weight, i.e. if an extensive moss carpet was present this would represent the peat surface.

internal and external dyke systems measurements of the water level were taken on either side of the sluice (Fig. 3.1) and the level in the external system calculated relative to the data provided for the internal system.

4.3.3. Peat Sampling

Five peat samples were taken from randomly located points within the same area as the water sampling tubes. The peat was removed from 10-20 cm below the peat surface with a spade and a sharp knife, care being taken to minimize compaction of the peat. The samples were transported in 250 ml polyethylene screw-top containers and stored at $5^{o}C$ prior to analysis. The subsequent extractions and analysis were performed on measured volumes of peat and all results are expressed on a volumetric basis. Living roots and rhizomes were excluded from the analyses as far as practically possible.

3.3.4. Methods for Chemical Analysis and Data Processing

Details of the methods used for chemical analysis and data processing are given in Appendix 2.

4.4. HYDROLOGICAL INVESTIGATIONS

4.4.1. Local Precipitation and Water Levels in the Dyke Systems

Measurements of monthly precipitation taken at Barton Hall (which is less than 1.5 km from the study area) are shown in Fig. 4.3. The precipitation measurements show that 1979 and 1981 were both wetter than average years; the annual mean rainfall in 1979 and 1980 was 681 mm and 615 mm compared with the 1954-1979 average of 609 mm. There were exceptionally wet periods in November and December 1979, June 1980 and March to May 1981 and unusually dry periods in June and August 1979, April and May 1980 and July and August 1981.

There is an obvious correlation between monthly precipitation (Fig. 4.3) and the water levels in the dykes (Fig. 4.4) high rainfall leading to high water levels, but the water level does not necessarily reflect the rainfall for that month (e.g. May 1981). There are also substantial differences in the water levels in the internal and external dyke systems.

As the dykes of the external system have free connection with Barton Broad and the River Ant the water level in these dykes will reflect the level of water prevailing in the river system. The catchment of the River Ant covers a large area which extends northwards to the Cromer Ridge and water levels in the river will depend on the precipitation and drainage from

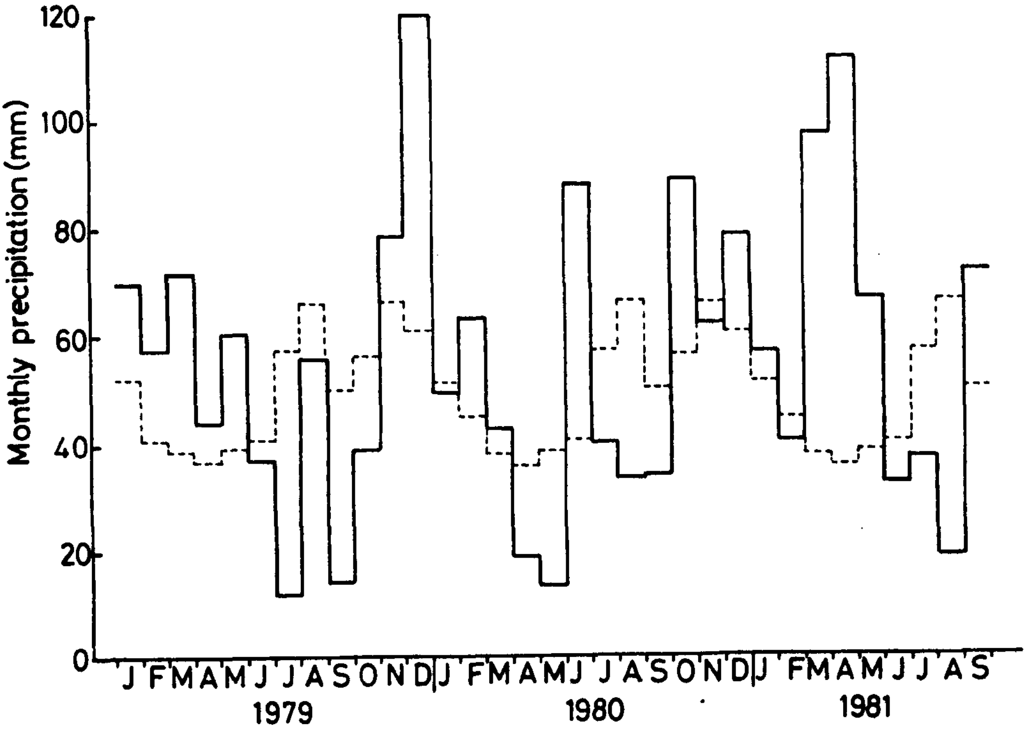

Fig. 4.3. Monthly precipitation measurements taken at Barton Hall, Barton Turf (N.G.R. TG 354223); actual precipitation (———), average for 1954-1978 (- - -). Data provided by Cptn. J. Peel.

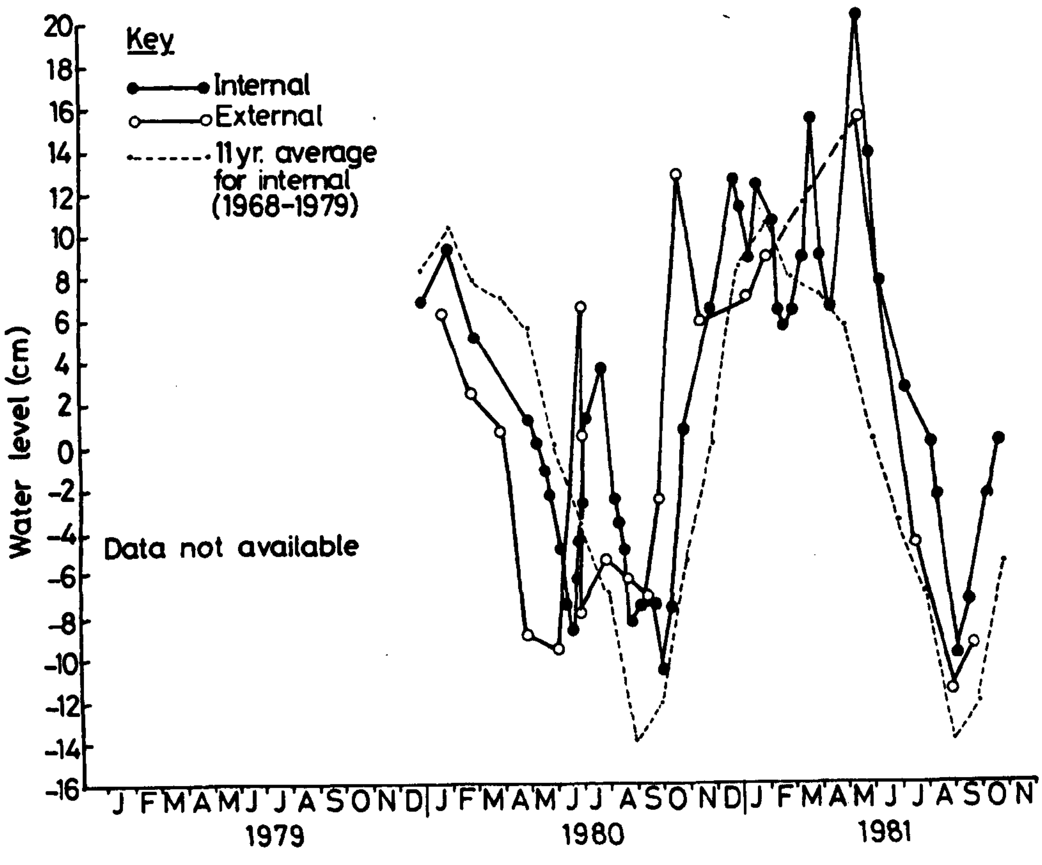

Fig. 4.4. Dyke water levels (relative to a guage situated between Middle and North Marshes). Readings for the internal system dykes have been provided by Mr D.S.A. McDougall.

this area together with the influence of particularly high tides (Gurney 1911). The catchment area of the internal system is comparatively small extending as far as the watersheds with Sutton Broad to the north and the Thurne valley to the east. The rate of drainage from the internal dyke system is controlled by the sluice and water is only allowed into the internal system through the sluice in unusual circumstances, for instance when summer water levels are very low, or when water levels in the external system rise suddenly to exceptionally high levels.

The presence of the sluice has two main effects on the relative dyke water levels of the internal and external systems. It prevents the water level in the internal system from rising as quickly and as high as that of the external system - in effect limiting the catchment area of the internal system. It also prevents or retards drainage from the internal system causing the water level to rise above that of the external system and to decrease more slowly. Fluctuations in water level are therefore more rapid in the external dyke system.

4.4.2. Water Level Relative to the Peat Surface

The water level fluctuations in each of the study sites are shown in Fig. 4.5 and summarized in Table 4.2. The confidence limits in Fig. 4.5 partly reflect the errors introduced in measurement of the water table in relation to the peat surface but such errors were small (< 3 cm). The confidence limits

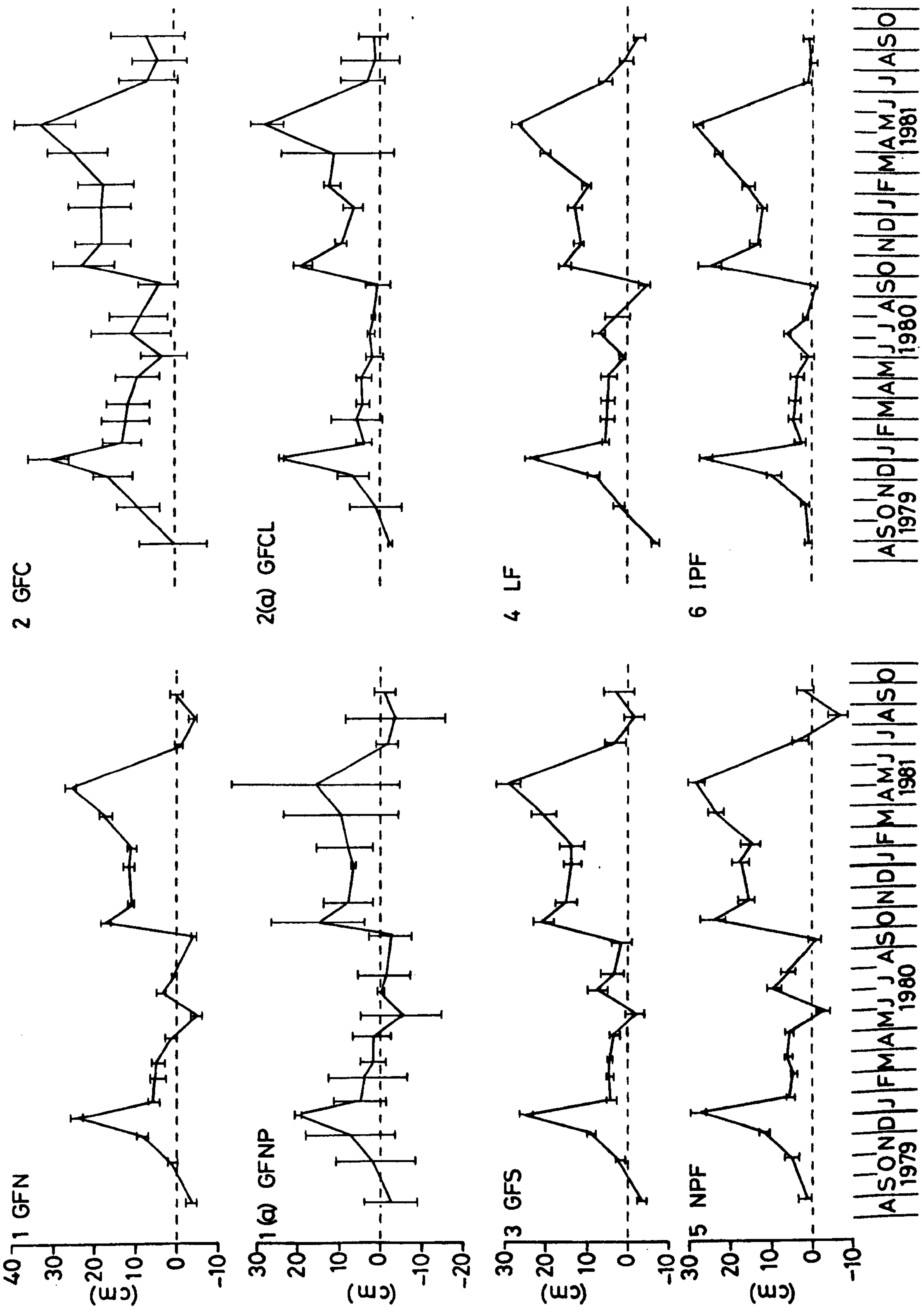

Fig. 4.5. a). Water level relative to the peat surface (cm) in the study sites described in Table 4.1. Values are means of 5 readings except in sites 1 a) and 2 a) which are means of two readings. Vertical lines indicate the 95% confidence interval for the mean.

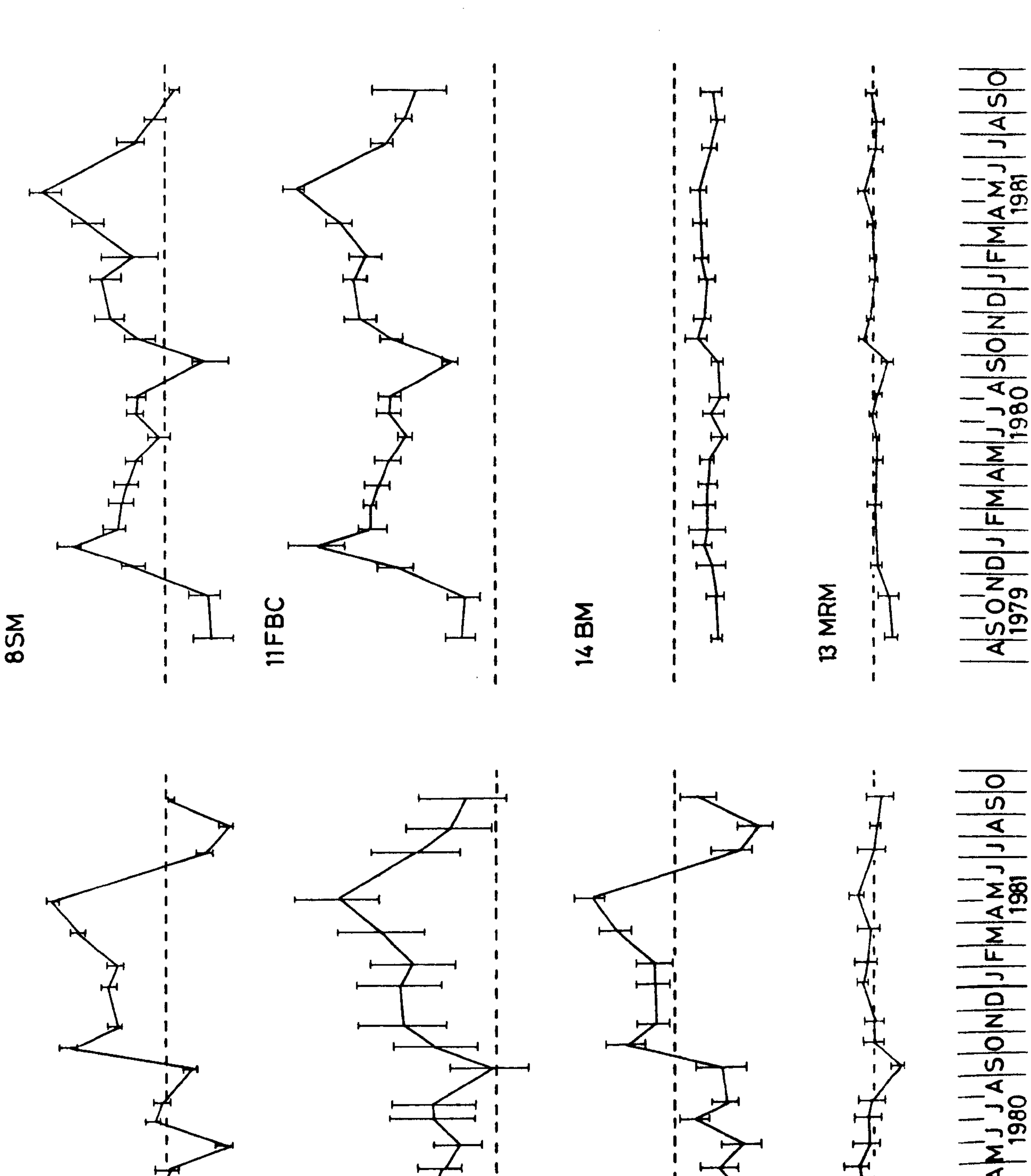
7MHM
10 FBR
9OA
12 FBDC
8SM
11FBC
14 BM
13 MRM
(cm)
A S O N D J F M A M J J A S O N D J F M A M J J A S O
1979
1980
1981

Fig. 4.5. b).

Table 4.2. Some characteristics of the water level fluctuations relative to the peat surface (cm). Values are the means of 5 replicates except for Sites 1 a) and 2 a) which are the means of 2 replicates.

Study Site		Minimum	Maximum	Maximum Difference	Difference May-July 1980
Peucedano-Phragmitetum caricetosum					
1	GFN	- 5.1	25.3	30.4	-25.9
1 a)	GFNP	- 5.3	20.0	25.3	-17.6
2	GFC	0.6	32.1	31.5	-25.7
2 a)	GFCL	- 2.0	27.4	29.4	-23.4
Peucedano-Phragmitetum cicutetosum					
3	GFS	- 3.4	29.5	32.5	-26.1
Peucedano-Phragmitetum typicum					
4	LF	- 6.9	26.5	33.4	-23.6
Phragmites-Typha angustifolia community					
5	NPF	- 6.2	28.5	34.7	-25.7
6	IPF	- 0.5	28.5	29.0	-27.0
Peucedano-Phragmitetum schoenetosum					
7	MHM	-13.8	26.0	39.8	-34.6
8	SM	-10.7	27.7	38.4	-19.4
Osmundo-Alnetum glutinosae					
9	OA	-18.5	18.8	37.3	-32.2
Cicuto-Phragmitetum					
10	FBR	- 1.7	36.2	37.9	-18.0
Cladietum marisci					
11	FBC	7.7	46.2	38.5	-19.8
Betulo-Dryopteridetum cristatae					
12	FBDC	- 5.5	5.4	10.9	- 3.6
13	MRM	- 3.9	2.9	7.8	- 3.1
Betulo-Myricetum					
14	BM	-10.2	-5.2	5.0	- 2.6

are probably also a reflection of the variation in the height of the peat surface within the study sites. The term water level is used to refer to the water level relative to the peat surface unless otherwise stated.

If the water level fluctuations in the sites where *Sphagnum* spp. are not present (sites 1-11) are considered it can be seen that the water level fluctuations in the study sites in the external system and those in the internal system were different, reflecting the hydrological isolation of the two dyke systems. Within each system water levels in the study sites reflected the water levels prevailing in the dykes (Fig. 4.4). However, there were considerable differences in the water level fluctuations between the study sites of each system. At times of high water level where the water level is well above the peat surface the actual height of the above surface water levels is probably a good estimate of the relative level of the peat surface in the different study sites at that time within each system. These differences are shown by the maximum water levels given in Table 4.2.

The two sites in Fenside Marsh, the *Cladietum marisci* community (11. FBC) and the *Cicuto-Phragmitetum* community (10. FBR) had water levels above the peat surface at virtually all times of measurement . The water levels were consistently higher in site 11. FBC than in site 10. FBR. The fluctuations in water level also exhibited very similar patterns in the *Peucedano-Phragmitetum schoenetosum* community (8. SM) in the internal system although here the water level fell well below the peat surface (minimum level = -10.7 cm) reflecting the relatively high level of the peat surface in this study site.

The minimum water level in the *P.-P. schoenetosum* community (7. MHM) in the external system was also low (-13.8 cm) but in many sites of the external system which had similar maximum water levels (e.g. 4. LF, 5. NPF, 6 IPF) the minimum water levels were not as low. This indicates that some factors other than the relative height of the peat surface must be influencing the water levels in these sites at times of low general water level in the summer months.

The sites which are quite isolated from the dykes of the external system, for instance the *P.-P. typicum* community (4. LF), probably have much poorer water drainage from the site than in those close to the river (e.g. 7. MHM) which could account for the relatively higher minimum water level (-6.9 cm). In the *Phragmites-Typha angustifolia* community in Irstead Poors Fen (6. IPF) the maximum water level is similar to that found in Site 7. MHM but the water level never falls appreciably below the peat surface (minimum = -0.5 cm) and the fluctuations are considerably damped about the peat surface. The water level fluctuations in the *Typha angustifolia* community in Neatishead Poors Fen (5. NPF) and in the *Peucedano-Phragmitetum cicutetosum* community (3. GFS) also appear to be damped to some extent when the water level is close to the peat surface.

Water levels in the *Peucedano-Phragmitetum caricetosum* communities in central Great Fen (sites 1. GFC and 1 a). GFCL) were higher than those in the northern compartment of Great Fen (Table 4.2, Fig. 4.5). The main study site in central Great Fen (2. GFC) was situated in a wetter part of the community than subsite 2 a). GFCL where again fluctuations of the water level were considerably dampened at the peat surface.

The gradual decrease in water levels in site 2. GFC after the very high water levels in January 1980 was similar to that in the study sites of the internal system (e.g. 8. SM) and may indicate that movement of water through the rond separating the two systems was taking place. The water levels in the northern compartment of Great Fen did decrease below the peat surface (minimum = -5.3 cm) but not to the same extent as in the *Peucedano-Phragmitetum schoenetosum* communities (7. MHM, 8. SM). The sluice separating the internal and external systems is situated close to this area of fen (Fig. 4.1) and drainage water through the sluice could be important in maintaining high water levels in this area.

The level of the peat surface in the *Osmundo-Alnetum glutinosae* community (9. OA) was high (maximum water level = 18.0 cm) and the peat surface was not flooded during the summer months. At times when the water level is below the peat surface the fluctuations do not follow the same pattern as those in the other study sites of the external system. This site is situated close to Barton Broad (Fig. 4.1) and has a very humified brushwood peat. When the water level was above the peat surface in this site the water level was the same as that in the broad as the water surface was continuous. This need not be the case when the water level fell below the peat surface as the water level may be maintained at a higher relative level due to capillary action within the peat. Indeed the water level may be below that in the broad if evapotranspiration rates in the study site exceed the rate of water movement through the peat from the broad (c f. Godwin & Bharuca 1932). The humified *Cladium* peats of the *P.-P. schoenetosum* communities (7. MHM, 8. SM) will probably also influence below surface water levels in a similar way but the effects will be much less in unhumified peats as they have a much higher hydraulic conductivity and larger pore sizes (Boelter 1974).

While the extent to which the water level fell below the peat surface in the study sites is probably partly related to the isolation of the sites from open dykes causing poor drainage, it does not seem to be adequately explained in this way. For example the *Phragmites-Typha angustifolia* community in Irstead Poors Fen (6. IPF) is not particularly isolated from the dyke system but the peat surface has a semi-quaking nature underfoot. It is possible that the level of the peat surface may fall at times of low water level in this study site preventing the occurrence of below surface water levels. Lowering of the peat surface may also occur in other communities which have fresh, unhumified peats underlying them, for instance in the *Phragmites-Typha angustifolia* community in Neatishead Poors Fen (5. NPF) and in the

Peucedano-Phragmitetum cicutetosum community (3. GFS). There was no suggestion that movement of the peat surface occurred in communities where the peat was more solid and humified such as the *P.-P. schoenetosum* communities (7. MHM, 8. SM).

The most striking difference between sites, demonstrated by both differences in the height and in amplitude of variation of water level, is that between the three communities with much *Sphagnum* spp. (sites 12. FBDC, 13. MRM, and 14. BM) and all other sites. There was little difference between the minimum and maximum levels in these sites (< 11 cm) and the water level never rose more than 6 cm above the surface in any of them. Indeed in the *Betulo-Myricetum* community (14. BM) the difference between the minimum and maximum water level was only 5.0 cm and the water level rose above -5 cm. This site has a greater depth of *Sphagnum* peat (3.3) and is probably raised in relation to the *Betulo-Dryopteridetum* communities (12. FBDC, 13. MRM) and the other sites . The slight decrease in water level below the surface compared to site 9. OA, which is also densely wooded, could be due to shrinkage or compaction of the peat but this is unlikely due to the weight of the trees, and the firm nature of the susbstratum. It may be mainly due to the water retention capacity of *Sphagnum* and *Sphagnum* peat (Boelter 1974) which can maintain a high water level (Burke 1961). The water level in site 14. BM and that in sites 12. FBDC and 13. MRM was not unaffected by rise and fall in water level in the surrounding system and does follow the same pattern, though the oscillations were damped considerably.

The water level did rise above the peat surface in sites 12. FBDC and 14. MRM, submerging some, but not the majority of the *Sphagnum* hummocks which are very loose and grow to 20-30 cm above the firm surface. A continuous water surface was never detected between these sites and the adjacent communities even under exceptional flooding conditions, and it seems likely that the water level is maintained in these sites by the *Sphagnum* peat. The lack of much flooding in these *Sphagnum* communities will be at least partly due to the relatively higher levels of the peat surface compared to other sites but could also be partly due to rising or swelling of the peat raising the peat surface during times of high water levels.

4.4.3. Vertical movement of the peat surface

To investigate the possibility of vertical movement of the peat surface, which had been indicated by the differences in water level fluctuations between study sites during 1979 and 1980, measuring posts were installed in a few selected areas. These consisted simply of three metre lengths of 1" diameter ABS pipe which were pushed firmly down through the surface peat layers into the solid brushwood peat below (3.3).
The height of the peat surface was measured from the top of these posts at the same time as the peat water levels were monitored. The results are shown in Fig. 4.6. The sites selected for the installation of the measuring posts were chosen to represent the main types of water level fluctuation observed over the previous study period, with particular attention to the *Sphagnum* communities.

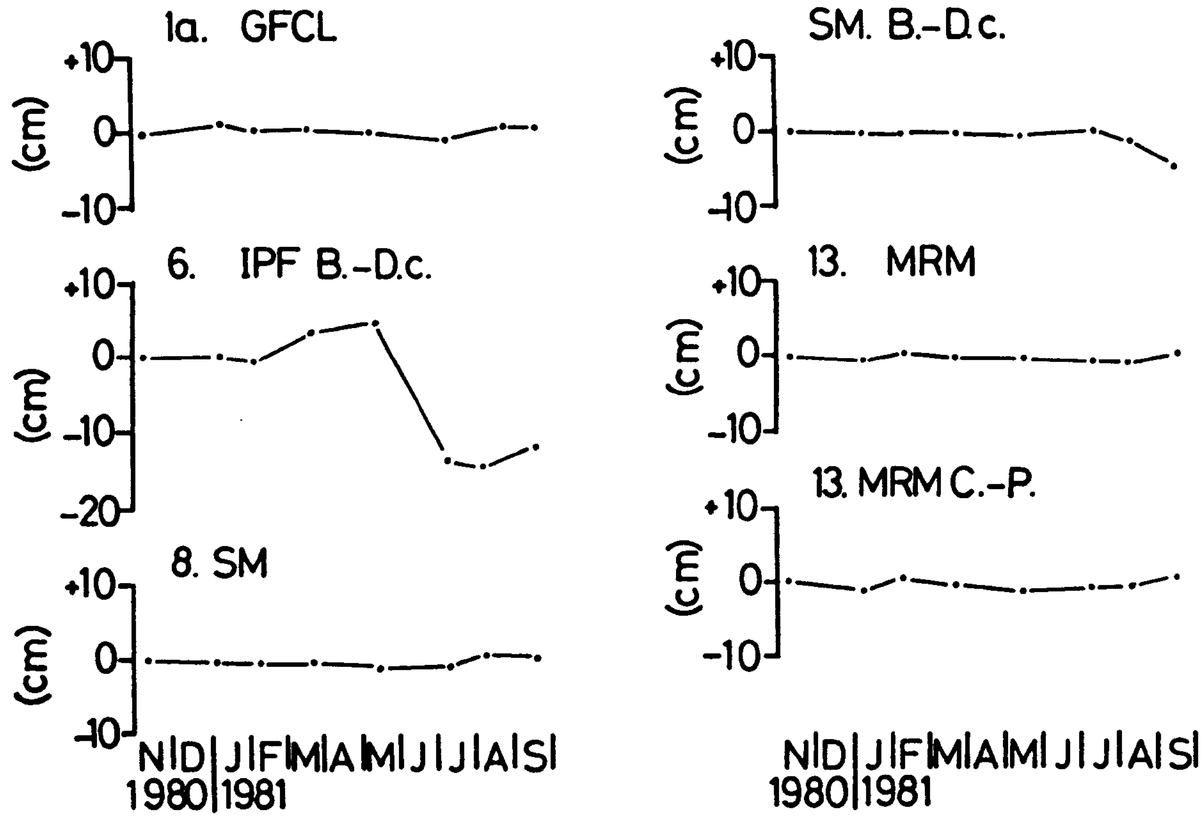

Fig. 4.6. Vertical movement of the peat surface (cm) relative to the height when first measured (0 cm). See text for site descriptions.

The most striking vertical movement of the peat surface was observed in the *Betulo-Dryopteridetum cristatae* on Irstead Poors Fen (IPF, *B-D. c.*). This site is situated roughly 10 m from study site 6. IPF and the peat surface over this whole area has a semi-quaking character underfoot. The peat surface rose nearly 5 cm between February and May 1981 before falling almost 17 cm between May and July. If the graph of peat surface movement in this site is compared with the water level fluctuations in site 6. IPF, it is obvious that the graphs have a similar shape, the peat surface rising and falling with the water level.

There was also noticeable movement in the peat surface in the *Betulo-Dryopteridetum cristatae* area in Sedge Marshes (SM, *B-D.c.*), while in the adjoining *Peucedano-Phragmitetum schoenetosum* community (study site 8. SM) there was no significant movement. SM, *B-D.c.*, is situated over an overgrown dyke (see transect A-B, 3.3) and **again** the peat surface has a semi-quaking character, while the peat surface in site 8. SM feels solid underfoot. The water level in site 8. SM only fell below the level of the peat surface in September 1981 during the period over which thèse measurements were taken and it is only when the water level fell below the peat surface in site 8. SM that the peat surface in SM. *B-D.c.* lowered nearly 5 cm.

The peat surface in site 13. MRM that in the *Cicuto-Phragmitetum* area roughly 20 cm from the edge of this study site did not move significantly over the period studied. This is also true of site 2 a). GFCL.

It is clear that there is significant movement of the peat surface in some situations. The maximum fall in level measured in this investigation was 17 cm although it is quite probable that further fall in the level of the peat surface would occur under conditions of generally lower water levels. (There was unusually high rainfall during the study period - 4.3.2.). It is also possible that vertical peat surface movement could occur in some of the other sites examined if lower water levels prevailed. It is of interest that measurements in site 2 a). GFCL did not demonstrate significant vertical movement of the peat surface despite the suggestion that movement was occuring from the water level fluctuations in this site when compared with other sites of the external system. It is possible that the prevention of water levels falling below the peat surface in this site could be due to the isolation of the site from open dykes causing poor drainage from such areas.

3.4.4. Water Movement

Three approaches were used to investigate lateral water movement through the peat. The first involved the construction of a flowmeter which was constructed using the design of Daniels, Pearson and Ryden (1977). Extensive field trials with the flowmeter did not indicate the presence of water movement in any of the study sites. The second method used fluorescent dyes; Rhodamine-WT, Lissamine-FF and Amino-G-acid (Smart & Laidlaw 1977). The dyes were introduced into a shallow pit, water samples being taken on a grid basis over an areas of 25 m^2 around the pit on four occasions over two days after introduction of the dyes. Initial tests indicated that adsorption of these dyes in the peat and background fluorescence of the peat waters were low enough to be acceptable. The applicability of the method was limited as it could only be used in situations with below surface water level to prevent surface movement of the dye by the investigator. The results obtained using this method were inconclusive and did not indicate any directional water movement, the movement of the dyes from the site of introduction simply being due to diffusion.

The third method of investigation was based on the principle that geogenous water is often thermostable (Todd 1980). A probe (Appendix 2) was used to measure the temperature within the peat at 10 cm vertical intervals over 150 cm on two occasions around midday in March and July 1981 (Fig. 4.7). Trials indicated agreement within 0.1°C between replicate profiles in each site, except for the surface readings.

The temperature differences between the sites in March were small, all below surface readings falling in the range 5.6-7.5°C. The pattern of temperature variation with depth is very similar in all the sites, reaching a minimum between 40 and 100 cm below the surface. The higher temperatures below this level are probably due to the insulation of the peat and water above and the higher temperatures in the top 40 cm of peat are possibly due to daytime warming of the surface layers of peat and water. As no night-time measurements are available this cannot be confirmed.

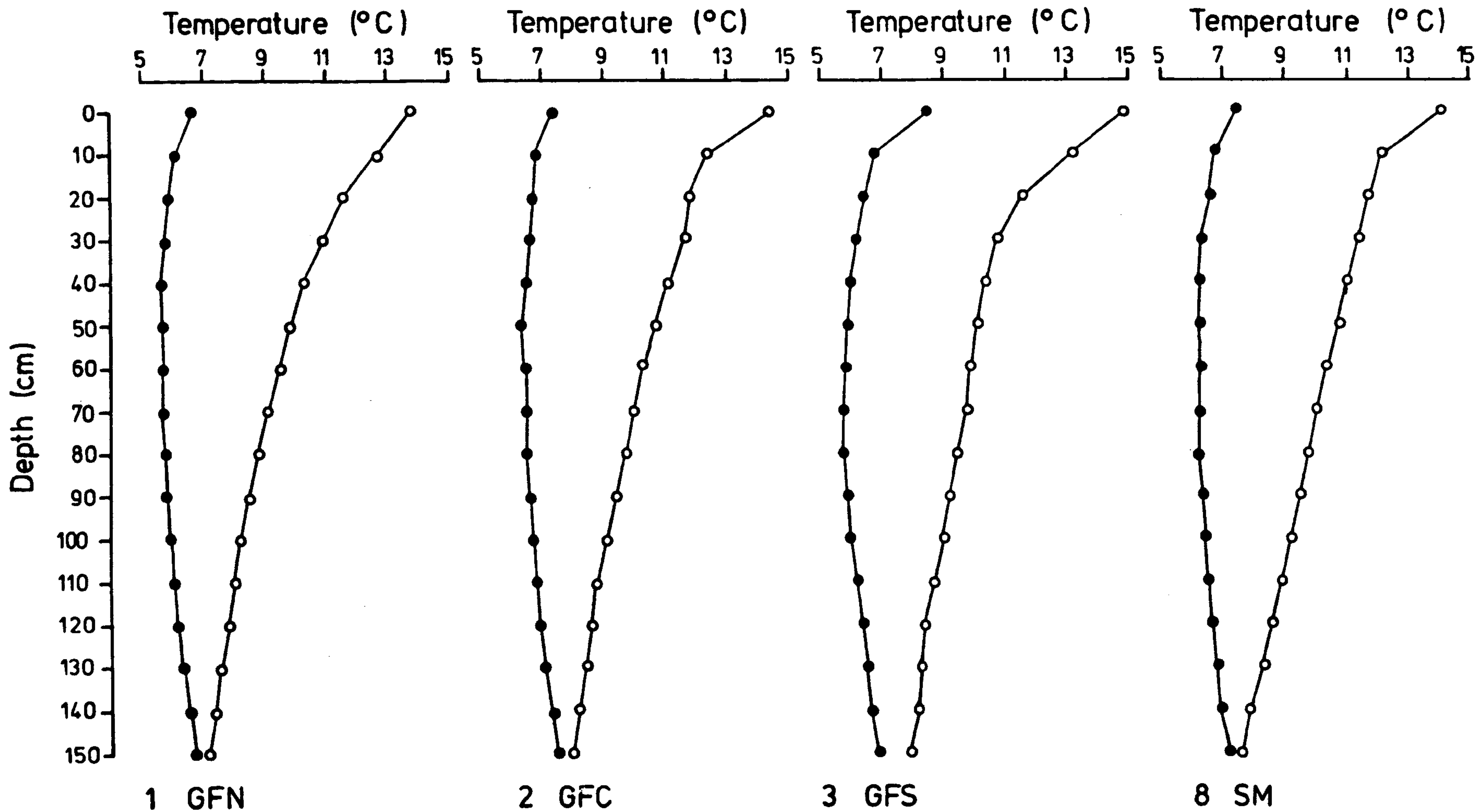

Fig. 4.7. Temperature (^{o}C) within the surface 150 cm of peat in some of the study sites in March 1981 (●) and August 1981 (o).

Site 2. GFC has the highest temperatures consistently down the profile, but only normally 0.2-0.4^{o}C above those at similar depths in 8. SM. The extent to which warming of the peat takes place could depend on the insulating effect of a deeper layer of water above the peat surface, in this case the greater depth of water maintaining higher temperatures in winter in site 2. GFC. The thermal conductivity of the peat may also vary with the type and humification of the peat.

In July the sites all show a considerable increase in temperature in the surface layers, the increase being successively smaller with increased depth. The shape of the temperature profiles is very similar in all of the sites examined but the increase at 150 cm depth in site 3. GFS is much larger (1^{o}C) than that in the other sites (0.4-0.5^{o}C). This could be due to the very loose *Phragmites-Typha* peat in this site allowing better conduction (and convection) of heat from the surface.

If an influx of thermostable water was present it was postulated that this would lead to smaller differences between the profiles in winter and summer and more constant temperatures down the profile in each case. As there are no such differences in the temperature profiles from the four sites examined or any other marked differences between sites, these results do not indicate the presence of seepage in all or any of the sites.

4.4.5. The relationship between the hydrology and vegetation of the study sites

The annual water level fluctuations in the internal dyke system are similar to those observed at Wicken Fen (Godwin & Bharuca 1932), Chippenham Fen (Kassas 1951) and Askham Bog (Fitter *et al.* 1980), and reflect the water level management implemented by varying the height of the sluice gate. The policy of water level management is to keep the water high during the winter and early spring to exclude 'weeds' from the reedbeds and to allow the water level to fall considerably during the summer to facilitate sedge cutting (McDougall 1972). This water level management augments the natural pattern of variation in water levels as observed in the external system where water levels also fall considerably during the summer when evapotranspiration exceeds precipitation and drainage inputs (c f. Godwin 1931). It is not clear whether the water management since 1968 when the sluice was installed has had significant effects on the vegetation in the internal system directly by changing the water level and fluctuations of it, as the situation is complicated by different histories of marsh management in the internal and external systems and the lack of floristic data prior to the installation of the sluice. It is possible that the sluice may have had significant effects by changing the source of the water and hence the water quality (4.5).

Over the period studied the sluice undoubtedly created significant differences in the water levels in the study sites of each dyke system, in general prolonging higher water levels in the internal system. The differences in water level between vegetation types were drawn out most clearly at times of very low or very high water in the dyke systems (Table 4.2). The two study sites situated in swamps had water levels above the peat surface almost all the time, the *Cladietum marisci* (11. FBC) having consistently higher water levels than the *Cicuto-Phragmitetum* (10. FBR). Examples of deep water *Phragmites* swamps were not studied.

The examples of the *Peucedano-Phragmitetum caricetosum* investigated all had minimum water levels less than -6 cm during the study period. The wettest of these was site 1. GFC which never had below surface mean water levels. As site 10. FBR, this area has a very uneven peat surface and contains many aquatic and swamp species (e.g. *Utricularia vulgaris, Cicuta virosa*) in the wetter areas. The other examples of the *Peucedano-Phragmitetum caricetosum* had water levels only slightly below the peat surface during dry periods, possibly explaining the abundance and diversity of bryophytes (e.g. *Calliergon giganteum, Scorpidium scorpioides*) and small, shallowly rooted vascular plants (e.g. *Anagallis tenella, Drosera anglica*) as they would be able to avoid desiccation. The possiblity of desiccation would also be reduced in most areas of open fen by the shade and shelter produced by the abundance of tall herbaceous plants.

The example of the *Peucedano-Phragmitetum cicutetosum* (site 3. GFS) and the species-poor *Phragmites-Typha angustifolia* community (site 6. IPF) which both have a semi-quaking peat surface rarely have below surface water levels and are both dominated by sparsely growing *Phragmites* and *Typha angustifolia*. However, site 5. NPF which is also an example of a *Phragmites-Typha angustifolia* community with sparse *Phragmites* and *Typha angustifolia* had a minimum water level 6.2 cm below the peat surface suggesting that high minimum water levels are not solely important in producing such vegetation. The *Peucedano-Phragmitetum typicum* study site (4. LF) also had water levels not far below the surface of the peat (minimum = -6.9 cm) and does contain some bryophytes (e.g. *Calliergon cordifolium*) which may be intolerant of desiccation.

All the vegetation types discussed above generally occur in areas which apparently were cut for peat during the last century (3.4.2.). The *Peucedano-Phragmitetum schoenetosum* is, however, restricted in distribution to areas which were apparently not subject to such cutting. These areas have water levels well below the peat surface in the summer months. This community type lacks an abundance or diversity of low growing species (e.g. *Anagallis tenella, Drosera anglica, Utricularia intermedia*). It appears likely that this is directly related to the greater likelihood of desiccation stress occurring in areas not recently cut for peat, especially after mowing when any effect of the vegetation in maintaining a high humidity will be removed. It must be remembered that the rainfall during the period of study was comparatively high and it seems likely that much lower water levels may occur in these areas of recently uncut peat during drier years. In particular, years of very low rainfall (e.g. 1976)[1] may have marked effects on the vegetation.

The *Osmundo-Alnetum glutinosae* has water levels well below the peat surface except during times of very high general water level in winter and in 1981 in spring. *Alnus glutinosa* can grow well in waterlogged soils (McVean 1953) but seems unable to withstand prolonged deep flooding (c f. Lambert 1951). Many of the associated species in this alder carr are not usually found on continuously waterlogged soils (e.g. *Rosa canina, Poa trivialis*) and are probably excluded from wetter areas in the study site due to their intolerance of prolonged flooding.

The community types which contain much *Sphagnum*, the *Betulo-Myricetum gale peucedanetosum Sphagnum* var. and the *Betulo-Dryopteridetum cristatae*, are never flooded to any extent and also retain water levels within 11 cm of the surface even during the driest periods. The maintenance of high water levels is in these communities, probably mainly due to the water retention capacity of *Sphagnum*. Experiments on drain spacing in blanket peat containing much *Sphagnum* demonstrated that water levels were only noticeably lowered within 2 m of the drains (Burke 1961). The isolation from flooding seems to be due to either the higher absolute level of the peat surface when compared with the other community types, or to the elevation of the peat surface

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1 Extensive invasion of *Myrica gale* and *Salix cinerea* into reed and sedge beds occurred during 1976 (D.S.A. McDougal pers. comm.)

by swelling of the peat or rising of a peat raft. In many situations both of these factors are probably important.

Semi-floating peat rafts

The occurrence of semi-floating rafts of vegetation is well documented; Gates (1940) found a maximum fluctuation of 62.5 cm in a bog surface over a 17 year study period and Buell & Buell (1941) found a maximum fluctuation of 37.5 cm in a sedge mat over 3 years. At Wybunbury Moss, Cheshire, Green & Pearson (1968) found a maximum amplitude of movement of 10.6 cm in a *Sphagnum* community in 1964 and 1965 which was lower than the maximum amplitude recorded here of almost 17 cm. O'Connell (1981) found peat surface movement in a fen community at Scragh Bog, Eire but concluded that it was due to compaction of the peat rather than semi-floating raft movement. The presence of a semi-floating raft of peat in a *Scorpidio-Caricetum diandrae* community in the Netherlands has been demonstrated (Raeymaekers 1977) but there was no direct evidence for the occurrence of such a peat raft in the vegetationally similar *Peucedano-Phragmitetum caricetosum* communities in the present study.

All the documented vertical movements of peat rafts mentioned above occurred in semi-quaking areas of mire, however, Buell & Buell (1941) also noted a 10.3 cm change in the level of the peat surface under mature mire woodland. Effects of such peat surface movement on the vegetation are probably mediated in two main ways; directly by maintaining water levels at or about the peat surface and thus preventing stress due to drought or flooding and indirectly by isolating vegetation on the peat surface from the chemical influences of flood water (4.5). In some communities (e.g. site 6. IPF) movement of the peat surface does not prevent flooding of the surface but appears to prevent the water level falling below the peat surface. Above surface water levels could have been important in preventing or controlling the spread of *Sphagnum* from the adjacent *Betulo-Dryopteridetum cristatae* community (IPF, *B-D.c.*).

Water movement through the peat

The importance of 'seepage' in determining the distribution of certain plant communities in North-West Overijsel, Netherlands was emphasized by Segal (1966). The main community types found in seepage areas were the *Caricetum diandrae*, *Phragmiteto-Caricetum lasiocarpae* and *Menyantheto-Juncetum subnodulosi*, the first two of which appear to be synonymous with the *Scorpidio-Caricetum diandrae* (Koch 1926) Westhoff 1969. This association was renamed the *Acrocladio-Caricetum diandrae* by Wheeler (1975) to cover very similar vegetation types within England and Wales which often do not contain *Scorpidium scorpioides* (Wheeler 1980b). Wheeler (1980a) indicates the close phyto-sociological affinity of the *Peucedano-Phragmitetum caricetosum* to the *Acrocladio-Caricetum diandrae*, and personal observations of the communities of seepage areas in North-West Overijsel described by Segal (1966) confirmed the close similarities of such vegetation to the *Peucedano-Phragmitetum caricetosum*.

The involvement of seepage in determining the distribution of the *Peucedano-Phragmitetum caricetosum* within the study area cannot be discounted although none of the methods employed provided any indication of water movement in any of the sites examined. G. van Wirdum (pers. comm.) examined the possibility of seepage in such vegetation in North-West Overijsel with particular attention to the possibility of the upwelling of water from the sub-soil beneath the peat, but could find no evidence for seepage.

The importance of water movement in controlling the distribution of *Molinia caerulea* in some situations has been demonstrated to be due to the degree of aeration of the peat caused by the turbulence of the water (Armstrong & Boatman 1967). It seems unlikely that seepage from the surrounding sub-soil would increase the aeration of the peat as water coming directly from underground sources is probably not well oxygenated. *M. caerulea* only occurs in abundance in the study area in the *Peucedano-Phragmitetum schoenetosum*, which has water levels well below the peat surface during the summer months.

Several examples of evidence for the existence of springs along the margins of the broadland flood plain mires do exist. In macrophyte-rich dykes surrounding wet pasture near Upton at the Bure valley margin (which is reclaimed mire) obvious upwelling of water occurs from the floor of the dykes. Similarly an excavated pool at the margin of the River Ant valley at How Hill exposed an active spring of water at the edge of the estuarine clay. Measurements of redox potential in the sediments of marginal dykes near North Marsh in the present study area were very high indicating the possibility of seepage of oxygenated water (Wheeler & Giller 1982) and the water in areas of fen near the margin e.g. 1. GFN, 8. SM, did not freeze over in the same way as happened in the central areas of the study site during cold weather in February 1979, which is possibly an indication of marginal seepage.

As already stated no direct evidence of seepage could be found in the present investigation and the way in which seepage may be influencing the distribution of the vegetation in the study site (if it does occur) is not obvious. While the possibility of seepage cannot be discounted it seems unlikely to be of particular importance in determining the distribution of the vegetation.

3.4.6. Conclusions

The water levels in the internal and external dyke systems are subjected to different hydrological control. The water levels in the external dyke system are regulated by the drainage system of the River Ant while those of the internal dyke system are controlled by the height of the sluice separating the two systems. This results in a differential response of the water levels in the two systems to precipitation and resulting land drainage inputs of water.

The water levels relative to the peat surface in the marshes reflect those of the surrounding dykes. Drainage from areas which are isolated from open dykes is less efficient than from those close to open dykes and sites near to the main boundary dyke of the internal system, but within the external system, may receive some water input through the rond separating the two systems when higher water levels prevail in the internal dyke system.

At times of flooding the differences in water levels between study sites of each system will reflect the relative heights of the peat surface at that time. When the water level falls considerably (usually during the summer months) the differences in water level in the sites reflect the relative height of the peat surface, the isolation of the sites from drainage, the capacity of the peat surface to rise and fall, the capacity for water retention of the peat in each site and probably differences in evapotranspiration rates between the sites. The extent to which the peat surface is able to rise and fall can probably be roughly assessed by observations of how semi-quaking the peat surface feels underfoot. Two main types of response to low summer water levels were observed. In areas not recently cut for peat the water level fell considerably below the peat surface (> 10 cm below), while in areas which were cut for peat in the last century the water level fell only slightly below the surface or not at all. High winter water levels (> 10 cm above the peat surface) were found in all except the sites with much *Sphagnum* and *Sphagnum* peat.

No direct evidence for water movement could be found although the possibility of seepage cannot be discounted.

4.5. INVESTIGATIONS OF THE CHEMISTRY OF THE PEATS AND PEAT WATERS

The results of preliminary chemical analyses of the peats and peat waters indicated that levels of dissolved nitrogen and phosphorus were very low, in fact undetectable in many samples. (Fig. 5.1) (cf. Daniels 1969; Fitter *et al.* 1981). Levels of nitrogen and phosphorus in the peats were detectable in all cases and therefore investigation of the spatial variation of these elements between study sites has been limited to analysis of the peats. The amounts of variables which are normally of low level in extractable or dissolved form (N, P, Fe, Mn) were also determined in peat digests. The main discussion is based on the analysis of peat and water samples collected in October 1979, the results of which are shown in Tables 4.3., 4.4. and 4.5.

In the subsequent discussion of the results of chemical analyses of the peats and peat waters, for each variable comparison the results of a one-way analysis of variance (Appendix 2) are summarized. The F-ratio and probability are given and the mean value of the variable for each site. The lines underneath the means indicate homogenous subsets generated using Duncan's New Multiple range test ($P < 0.05$). Heterogeneity of error variances is indicated by the probability of the Bartlett Box-F test and where this is significant ($P < 0.05$), as in many cases, the subsets can only be regarded as indicative of differences between the study sites. Transformation of the data

Table 4.4. Some chemical characteristics of digestible fractions of the peat from the study sites. The concentrations are expressed (mg l^{-1} peat), values refer to the mean ($\bar{x}$) and the standard error (S.E.). A description of the study sites is given in Table 3.1.

	Ash (% dry wt)	N	P	Fe	Mn
	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.
1 GFN	9.1 (0.85)	996 (113)	42 (5.0)	390 (73)	104 (31.0)
2 GFC	9.0 (0.43)	818 (79)	31 (2.2)	122 (13)	20 (4.3)
3 GFS	8.6 (0.39)	1320 (48)	45 (2.7)	162 (27)	2.6 (0.47)
4 LF	9.2 (0.49)	1580 (56)	73 (2.7)	144 (8)	6.2 (0.29)
5 NPF	7.2 (0.49)	1070 (70)	37 (3.9)	111 (11)	2.1 (0.25)
6 IPF	7.2 (0.49)	943 (57)	30 (1.3)	156 (71.1)	3.6 (0.24)
7 MHM	12.0 (0.63)	1500 (100)	50 (2.6)	483 (51.9)	43 (9.8)
8 SM	10.0 (0.63)	1230 (74)	33 (1.5)	233 (51.0)	39 (5.9)
9 OA	19.2 (0.66)	3010 (133)	110 (5.8)	666 (42.5)	39 (8.1)
10 FBR	7.2 (0.58)	1410 (92)	53 (4.3)	127 (7.8)	18 (2.5)
11 FBC	8.0 (0.55)	1230 (73)	37 (6.5)	184 (14.1)	42 (8.9)
12 FBDC	5.2 (2.28)	1270 (181)	50 (8.7)	202 (26.5)	2.8 (0.59)
13 MRM	3.2 (0.49)	508 (69)	17 (2.8)	51 (7.6)	3.4 (1.28)
14 BM	4.4 (1.16)	1760 (113)	49 (2.2)	218 (29.3)	8.7 (1.30)

Table 4.5. Chemical variables measured on samples of peat waters collected in October 1979. The values refer to the mean ($\bar{x}$) and standard error (S.E.) of 5 replicate water analyses

		pH	Conductivity (μS)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	HCO_3 (mg/l)	SO_4 (mg/l)	Cl (mg/l)	Fe (mg/l)	Mn (mg/l)
		$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.	$\bar{x}$ ± S.E.
1	GFN	6.65 (0.08)	780 (19)	96 (2.9)	21.2 (0.4)	102 (3.2)	7.0 (0.98)	505 (33.5)	140 (13.4)	125 (4.6)	0.25 (0.05)	1.01 (0.39)
1a)	GFNP	6.60 (0.10)	770 (5)	95 (3.0)	20.5 (0.5)	96 (0.0)	7.1 (0.50)	480 (18.3)	160 (39.4)	115 (0.9)	0.05 (0.05)	0.21 (0.21)
2	GFC	6.55 (0.02)	675 (28)	89 (4.7)	15.8 (0.4)	79 (4.7)	10.0 (0.32)	550 (49.6)	180 (3.3)	85 (7.6)	-	-
2a)	GFCL	6.85 (0.15)	700 (65)	86 (7.5)	17.0 (1.0)	93 (11.5)	8.2 (0.40)	535 (36.6)	120 (39.4)	120 (9.3)	-	-
3	GFS	6.70 (0.08)	945 (30)	111 (3.8)	21.8 (1.0)	126 (2.5)	5.9 (0.65)	610 (19.3)	185 (22.2)	160 (7.7)	0.04 (0.04)	-
4	LF	6.40 (0.03)	1430 (35)	154 (2.6)	31.2 (0.7)	184 (4.0)	4.9 (0.27)	820 (36.3)	120 (11.5)	295 (15.6)	0.14 (0.03)	0.33 (0.05)
5	NPF	6.70 (0.04)	1810 (158)	96 (2.3)	50.4 (2.6)	480 (21.5)	17.8 (4.19)	525 (56.8)	200 (7.6)	490 (36.5)	0.15 (0.07)	0.25 (0.01)
6	IPF	6.50 (0.03)	1120 (195)	89 (0.9)	23.4 (0.4)	125 (1.8)	8.9 (0.19)	460 (33.0)	205 (10.5)	120 (5.3)	-	0.11 (0.05)
7	MHM	6.70 (0.08)	1800 (155)	106 (3.9)	44 (3.4)	440 (31.5)	8.7 (1.41)	430 (15.7)	250 (13.3)	460 (29.4)	1.78 (0.40)	1.10 (0.30)
8	SM	6.95 (0.05)	925 (73)	87 (9.7)	29.8 (2.7)	131 (6.8)	4.7 (0.45)	355 (18.8)	125 (24.6)	165 (15.2)	1.24 (0.43)	0.63 (0.26)
9	OA	6.75 (0.10)	1220 (107)	145 (7.1)	21.0 (0.3)	158 (16.5)	5.8 (0.68)	540 (43.6)	240 (25.3)	255 (42.9)	0.25 (0.07)	0.44 (0.15)
10	FBR	6.60 (0.10)	820 (21)	79 (2.6)	24.4 (0.9)	111 (4.5)	4.5 (0.75)	345 (20.3)	160 (27.4)	155 (8.8)	0.17 (0.06)	0.44 (0.21)
11	FBC	6.65 (0.05)	690 (17)	59 (6.0)	20.4 (1.6)	104 (3.7)	9.6 (0.83)	305 (37.3)	120 (13.7)	145 (7.9)	-	0.25 (0.18)
12	FBDC	5.25 (0.42)	585 (12)	26.4 (2.5)	13.2 (0.8)	111 (2.5)	5.4 (1.62)	78 (21.9)	90 (11.9)	150 (6.7)	0.41 (0.12)	0.07 (0.03)
13	MRM	5.90 (0.14)	315 (15)	24.6 (1.9)	7.4 (0.5)	56 (4.2)	4.2 (1.01)	59 (7.1)	60 (4.5)	60 (6.1)	2.16 (0.11)	0.23 (0.01)
14	BM	5.30 (0.49)	555 (68)	32.8 (8.9)	10.3 (2.3)	103 (7.9)	3.9 (0.69)	55 (28.4)	90 (26.9)	150 (11.6)	0.67 (0.23)	0.04 (0.01)
15	BRD	7.70 (0.20)	695 (3)	107 (0.0)	13.5 (0.5)	65 (1.5)	85 (0.10)	305 (0.05)	240 (8.6)	67 (5.6)	-	-
16	RIV	8.00 (0.05)	675 (5)	110 (2.1)	15.0 (1.0)	64 (0.5)	8.9 (0.70)	290 (0.05)	240 (6.7)	66 (2.8)	-	-

using $\log_{10}$ was found to reduce the heterogeneity of the error variances in the case of sodium and chloride concentrations and in these cases the analysis of variance was performed on transformed values. The data means and confidence limits were back-transformed in these areas to allow easier comparison of the results.

In most cases values are means of five replicates, the values from subsites 1 a). GFNP and 1 b). GFCL and sites 15. BRD and 16. RIV are means of two replicate analyses.

4.5.1. pH

Peat Water pH

F ratio = 11.267 $P < 0.001$ Bartlett Box-F $P < 0.001$

Site	12	14	13	4	6	2	10	1a	11	1	5	3	7	9	2a	8	17	18
	FBDC	BM	MRM	LF	IPF	GFC	FBR	GFNP	FBC	GFN	NPF	GFS	MHM	OA	GFCL	SM	BRD	RIV
Mean	5.25	5.30	5.90	6.40	6.50	6.55	6.60	6.60	6.65	6.65	6.65	6.70	6.70	6.75	6.85	6.95	7.70	8.05

The sites separated into three clear groups on the basis of peat water pH. The three sites with much *Sphagnum* had considerably lower pH (< 6.00) than all of the other sites (pH > 6.40).

The water samples taken from the broad and river (17. BRD, 18. RIV) had much higher pH values than all other sites due to effects of the equilibrium of dissolved carbon dioxide compounds on the pH resulting from algal photosynthesis (Golterman *et al.* 1978).

Peat-pH

F ratio = 166.943 P < 0.001 Bartlett Box-F P < 0.001

Site	14	13	12	8	1	10	11	4	2	6	9	7	3	5
	BM	MRM	FBDC	SM	GFN	FBR	FBC	LF	GFC	IPF	OA	MHM	GFS	NPF
Mean	3.75	4.15	4.70	6.15	6.25	6.35	6.40	6.40	6.45	6.50	6.50	6.55	6.55	6.65

The *Sphagnum* sites have much lower peat pH (< 5.00) than all of the other sites (pH > 6.00).

The mean values of peat water pH were higher than the mean values of peat pH in almost all of the study sites. Newbould and Gorham (1956) found no consistent significant difference between pH values obtained by direct insertion of an electrode into the peat or by measurements on peat waters. In this case the measurements are not directly comparable as the peat samples were taken from 10-20 cm depth, whereas the peat water samples were taken from sampling tubes and represent water from 0-50 cm depth. The peat water pH has been shown to exhibit stratification and these results are discussed in Chapter 5 . The difference in depth from which the peat and peat water samples were taken probably explains the difference in the two values from each site.

The three sites which contain much *Sphagnum* had much lower peat and peat water pH than all of the other sites. The ability of *Sphagnum* species to decrease the pH of its environment has been demonstrated by Clymo (1964) and is thought to be due mainly to cation exchange in the cell walls of the *Sphagnum* plants (Clymo 1967). All of these study sites are isolated from inundation by floodwater (4.4.2.) which is normally of high pH. (5.3.1.) site 14. BM which has the greatest depth of *Sphagnum* peat has the lowest peat pH and has probably been isolated from inundation for a longer period. Site 13. FBDC which has a shallow *Sphagnum* containing much herbaceous plant material had much more variable peat pH than site 13. MRM which has a more pure shallow *Sphagnum* peat.

Sites 1-11 which are all periodically flooded (4.4.2) had much higher peat pH. The maximum difference between the peat water and peat pH of these sites was only 0.5 units and much more detailed investigations would be required to determine whether differences between these sites were significant.

4.5.2. Dry Weight per unit volume

F ratio = 14.06 $P < 0.001$ Bartlett Box-F N.S.

Site	13	5	2	6	8	3	12	10	11	1	4	7	14	9
	MRM	NPF	GFC	IPF	SM	GFS	FBDC	FBR	FBC	GFN	LF	MHM	BM	OA
Mean (g/l peat)	53	58	59	60	61	61	62	63	65	68	72	79	103	109

The dry weight per unit volume or bulk density has been used to estimate the humification of the peat (Kaila 1956).

Sites 14. BM and 9. OA had much higher bulk density than all of the other sites (> 100 g/l) which reflects the more humified nature of the peat in these two relatively mature fen woodland sites. As both of these sites had water levels below the peat surface for considerable periods of the year the surface layers of the peat will be at least partially aerated allowing decomposition to occur more quickly (Ponnamperuma, 1972). The slightly higher bulk density in site 9.OA is probably related both to the lower water table in the summer months and the species composition of the peat, that of site 9. OA is an amorphous brushwood peat while the peat from site 14. BM is composed predominantly of *Sphagnum* remains and tree litter.

Sites 7. MHM and 4. LF had significantly higher bulk densities than the remaining sites, except for site 1. GFN. The water level in these three sites did fall below the surface allowing decomposition to take place,which would explain these higher values. What is more surprising is that site 8. SM, which also had below surface water levels and a dark solid peat, had quite a low bulk density, but it is not significantly lower than that of 1. GFN. The remaining sites all have water levels near or above the peat surface year round which will reduce the rate of decomposition in these sites. The fresh *Sphagnum* peat from site 13. MRM had the lowest bulk density (53 g l^{-1}) while the *Sphagnum* peat from site 12. FBDC had a higher bulk density

(63 g l^{-1}), the difference probably being due to the more frequent fragments of herbaceous and woody species in the peat from site 12. FBDC. Sites 2. GFC and 11. FBC which had a fresh *Cladium* peat and sites 3. GFS, 5. NPF, 6. IPF and 10. FBR which had a fresh *Phragmites* peat all had quite low bulk densities.

4.5.3. Ash Content (% dry weight)

F ratio = 32.673 $P < 0.001$ Bartlett Box-F N.S.

Site	13	14	12	10	6	5	11	3	2	1	4	8	7	9
	MRM	BM	FBDC	FBR	IPF	NPF	FBC	GFS	GFC	GFN	LF	SM	MHM	OA
Mean (%)	3.2	4.4	5.2	7.2	7.2	7.2	8.0	8.6	9.0	9.1	9.2	10.0	12.0	19.2

All of the peats sampled had low percentage ash contents reflecting the almost purely organic nature of the peats. The ash contents are all within the range for wetland plants of 6.1-40.6% quoted by Boyd (1978) and slightly higher in some cases than the average for emergent vascular plants of 9.7% found by Boyd (1968).

The high ash content of site 9. OA is probably a reflection of the humified, lignaceous nature of the peat although it is possible that some silt deposition from the river may have occurred here and in site 7. MHM. Sites 8. SM and 1. GFN which are close to the land margins have quite high ash contents, perhaps due to wind-blown material although these sites do not have significantly higher levels than some sites which are further from the margins (e.g. 4. LF). In general more humified peats had higher ash contents, with the exception of three acidic *Sphagnum* peats which all have very low ash contents. This is probably due both to the isolation of these sites preventing any mineral deposition during flooding episodes as well as the low ash content of *Sphagnum* remains (Mörnsjö 1968). The lowest ash content was found in site 13. MRM which had a very pure *Sphagnum* peat.

The peat ash contents found here are similar to those reported from the Mallam Tarn Fens (Proctor 1974) for areas with little silt deposition.

4.5.4. Nitrogen

F ratio = 5.004 $P < 0.001$ Bartlett Box-F N.S.

Site	8	7	13	11	12	1	5	6	14	10	2	4	3	9
	SM	MHM	MRM	FBC	FBDC	GFN	NPF	IPF	BM	FBR	GFC	LF	GFS	OA
Mean (mg/l peat)	0.19	0.31	0.54	0.62	0.89	1.01	1.01	1.05	1.16	1.36	1.56	1.59	1.94	2.37

The amount of extractable nitrogen measured from all the study sites was very low (< 2.5 mg/l peat) and there was much variation between extracts from peat samples within each study site, leading to poor separation of the sites into homogeneous subsets. Site 9. OA had the highest level of extractable-N while other study sites with a humified peat did not all have high levels. The main tree species in site 9. OA is *Alnus glutinosa* which is well known to have symbiotic nitrogen fixation within root nodules (Stewart 1966).

Input of nitrogen fixed in *A. glutinosa* to the peat will occur through leaching and decomposition of falling litter but it is not clear how much of the nitrogen incorporated into the peat would be in an extractable form. Sites 7. MHM and 8. SM which have a dark humified peat did not have levels of total extractable-N significantly above zero. These two sites contain much *Myrica gale* which is also known to have symbiotic nitrogen fixing bacteria associated with its roots (e.g. Sprent *et al.* 1978) but again the amount of the nitrogen incorporated into the peat which is in an extractable form will depend upon the rates of leaching and mineralisation of fallen litter.

Other sites which had quite high extractable-N include 3. GFS, 4. LF, 2. GFC, 10. FBR and 14. BM, but there is no obvious reason why these sites should have higher levels. For instance sites 3. GFS, 10. FBR and 2. GFC had high water levels (4.4.2.) and little mineralisation of organic nitrogen would be expected to occur in these conditions compared with sites with low summer water levels e.g. 8. SM.

The form of extractable nitrogen in each site will depend on the state of reduction of the peats (Ponnamperuma 1972).

Extractable-(NH_4-N)

F ratio = 3.066 P < 0.001 Bartlett Box-F N.S.

Site	14	7	1	8	9	4	11	2	3	13	6	12	5	10
	BM	MHM	GFN	SM	OA	LF	FBC	GFC	GFS	MRM	IPF	FBDC	NPF	FBR
Mean (mg/l peat)	-	0.08	0.08	0.19	0.27	0.35	0.39	0.39	0.39	0.54	0.62	0.66	0.85	1.20

The sites which had higher levels of extractable-(NH_4-N) were all sites with constantly high water levels (4.4.2.). Conversely sites which had low levels of extractable-(NH_4-N) were those which had water levels more often below the peat surface. There are few significant differences in the level of extractable-(NH_4-N) the *Phragmites* reedswamp peat (10. FBR) having the highest level.

Extractable-(NO_2+NO_3)-N)

F ratio = 12.865 P < 0.001 Bartlett Box-F P < 0.001

Site	8	13	5	10	7	11	12	6	1	14	2	4	3	9
	SM	MRM	NPF	FBR	MHM	FBC	FBDC	IPF	GFN	BM	GFC	LF	GFS	OA
Mean (mg/l peat)	-	-	0.16	0.16	0.23	0.23	0.23	0.43	0.93	1.16	1.17	1.24	1.55	2.10

Site 9. OA had significantly higher levels of (NO_2+NO_3)-N than all the other sites, which accounted for nearly all of the extractable-N in the peat from site 9. OA. Most of the extractable-N in sites 14. BM, 4. LF and 1. GFN was in the form of (NO_2+NO_3)-N which was probably as the time of analysis was preceeded by low water levels which may have created more oxidising conditions in the peat. This may also be true for site 3. GFS, but site 2. GFC had constantly high water levels (4.4.2.) yet high levels of (NO_2+NO_3)-N. It is possible that most of the (NO_2+NO_3)-N is in the nitrite form (c f. Waughman 1980) except in particular well aerated situations (e.g. 9. OA) as nitrate is unstable at redox potentials below 338 mV (Ponnamperuma 1972). Sites 7. MHM and 8. SM had low levels of (NO_2+NO_3)-N despite the low water levels found in these sites, but this is simply a reflection of their very low levels of extractable-N.

Digestible-N

F ratio = 36.448 P < 0.001 Bartlett Box-F N.S.

Site	13	2	6	1	5	11	8	12	3	10	7	4	14	9
	MRM	GFC	IPF	GFN	NPF	FBC	SM	FBDC	GFS	FBR	MHM	LF	BM	OA
Mean (mg/l peat)	508	818	943	996	1066	1231	1233	1263	1320	1409	1497	1551	1760	3010

These figures are an estimate of the total organic and inorganic nitrogen content of the peat. While the levels of extractable-N were very low, the levels of digestible-N were high reflecting the almost purely organic nature of the peats (4.5.3.).

Site 9. OA had by far the highest levels of digestible-N probably due both to the amorphous humified nature of the brushwood peat and the input of nitrogen from fixation associated with *Alnus glutinosa*. At the other end of the scale the peat samples from site 13. MRM had a mean level of digestible-N six times smaller than that of site 9. OA. The peat from site 13. MRM had the lowest bulk density and ash content of all the peats and is almost completely composed of *Sphagnum* spp. which are known to contain very low concentrations of nitrogen (Malmer and Sjörs 1955). Site 14. BM had quite high levels of digestible-N although the peat also contains much *Sphagnum*. The peat from this site contains wood and leaf litter and is much more humified which probably explains these higher levels. Similarly, Waughman (1980) found no consistent relationship between total-N and fen or bog vegetation. Sites 7. MHM and 4. LF which also have quite humifiedpeats had relatively high levels of digestible-N as did sites 10. FBR and 3. GFS which, although they have quite a fresh, unhumified peat have an oozy sediment in the peat which may be quite nitrogen rich. While the remaining sites did not have markedly different levels of digestible-N the relative amounts in these sites does not seem to depend on bulk density, ash content or the main macrofossil components of the peat.

The concentrations of digestible-N were between 500 and 1500 times greater than the concentrations of extractable-N, that is 0.07-0.2% of the digestible-N is in the extractable form. This is less than the proportions quoted by Kaila, Soini & Kivinen (1954) for fens of 0.6-1.2% and 0.1-1.7% for bogs and that suggested by Waughman (1980) who generally found roughly 100 times more total-N than extractable-N. Richardson *et al.* (1976) recorded 0.1% of nitrogen in available form in a fen peat, suggesting that the proportion found in extractable form here is not unusual.

The amount of nitrogen in extractable form will depend on the rate of mineralisation of the peat and losses of extractable forms of nitrogen due to uptake, leaching or denitrification. Kaila, Köylijävi & Kivinen (1953) found rates of nitrogen mineralisation to be low, even over six-monthly periods and Kaila, Soini and Kivinen (1954) showed that mineralisation was dependent on temperature, although a noticeable increase in avaiable-N was found at 5°C. The peat temperatures of some study sites shown in Fig. 4.6 indicate that the peat temperature is normally below 15^{o}C except at the surface and at these temperatures, rates of nitrogen mineralisation would be expected to be low. The rate of heterotrophic nitrogen fixation in mires has been demonstrated to be highest in rich fens (Bellamy & Waughman 1980) but this input would probably be in organic rather than readily available form.

The major losses of available-N are probably plant uptake, which is likely to be low at this time of year, and denitrification. Denitrification can occur at very high rates in peats and swamp soils (Avnimelech 1971; Engler & Patrick 1974) especially at near-neutral pH and low redox potential (van Cleemput *et al* 1975) and at any temperature above freezing conditions (Ponnamperuma 1972).

The proportion of the nitrogen in the extractable form would therefore be expected to be low. The level of digestible-N is not generally indicative of the level in the extractable form and to determine the amount of nitrogen available to the plants for growth a detailed study of nitrogen cycling is necessary.

4.5.5. Phosphorus

Extractable-P

F ratio = 6.980 P < 0.001 Bartlett Box-F P < 0.001

Site	8 SM	6 IPF	14 BM	12 FBDC	13 MRM	3 GFS	7 MHM	2 GFC	1 GFN	5 NPF	11 FBC	10 FBR	9 OA	4 LF
Mean (mg/l peat)	0.26	0.38	0.55	0.63	0.73	0.76	0.79	0.90	0.92	0.92	1.23	1.33	1.44	1.57

There were few distinct differences between study sites for extractable-P, for similar reasons suggested for poor separation of study sites with extractable-N analysis. Sites 9. OA and 4. LF had higher levels of extractable-P than most other sites which cannot be directly related to the degree of humification of the peat. Swamp sites 10. FBR and 11. FBC had quite high levels which could be related to absorption of phosphorus from the overlying water by the sediments (cf. Sloey *et al.* 1978). The three *Sphagnum* sites had generally lower levels than most sites of extractable-P with the exception of sites 8. SM and 6. IPF, the opposite of the trend found in fen and bog sites by Waughman (1980). In general levels are very low and there are only small differences between the sites.

The amounts of extractable-P expressed on a dry weight basis fall in the range of 4-19 μg g^{-1} which is higher than the range from the literature quoted by Waughman (1980) of 10 μg g^{-1}

or less for fen systems but lower than that for bogs of 19-64 $\mu g\ g^{-1}$. It is likely that the low levels of extractable-P present are at least partly due to phosphate fixation in iron, aluminium and calcium phosphate (Doughty 1930; Waughman 1980) and stable organic-metallic phosphates (Sinha 1971). Rates of mineralisation of phosphorus are also likely to be low under anaerobic conditions in the peats (Patrick & Mahapatra 1968).

Digestible-P

F ratio = 28.545 $P < 0.001$ Bartlett Box-F $P < 0.001$

Site	13	6	2	8	5	11	1	3	14	7	12	10	4	9
	MRM	IPF	GFC	SM	NPF	FBC	GFN	GFS	BM	MHM	FBDC	FBR	LF	OA
Mean (mg/l peat)	17	29	31	33	37	37	42	45	49	50	50	52	73	111

Site 9. OA, the site with the most humified peat, had by far the highest level of digestible-P. Site 4. LF also had significantly more digestible-P than all of the other study sites and had the highest levels of extractable-P. It is not clear why this site should have high levels of phosphorus, although it may in some way be related to the underlying clay (5.6.2.). The amount of digestible-P is not simply dependent on the degree of humification of the peat as the reedswamp site 10. FBR which has a fresh *Phragmites* peat had relatively high levels of both extractable and digestible phosphorus. Site 13. MRM had

significantly lower levels than all of the other sites, as with digestible-N, but the other more humified *Sphagnum* peats from Sites 12. FBDC and 14. BM had quite high levels of digestible-P.

The levels of digestible-P are well within the range of total phosphorus levels reported for the peats of the Malham Tarn Fens by Proctor (1974) and slightly higher than those reported from German mires by Waughman (1980) in some cases.

4.5.6.1. Iron and Manganese

Iron in Peat Waters

F ratio = 13.813 $P < 0.001$ Bartlett Box-F $P < 0.001$

Site	3 GFS	2a GFNP	4 LF	5 NPF	10 FBR	9 OA	1 GFN	12 FBDC	14 BM	8 SM	7 MHM	13 MRM
Mean (mg/l peat)	0.04	0.05	0.14	0.15	0.17	0.25	0.25	0.41	0.67	1.24	1.78	2.16

Detectable levels of iron were found only in those sites listed above. There was much variation in the level of iron between different replicate water samples from each study site, leading to poor separation of the sites into homogeneous subsets. In general, acidic *Sphagnum* sites and sites with humified peats (especially humified *Cladium* peat) had higher levels than sites with fresh unhumified peats, although levels were detectable in some fresh *Phragmites* peats.

Extractable-Fe

F ratio = 11.803 P < 0.001 Bartlett Box-F P < 0.001

Site	8	7	3	12	1	13
	SM	MHM	GFS	FBDC	GFN	MRM
Mean (mg/l peat)	0.03	0.04	0.09	0.10	0.29	0.70

Detectable levels were present only in the sites listed above. Only sites 1. GFN and 13. MRM had mean levels significantly above zero, the level in site 13. MRM being much higher. Ammonium acetate at pH 7.0 would be likely to release easily exhangeable iron as the pH of the peats is in most cases close to that of the extractant, while more acidic extractants would tend to dissolve iron compound not normally soluble (Andersson 1975). It is likely that the use of this extractant may under-estimate the amount of exchangeable-Fe in the more acidic sites.

Digestible-Fe

F ratio = 19.309 P < 0.001 Bartlett Box-F P < 0.001

Site	13	5	2	10	4	6	3	11	12	14	8	1	7	9
	MRM	NPF	GFC	FBR	LF	IPF	GFS	FBC	FBDC	BM	SM	GFN	MHM	OA
Mean (mg/l peat)	51	111	122	128	144	156	162	184	202	218	234	390	483	666

The sites with the higher levels were all sites with quite humified peats, Site 9. OA having by far the highest level. The three sites 7 . MHM, 1. GFN and 8. SM which also have quite high levels are all sites situated close to the margins of the fens. Overall *Cladium* peats had higher levels than *Phragmites/Typha* peats. Two of the acidic *Sphagnum* sites had quite high levels (> 200 mg/l peat) while the open *Sphagnum* site (13. MRM) had a low mean level of 51 mg/l peat.

Manganese in peat waters

F ratio = 3.480 P < 0.001 Bartlett Box-F P < 0.001

Site	14 BM	12 FBDC	6 IPF	1a) GFNP	13 MRM	5 NPF	11 FBC	4 LF	9 OA	10 FBR	8 SM	1 GFN	7 MHM
Mean (mg/l)	0.04	0.07	0.11	0.21	0.23	0.25	0.25	0.33	0.44	0.44	0.63	1.01	1.10

The highest levels were found in sites with humified *Cladium* peats. *Sphagnum* sites had relatively low levels and levels in the other sites were very variable, especially between sampling times (Appendix 3). Manganese was not detectable in site 2. GFC (or 2 a). GFCL) although detectable levels were found on other sampling occasions.

Extractable-Mn

F ratio = 20.597 P < 0.001 Bartlett Box-F P < 0.001

6	5	12	13	3	14	4	9	2	10	1	7	11	8
IPF	NPF	FBDC	MRM	GFS	BM	LF	OA	GFC	FBR	GFN	MHM	FBC	SM
0.20	0.22	0.29	0.35	0.38	0.46	0.61	0.99	1.63	3.76	4.13	5.43	5.96	5.99

Most sites which have *Cladium* peats had high levels of extractable-Mn while the sites with *Phragmites* and *Sphagnum* peats had lower levels, with the exception of the reedswamp site (10. FBR). As in the case of extractable-Fe, ammonium acetate at pH 7.0 will extract only easily exchangeable manganese from the peats with high pH (Andersson 1975).

Digestible-Mn

F ratio = 8.898 P < 0.001 Bartlett Box-F P < 0.001

Site	5	3	12	13	6	4	14	10	2	9	8	11	7	1
	NPF	GFS	FBDC	MRM	IPF	LF	BM	FBR	GFC	OA	SM	FBC	MHM	GFN
Mean (mg/l peat)	2.1	2.6	2.8	3.4	3.6	6.2	8.7	18	20	39	39	42	43	104

Site 1. GFN had much higher levels of digestible-Mn than all of the other sites. All of the *Cladium* peats had higher levels than *Phragmites/Typha* peats or *Sphagnum* peats. The reedswamp site (10. FBR) had quite a high level as did site 9. OA.

The proportion of the digestible iron and manganese which is in soluble form will depend on the pH and redox potential of the peat. Iron is soluble above pH 4.8 only in the ferrous form and then only at redox potentials below 200 mV (Hem 1970). The concentration of dissolved iron will also depend on the concentrations of dissolved carbon dioxide compounds and sulphate present; insoluble iron compounds present are likely to include hydroxides, phosphorus and sulphur complexes and organo-metallic complexes (Sinha 1971). Soluble manganese is likely to be in the divalent form under the conditions prevailing in the peats, MnO_2, $MnCO_3$ and organic complexes being the main insoluble forms (Ponnamperuma *et al.* 1969). It is not unusual that low levels of dissolved and extractable iron and manganese are present in all of the study sites.

The higher levels of dissolved iron in acidic *Sphagnum* sites are at least partly a reflection of the increased solubility of iron compounds at lower pH. Site 13. MRM had very low levels of digestible-Fe but the highest levels of dissolved and extractable iron indicating that a much higher proportion of the iron present will be available to the plants. Manganese does not exhibit the same trend; levels of dissolved and extractable manganese were low in the acidic sites. This was probably due to the low levels of digestible-Mn in these sites.

Cladium peats had high levels of digestible iron and manganese, even the unhumified peat from the *Cladium* swamp (site 11. FBC). Many wetland plants are known to accumulate quite high levels of iron and manganese (Mayer & Gorham 1951) and although this does not seem to be documented for *Cladium mariscus*, it seems likely that the species composition of the peat is influencing the amount of iron and manganese present in the peat. Many of the *Cladium* dominated sites also contain much *Schoenus nigricans* which has high concentrations of iron and manganese in its leaves (Mayer & Gorham 1951), but this is not present in site. 11. FBC. The very high levels of digestible-Mn in site 1. GFN are probably related to the close proximity of the site to the mineral soil of the land margin.

Levels of dissolved and extractable iron and manganese are also high in *Cladium* peats, in part reflecting the high levels of digestible iron and manganese present. Levels of dissolved iron and manganese were only high in more humified *Cladium* peats and from the colouration of the waters from these sites it seems likely that some of iron and manganese are present as suspended organic complexes (c.f. Puustjarvi 1952). The redox potentials measured in all sites indicate that dissolved Fe^{2+} and Mn^{2+} could also be present, at least below the very surface horizons (4.5.10).

Site 9. OA had the highest levels of digestible-Fe although extractable-Fe was not detectable in this site, probably due to the high surface redox potentials prevailing here. The reedswamp site (10. FBR) was the only site with fresh *Phragmites* peat to have high levels of all forms of manganese which could be due to the presence of an oozy sediment in the peat, or the presence of remains of aquatic plants which are known to accumulate very high levels of manganese and iron (Boyd 1978).

The levels of extractable and digestible iron and manganese are similar to those found in German mires by Waughman (1980).

4.5.7. Major Cations

Calcium in peat waters

F ratio = 53.759 $P < 0.001$ Bartlett Box-F $P < 0.01$

Site	13	12	14	11	10	2a	8	2	6	1a	1	5	7	15	16	3	9	4
	MRM	FBDC	BM	FBC	FBR	GFCL	SM	GFC	IPF	GFNP	GFN	NPF	MHM	BRD	KIV	GFS	OA	LF
Mean (mg/l)	25	26	33	59	79	86	87	89	89	95	96	96	105	107	110	111	145	153

The three *Sphagnum* sites had much lower levels of calcium than all of the other sites. The two swamp sites, 10. FBR and 11. FBC also had relatively low levels. Sites 9. OA and 4. LF had much higher levels than all of the other sites.

Extractable-Ca

F ratio = 73.296 $P < 0.001$ Bartlett Box-F $P < 0.05$

Site	13	12	14	10	5	6	1	3	7	11	8	4	2	9
	MRM	FBDC	BM	FBR	NPF	IPF	GFN	GFS	MHM	FBC	SM	LF	GFC	OA
Mean (mg/l peat)	174	305	412	495	499	531	678	723	774	792	805	869	910	1840

Site 9. OA had more than double the amount of extractable-Ca than any other site, and other differences were large enough to allow better separation of the sites into homogeneous subsets than with some of the other analyses previously discussed. Site 14. BM which also had quite a humified peat had low levels of extractable-Ca as do the other sites with much *Sphagnum* (sites 12. FBDC and 13. MRM).

All of the sites dominated by *Cladium mariscus* have levels of extractable-Ca above 650 mg/l peat (while with the exception of site 3. GFS) all of the study sites dominated by *Phragmites* or *Typha angustifolia* have levels below 550 mg/l peat. Site 4. LF which is dominated by *Juncus subnodulosus* and *Phragmites* had quite high levels of extractable-Ca.

Magnesium in peat waters

F ratio = 46.671 P < 0.001 Bartlett Box-F P < 0.001

Site	13	14	12	15	16	2	2a	10	1a	9	1	3	6	10	8	4	7	5
	MRM	BM	FBDC	BRD	RIV	GFC	GFCL	FBC	GFNP	OA	GFN	GFS	IPF	FBR	SM	LF	MHM	NPF
Mean (mg/l)	7.4	10.2	13.2	13.5	15.0	15.8	17.0	20.4	20.5	21.0	21.2	21.8	23.4	24.4	29.8	31.2	43	50

The two sites closest to the lower reaches of the River Ant had much higher levels of Mg^{2+} in the peat waters than all of the other sites. Sites 8. SM and 4. LF also had quite high levels, while the three acidic *Sphagnum* sites had much lower levels than all of the other sites.

Extractable-Mg

F ratio = 49.757 P < 0.001 Bartlett Box-F P < 0.001

Site	13	1	14	12	3	6	10	4	2	7	11	5	9	7
	MRM	GFN	BM	FBDC	GFS	IPF	FBR	LF	GFC	SM	FBC	NPF	OA	MHM
Mean (mg/l peat)	16.3	45.6	53.0	58.3	62.2	71.3	74.2	75.7	86.5	87.9	89.4	128	129	146

Three sites 5. NPF, 7. MHM and 9. OA had much higher levels of extractable-Mg than the other study sites; the highest level being found in Site 7. MHM. Sites 7. MHM and 9. OA have quite humified peats whilst Site 5. NPF has a fresh *Phragmites* peat but all three sites are situated close to the River Ant. Of the other sites, those with *Cladium* peat had higher levels than those with *Phragmites/Typha angustifolia* or *Phragmites* peat with the exception of Site 1. GFN which had low levels, for which the reason is not clear. The three *Sphagnum* sites all had low levels of extractable-Mg.

Sodium in peat waters

F ratio = 99.898 $P < 0.001$ Bartlett Box-F $P < 0.05$

Site	13	15	16	2	2a	1a	1	14	11	10	12	6	3	8	9	4	7	5
	MRM	RIV	BRD	GFC	GFCL	GFNP	GFN	BM	FBC	FBR	FBDC	IPF	GFS	SM	OA	LF	MHM	NPF
Mean (mg/l)	56	64	65	80	93	96	102	103	104	111	112	125	126	132	158	184	440	480

Sites 5. NPF and 7. MHM had extremely high levels of Na^+ in the peat waters, more than double the levels in all the other sites. Sites 4. LF and 9. OA also had high levels (> 150 mg/l). Acidic sites (12-14), swamp sites (10 and 11) and more isolated sites of the external system (1 and 2) all had relatively low levels (< 115 mg/l).

Extractable-Na

F ratio = 26.673 P < 0.001 Bartlett Box-F P < 0.001

Site	13	12	10	1	8	11	2	3	14	4	9	6	7	5
	MRM	FBDC	FBR	GFN	SM	FBC	GFC	GFS	BM	LF	OA	IPF	MHM	NPF
Mean (mg/l peat)	61	102	105	115	116	116	124	140	154	179	179	188	331	357

Sites 5. NPF and 7. MHM had much higher levels of extractable-Na than all of the other sites. Of the other sites in general, sites of the external system had higher levels than those of the internal system. The sites of the external system which are more isolated from the river, or open dyke connection to it, had lower levels than those close to the river. The two open *Sphagnum* communities, 13. MRM and 12. FBDC had the lowest levels while 14. BM which has more humified woody peat had quite high levels.

Potassium in peat waters

F ratio = 5.689 P < 0.001 Bartlett Box-F P < 0.001

Site	14	13	10	8	4	12	9	3	1	1a	2a	15	7	16	6	11	2	5
	BM	MRM	FBR	SM	LF	FBDC	OA	GFS	GFN	GFNP	GFCL	BRD	MHM	RIV	IPF	FBC	GFC	NPF
Mean (mg/l)	3.9	4.2	4.5	4.7	4.9	5.4	5.8	5.9	7.0	7.1	8.2	8.5	8.7	8.9	8.9	9.6	10.0	17.8

Site 5. NPF had much higher levels than all of the other sites. There is poor separation of the other sites into homogeneous subsets as the variability between samples from each site was quite high. The acidic *Sphagnum* sites had quite low levels (< 6 mg/l) and two comparatively wet sites (11. FBC and 2. GFC) had quite high levels of potassium (> 9 mg/l).

Extractable-K

F ratio = 3.254 P < 0.001 Bartletts P > 0.05

Site	3	9	8	5	12	1	2	4	10	11	6	13	7	14
	GFS	OA	SM	NPF	FBDC	GFN	GFC	LF	FBR	FBC	IPF	MRM	MHM	BM
Mean (mg/l peat)	3.9	7.9	9.1	12.0	13.7	20.1	20.6	20.9	22.7	23.8	26.8	28.6	29.8	34.5

Two of the acidic *Sphagnum* sites (13. MRM and 14. BM) had quite high levels as did Site 7. MHM. Sites with low levels included sites with fresh peats (e.g. 3. GFS, 5. NPF) and humified peats (e.g. 9. OA).

Dissolved and Extractable Fractions

The levels of the major cations in the peat waters did not always reflect the same trends as those extracted from the peat. For instance, the humified brushwood peat from Site 9. OA had relatively high levels of extractable-Mg but only average levels of Mg^{2+} in the peat waters. The results of a preliminary analysis of the amount of the major cations in a water extract compared with the amount extracted by an ammonium acetate extractant from the peat of two of the study sites are shown in Table 4.6.

Table 4.6. The relative amounts (%) of the major cations in peats from two of the study sites extracted by equivalent amounts of deionised water and 0.5 M ammonium acetate pH 7.0 (AmAc)

i.e. $\left(\frac{\text{amount in water extract}}{\text{amount in AmAc extract}} \times 100 \right) \%$

Each value is the mean of ten comparisons.

Site	% cation in water extract			
	Ca	Mg	Na	K
12. FBDC	4	7	65	53
8. SM	2	5	85	43

Less than 7% of the calcium and magnesium extracted by ammonium acetate from the peats was extractable in water, while more than 40% of the potassium and more than 60% of the sodium was extractable in water. This indicates that a very large proportion of the calcium and magnesium present in the peats is bound onto exchange sites within the peat. The differences between sites in relative amounts of the major cations in the peat water and extractable fractions is probably largely due to differences in the cation exchange capacities of the peats. Cation exchange capacities are known to be very high in peats (Puustjarvi 1956; Richardson *et al.* 1978) and probably depend on the degree of humification and the composition of the peat (Puustjarvi 1956).

The above data suggest that *Cladium* peats have higher exchange capacities than *Phragmites/Typha angustifolia* or *Phragmites* peats as sites with *Cladium* peats in general had much higher levels of extractable-Ca and Mg, even though some sites had quite low levels of Ca and Mg in the peat waters. This does not appear to be simply due to different degrees of humification as two sites had quite fresh unhumified *Cladium* peat (sites 2. GFC and 11. FBC) and yet high levels of extractable-Ca and Mg.

In the case of site 5. NPF which had high levels of dissolved and extractable magnesium and sodium there may be replacement of potential exchange sites for calcium by these cations, giving rise to the relatively lower levels of extractable-Ca compared with other sites. This effect was not as pronounced in site 7. MHM (which also had very high levels of dissolved and extractable magnesium and sodium) as it has a quite humified *Cladium* peat and probably a higher cation exchange capacity.

Acidic *Sphagnum* sites

The three acidic *Sphagnum* sites all had low levels of dissolved and extractable calcium and magnesium. The levels of dissolved and extractable sodium were not particularly low in all of the *Sphagnum* sites. These three sites are isolated from inundation by floodwater and will receive most water input from precipitation which has generally low concentrations of dissolved cations (Gorham 1961), although higher concentrations especially of sodium and magnesium can be found in rainfall near the sea (Sparling 1967). The levels of cations in the peat waters are higher than would be expected for areas fed mainly by precipitation, (c.f. Bellamy 1972) but the samples are taken from below the peat surface (4.2.1.) and will contain water from lower horizons of higher concentration.

The open *Sphagnum* community of study site 13. MRM had much lower levels of calcium, magnesium and sodium in both dissolved and extractable form than the other two *Sphagnum* sites possibly because of lower recycling rates due to the lack of trees.

Levels of Potassium

Two of the acidic *Sphagnum* sites, Sites 14. BM and 13. MRM had quite high levels of extractable-K which is compatible with the trend found by Waughman (1980) for German mires where levels of extractable-K were usually higher in bogs than fens. Proctor (1974) found a reverse trend in the Malham Tarn Fens where levels of extractable-K in the peats and potassium in the waters were generally lower in areas with much *Sphagnum*. The levels of potassium in the peat waters found here follow the trend found by Proctor (1974).

The high levels of potassium in the peat waters of Site 5. NPF are probably related to the influence of the underlying marine clay (5.6.2.). Site 7. MHM which seems to be influenced by brackish water had quite high levels of dissolved and extractable-K. The variation in levels of potassium in the other study sites does not seem to be obviously explicable. For instance, Site 9. OA which has a highly humified peat had low levels and sites with fresh unhumified peats (e.g. 3. GFS, 6. IPF, 10. FBR, 11. FBC) had very variable levels of dissolved and extractable-K.

Other inter-site differences

The two sites which had particularly high levels of calcium in the peat waters (sites 9. OA and 4. LF) both have quite a humified peat and are underlain by clays (3.3) which appear to contain quite high levels of calcium (5.6.2). The same is true of site 3. GFS. Sites more isolated from the river tended to have lower levels of calcium in the peat waters (e.g. 8. SM). The two swamp sites of the internal system (10. FBR and 11. FBC) had relatively low levels of calcium in the peat waters possibly due both to isolation of these sites from an inflow of calcium rich water and the depth of water present reducing any potential concentrating effects due to evapotranspiration of water. The levels of extractable-Ca do not demonstrate the same trends probably due to differences in humifieation and macrofossil composition of the peats (see above).

The levels of magnesium and sodium in the peat waters seem to reflect similar trends. Sites 5. NPF and 7. MHM had much higher levels than all of the other sites and it seems probable that this is due to the influence of periodic incursions of brackish water up the River Ant (4.5.12.). Other sites quite close to the River Ant or Barton Broad also had quite high levels of sodium and magnesium in the peat waters as did sites 10. FBR and 8. SM of the internal system. The sites of the internal system had lower levels of calcium than the external system sites close to the river system. This suggests that the water feeding the dykes of the internal system may be of differing composition from that of the external system.

Cation levels reported from similar vegetation

Some analysis of surface waters from some flood plain mires of the Bure and Yare valleys were made by Bellamy (1967). All of these surface waters were from open fen vegetation and were of pH 6.9-7.5. Calcium concentrations were similar to those measured in the peat waters with the open fen vegetation of the study site and ranged from 59-128 mg l^{-1} while levels of sodium and magnesium were generally much lower (2.9-7.3 mg l^{-1} and 19-38 mg l^{-1}) respectively. Potassium levels reported by Bellamy (1967) were similar if slightly lower than those measured in the Catfield and Irstead Fens (2.5-7.9 mg l^{-1}). The lower sodium levels in surface waters from these areas compared to the study area have been confirmed by Wheeler & Giller (1982c). The differences are probably partly explained by the more dilute character of surface waters compared with waters from below the peat surface (5.6.2.) but also suggest that these other sites are more isolated from the influence of brackish water from the study area.

The *Peucedano-Phragmitetum caricetosum* has close floristic affinities to some stands of vegetation in the Malham Tarn Fens placed within the *Potentilla palustris-Acrocladium* nodum (Proctor 1974). Some analyses of exchangeable cations in the peats from such communities in the Malham Tarn Fens have been made by Proctor (1974). He found levels to be in the ranges; calcium 340-1040 mg/l peat, magnesium 2.9-6.8 mg/l peat, sodium 51-99 mg/l peat and potassium 21-70 mg/l peat. The levels of calcium are similar to those found in the peat from the *Peucedano-Phragmitetum caricetosum* study sites, while levels of sodium and in particular magnesium were much lower than those reported here. The same is true of levels in surface waters reported from rich fen sites of the Malham Tarn Fens and reflects the different chemical composition of the waters feeding this site and in particular the greater distance of this site from the coast.

The *Cirsio-Schoenetum nigricantis scorpidietosum* communities of Scragh Bog, Eire (O'Connell 1981) also have floristic affinity to the *Peucedano-Phragmitetum caricetosum*. Levels of cations in the surface waters of such communities reported by O'Connell (1981) were similar to those reported here with respect to calcium but levels of sodium, magnesium and potassium were much lower.

Levels of calcium, sodium and potassium in water samples from beneath fen carr at Askham bog referable to the *Osmundo-Alnetum glutinosae lycopetosum* vary from 50-224 mg l^{-1} 40-127 mg l^{-1} and 12-19 mg l^{-1} respectively, in general being similar to those found within the *Osmundo-Alnetum* study site (9. OA) (Fitter *et al.* 1981). Concentrations of these cations in water samples from a *Betulo-Myricetum* community at Askham bog had levels of calcium of 16-40 mg l^{-1}, sodium of 15-30 mg l^{-1} and potassium of 2-8 mg l^{-1}, similar to those recorded in comparable from the study area (14. BM) with the exception of sodium. These measurements from Askham bog are comparable to those taken here as the water samples were taken from the water table beneath the peat surface.

4.5.8. Major anions in peat waters

Bicarbonate

F ratio = 37.092 P < 0.001 Bartlett Box-F P < 0.001

Site	14	13	12	16	11	15	10	8	7	6	1a	1	5	2a	9	2	3	4
	BM	MRM	FBDC	RIV	FBC	BRD	FBR	SM	MHM	IPF	GFNP	GFN	NPF	GFCL	OA	GFC	GFS	LF
Mean (mg/l)	55	59	78	290	305	305	350	355	430	460	480	505	530	535	540	550	610	820

The peat waters from the three acidic *Sphagnum* sites had very low levels of bicarbonate. The levels in the other study sites were in general much higher than those in the river and broad, being very high in Site 4. LF.

Sulphate

F ratio = 9.859 P < 0.001 Bartlett Box-F P < 0.05

Site	13	14	12	4	11	2a	8	1	10	1a	2	3	5	6	15	16	9	7
	MRM	BM	FBDC	LF	FBC	GFCL	SM	GFN	FBR	GFNP	GFC	GFS	NPF	IPF	BRD	RIV	OA	MHM
Mean (mg/l)	60	90	90	120	120	120	125	140	160	160	185	190	200	205	240	240	240	250

Levels of sulphate in the peat waters will be affected considerably by bacterial sulphate reduction to sulphide, at least in some of the study sites (Ponnamperuma 1972, 4.5.11). The acidic *Sphagnum* sites had low levels and sites with high levels were in general those of the external system with open connections to the River Ant.

Chloride

F ratio = 35.659 $P < 0.001$ Bartlett Box-F $P < 0.001$

Site	13	16	15	2	1a	6	2a	1	11	12	14	10	3	8	9	4	7	5
	MRM	RIV	BRD	GFC	GFNP	IPF	GFCL	GFN	FBC	FBDC	BM	FBR	GFS	SM	OA	LF	MHM	NPF
Mean (mg/l)	60	66	67	87	115	120	122	125	145	150	150	155	160	165	255	295	460	490

The relative levels of chloride between sites reflect the levels of sodium in the peat waters very closely. Site 6. IPF is the only real anomaly having relatively lower levels of chloride than of sodium.

The levels of chloride and sulphate are highest in sites quite close to the River Ant or Barton Broad and mirror the variations of sodium in this respect, probably due to the influence of brackish water and of the underlying clay in some of the sites.

The sites with much *Sphagnum* all had very low levels of bicarbonate, as would be expected of acidic waters (Bellamy 1972). Other variations in the level of bicarbonate are not easily explicable. They are generally higher than levels found in the river and the broad (15. BRD, 16. RIV) possibly due to the effects of root respiration of the vegetation. It is not clear why site 4. LF has much higher levels of bicarbonate than the other sites, but it could possibly be due to the presence of the underlying clay (5.5.2.).

Bellamy (1967) reported levels of bicarbonate in surface waters from the Woodbastwick Marshes between 120 and 170 mg l^{-1} and from the fens around Upton Broad between 330 and 350 mg/l^{-1}. The higher levels reported here are probably related to the method of sampling. Levels of chloride and sulphate measured by Bellamy (1967) were also generally lower than those determined from the study area.

4.5.9. Electrical conductivity of the peat waters (K_{corr})

F ratio = 21.127 $P < 0.001$ Bartlett Box-F $P < 0.001$

Site	12 MRM	14 BM	12 FBDC	2 GFC	16 RIV	11 FBC	15 BRD	2a GFCL	1a GFNP	1 GFN	10 FBR	8 SM	3 GFS	6 IPF	9 OA	4 LF	7 MHM	5 NPF
Mean µS	315	555	585	675	675	690	695	700	770	780	820	925	945	1120	1220	1430	1800	1810

The conductivity reflects the overall ionic concentration of the peat waters, being highest in the sites 5. NPF and 7. MHM and lowest in the acidic *Sphagnum* sites.

4.5.10. Redox potential (E_7)

Measurements of redox potential (E_7) were made in the surface 50 cm of the peat on two occasions. The first was in March 1981 when water levels were quite high and the second in August 1981 when water levels were generally low (Fig. 4.5). Unfortunately no redox potential measurements were taken at the time of collection of peat samples. Replicate measurements of redox potential made in some sites were quite reproducable (Appendix 3) and only one profile is shown in each case (Fig. 4.8).

Values of E_7 measured in March were generally higher than those measured in August. This was probably due to increased microbial activity in the summer months. E_7 measurements taken at the peat surface did not show this trend and were higher in August probably as a result of lower water levels allowing aeration of the surface peat.

Site 7. MHM and 8. SM had quite high E_7 on both occasions, even when the peat surface was inundated with water. This is probably due to the low water levels found in these areas during the summer months allowing more oxidising conditions to occur in the peat. E_7 is also high in the surface 20 cm of peat in site 1. GFN which also has water levels below the peat surface to some extent during the summer months (Fig. 4.5).

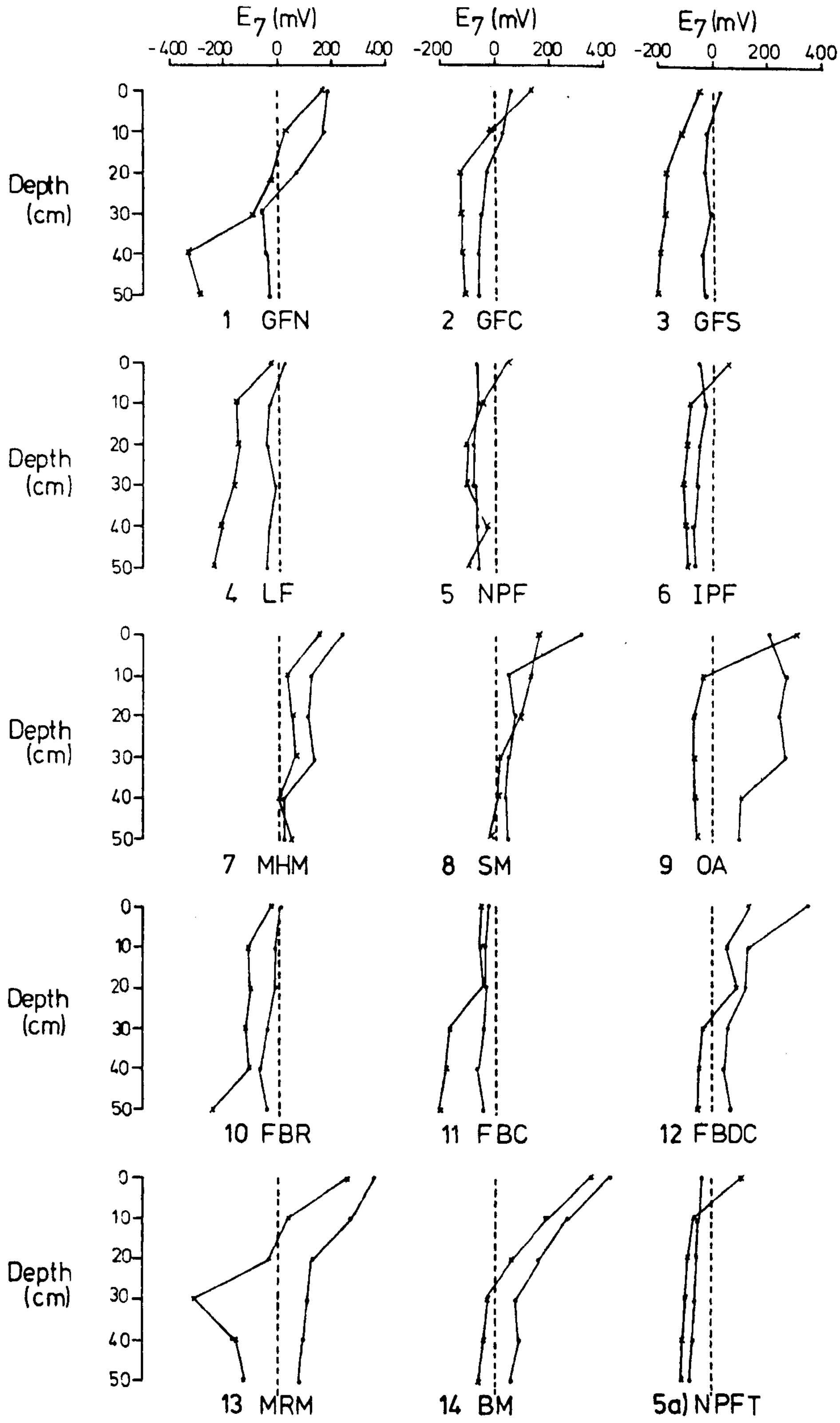


Fig. 4.8. Redox potential, E_7 (mV), against depth below the peat surface (cm) in March (•——•) and August 1981 (×——×).

It is not clear why the redox potentials at 40 and 50 cm depth were so low in August. The redox potentials in site 9. OA were high at the peat surface on both occasions and were high throughout the surface 50 cm in March. This is consistent with the low water levels found in this site at most times of the year. In measurements taken in August the E_7 was quite low at depths of 10 cm and below. These low redox potentials could be due to increased microbial activity but do seem unusual.

The three acidic *Sphagnum* sites (sites 12-14) had high E_7 in the surface 20 cm of peat at both times of measurement. The values decreased with depth below the peat surface probably due to the continual waterlogging in the lower peat layers. The quite high redox potentials found in the acidic *Sphagnum* sites relative to those found in some of the herbaceous fen study sites is compatible with the higher redox potentials found at Tregaron Bog compared with those at Oxwich Fen by McColl (1969).

There seemed to be little difference in the redox potentials measured in study site 5. NPF and those in sub-site 5 a) NPFR.

4.5.11. Sulphide

Sulphide levels in the top 30 cm of the peat were determined at six study sites. Samples were collected on the two occasions that measurements of redox potential were made. The samples were collected from dialysis bags which had been buried

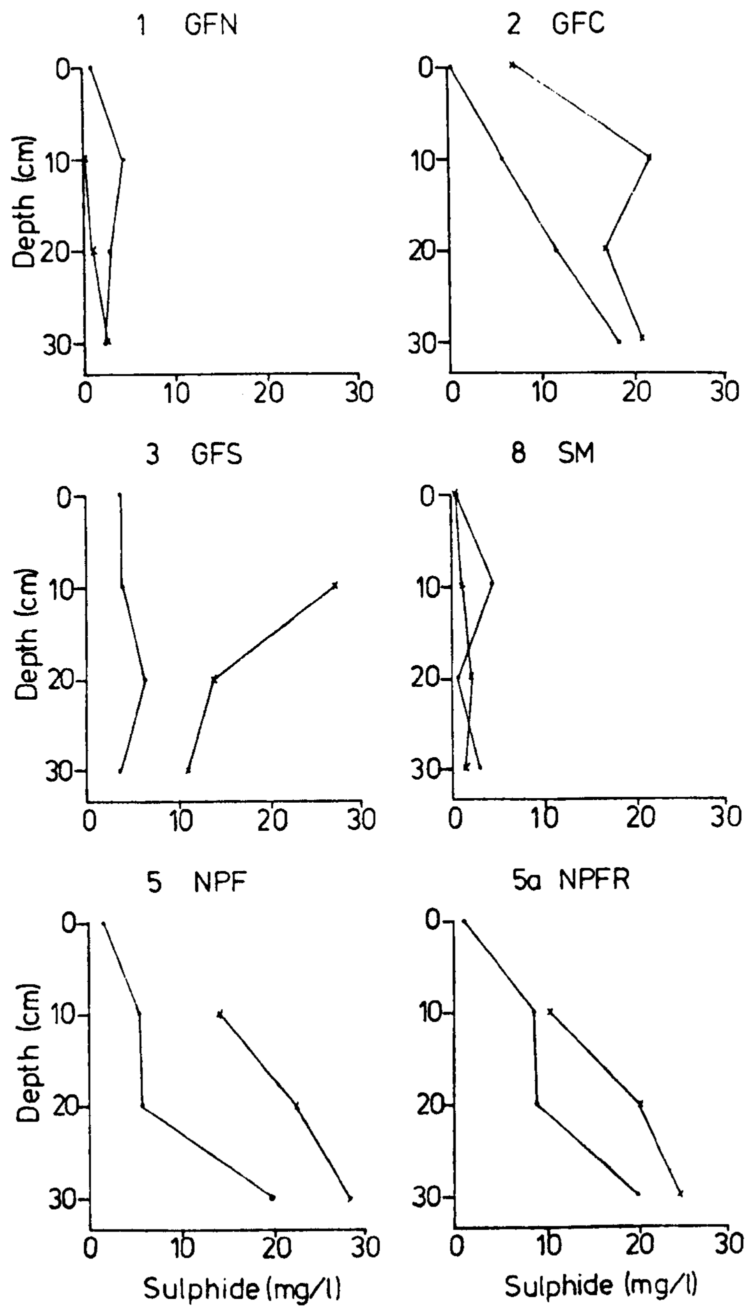


Fig. 4.9. Sulphide concentrations (mg/l) in waters from the upper 30 cm of peat in March (•—•) and August 1981 (x—x).

2-3 weeks previously. The bags were made of visking tubing and were completely filled with deionised water (volume ≃ 80 ml). It was assumed that the concentrations of sulphide in the interstitialpeat waters would have reached equilibrium with the water within the dialysis bags over the period for which they were buried. This method of sampling allowed the water to be poured directly into bottles containing cadmium chloride to 'fix' the sulphide as CdS (Appendix 2). This minimised problems of oxidation of the sulphide and interference of organic matter during the subsequent analysis from organic matter. Dialysis bags placed on the peat surface to measure sulphide concentrations at this level were covered by a thin layer of litter to prevent desiccation of the bags.

Surface samples were lost in some cases due to disintegration of the dialysis bags, presumably as a result of decomposition.

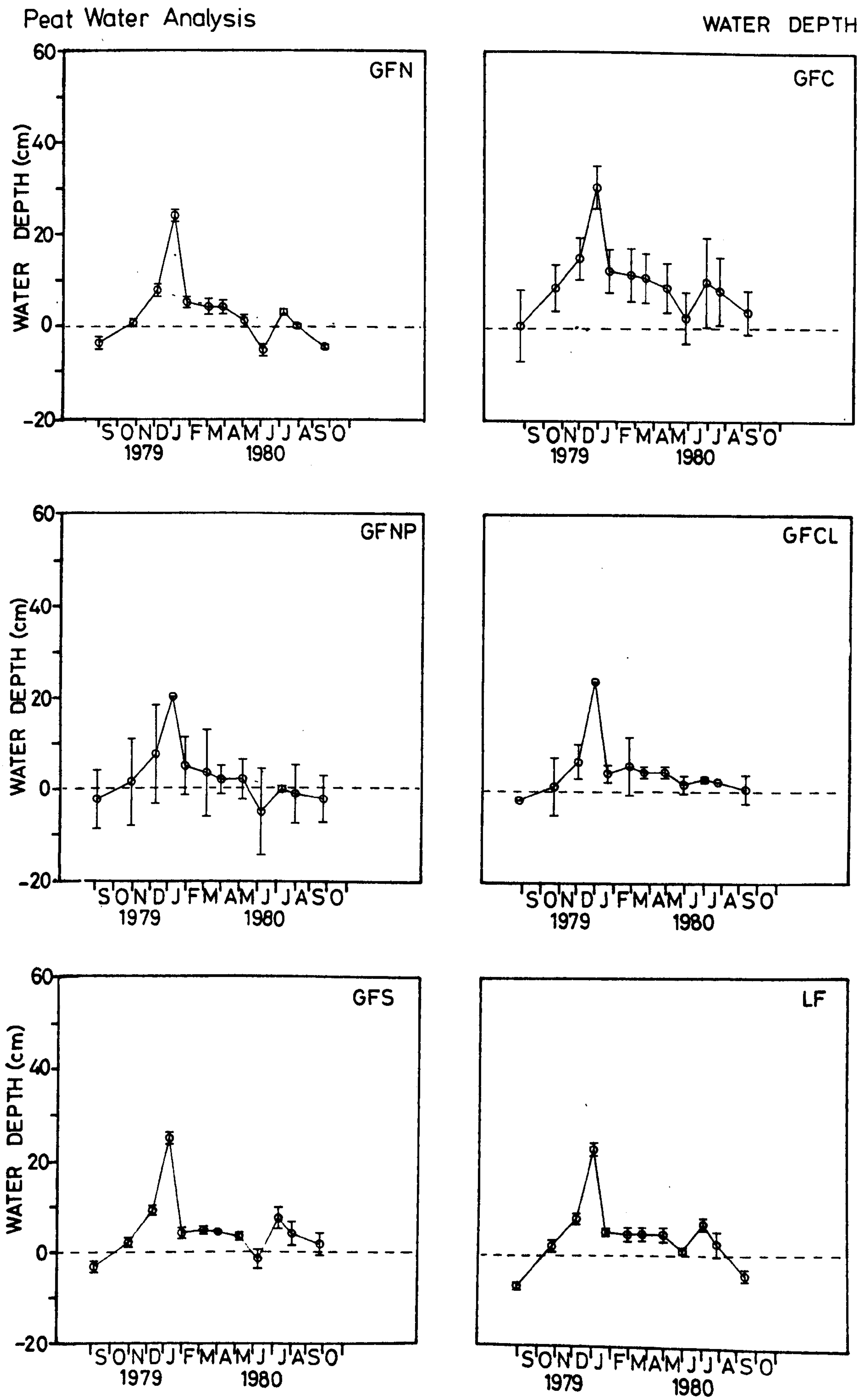
Sulphide levels were quite low at the peat surface in all of the sites. Sites 1. GFN and 8. SM had low levels (< 5.0 mg l^{-1}) on both sampling occasions, levels being very low in August. These sites have quite low water levels in the summer months (4.4.2.) and quite high redox potentials in the peat on both sampling occasions. The sulphide levels in site 1. GFN were low at 30 cm below the peat surface despite the lower redox potential at this depth (Fig. 4.8). Sulphate reduction normally occurs only at redox potentials below zero (Postgate 1959). However, Armstrong and Boatman (1967) recorded

8 mg l^{-1} free sulphide in surface peat with much higher redox potential (E_7 > 150 mV). The quite high levels of iron in solution in these sites (4.5.6.) may contribute to the low sulphide levels due to deposition of insoluble iron sulphide.

Sulphide levels in the other sites which all had quite high water levels throughout the year (4.4.2.) were much higher than in the above sites. Levels were generally highest in August, probably because of the lower redox levels found at this time of year and increased activity of sulphate-reducing bacteria. Levels were highest at 10 cm below the peat surface in sites 2. GFC and 3. GFS in August although levels at sites 5. NPF and 5 a) NPFR were highest at 30 cm below the peat surface. Clymo (1965) found highest levels of sulphide production at 30 cm below the surface at Thursley Bog, while Collins (Urqhart & Gore 1973) found the greatest number of sulphate-reducing bacteria between 10 and 20 cm below the peat surface in estuarine and blanket bog. In study site 3. GFS where the redox potential is below -150 mV in August sulphide levels may have been contributed to abiotically as sulphate is unstable at such low redox potentials (Connel & Patrick 1968).

4.5.12. Fluctuations in the chemical composition of the peat waters between September 1979 and September 1980

The fluctuations in pH, conductivity and major cations and anions are shown in Figs. 4.11-4.19. The water depths relative to the peat surface in each study site over the same period are shown (Fig. 4.10) to allow correlations of water depth with concentration of the chemical variables measured to be made by superimposing the relevant graphs (cf. McColl 1969). The confidence limits of most variables are much wider in sites 1 a). GFNP, 2 a). GFCL, 15. BRD and 16. RIV as the points represent means of only two samples. The same is true of site 7. MHM on the last sampling occasion as three of the five samples were lost due to contamination of the sampling tubes. Generally there was much higher variability between replicate samples when the water levels were below the peat surface, probably due to less dilution by more uniform surface waters allowing conditions to vary more between sampling tubes in each study site. The levels of iron and manganese were generally low and variable and exhibited no consistent variation (Appendix 3).



Peat Water Analysis
WATER DEPTH
GFN
GFC
GFNP
GFCL
GFS
LF
WATER DEPTH (cm)
60
40
20
0
-20
S O N D J F M A M J J A S O
1979
1980

Fig. 4.10.

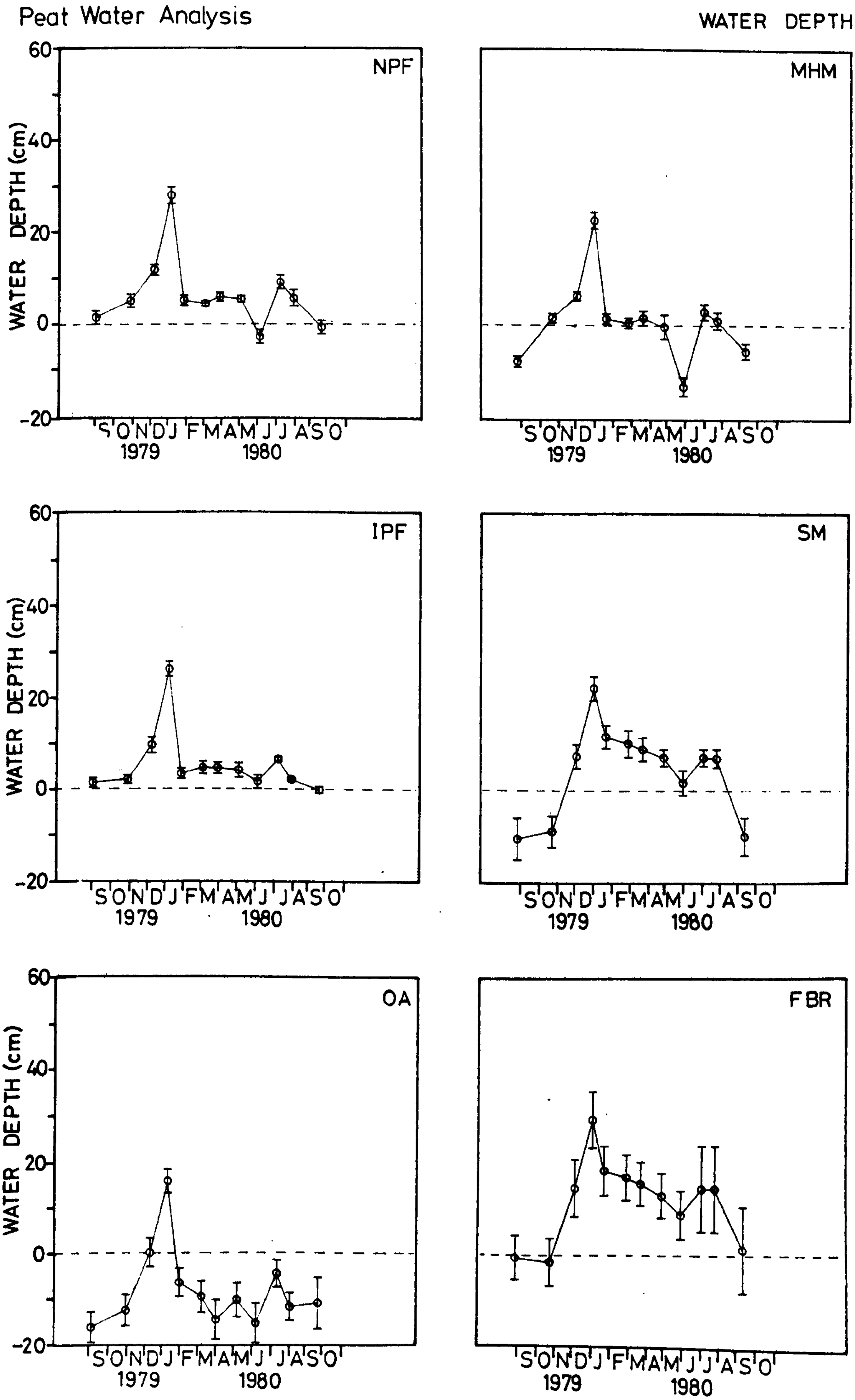

Peat Water Analysis
WATER DEPTH
NPF
MHM
IPF
SM
OA
FBR
WATER DEPTH (cm)
60
40
20
0
-20
S O N D J F M A M J J A S O
1979
1980

Fig. 4.10a

Peat Water Analysis

WATER DEPTH

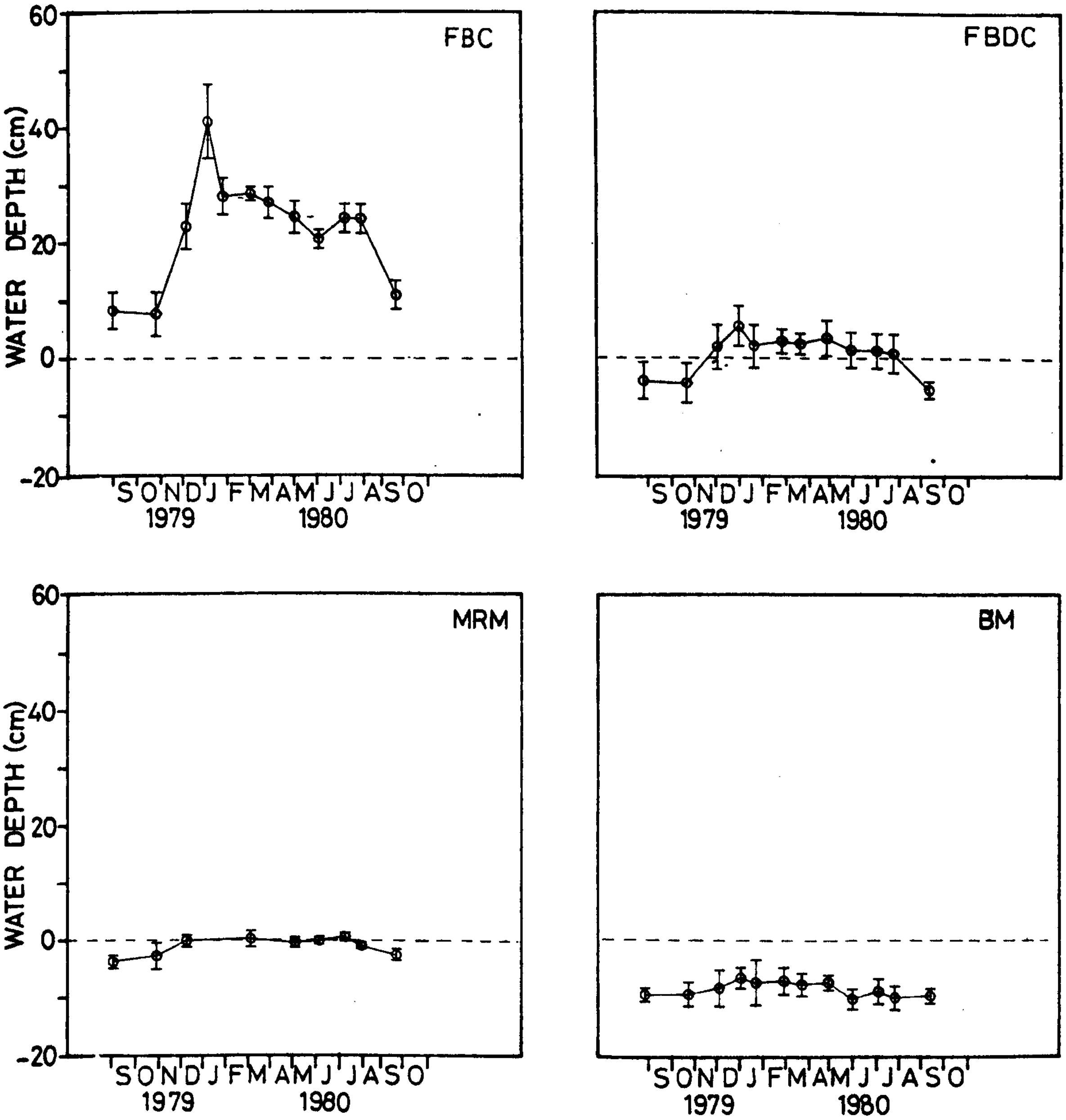


Fig. 4.10b

Notes to Figures 4.11 to 4.19

Loss of samples due to contamination (usually by dead animals in the sampling tubes) occurred in some cases leaving the following reduced numbers of replicates.

Sampling time	Study site with number of replicates in parentheses
1.9.79	1. GFN (4), 8. SM (4)
26.10.79	14. BM (4)
6.1.80	9. OA (4), 14. BM (4)
26.3.80	14. BM (4)
1.5.80	14. BM (4)
6.7.80	3. GFS (4), 4. LF (4), 7. MHM (3), 14. BM (4)
13.9.80	2. GFC (4), 4. LF (3), 7. MHM (2), 10. FBR (4)

In all other cases the values represent the means of 2 replicates for sites 1 a). GFNP, 2 a). GFCL, 15. BRD and 16. RIV and 5 replicates for the other sites. The bars indicate the 95% confidence limits for the means. These are skewed in the cases of sodium and chloride as they represent back-transformed $\log_{10}$ values. The confidence limits were omitted from the graphs of some of the variables of site 7. MHM on the 13.9.80 as the loss of samples at this time caused them to be very wide. These values were not significant from those of any previous sampling occasion. Site 13. MRM could not be reached on the sampling occasion in January 1980.

pH

There was generally little fluctuation in peat water pH over the sampling period in most study sites (Fig. 4.11). In most cases the pH was slightly lower when the water levels were higher and *vice versa* (e.g. 8. SM). This was similar to the trend found by McColl (1969). The pH in site 11. FBC increased considerably between May and September 1980 which may have been due to the respiration of phytoplankton and aquatic macrophytes present. The pH decreased markedly over the winter months in the water from Barton Broad (15. BRD) and the River Ant (16. RIV) due probably to decreased phytoplankton respiration affecting the carbonate-bicarbonate equilibrium system (Golterman *et al.* 1978).

Conductivity (K_{corr})

In sites 1-11 there was a marked decrease in conductivity during the period from September 1979 to January 1980, although the extent and timing of the decrease varies between sites (Fig. 4.12). The decrease was greatest between September and October in sites 5. NPF and 7. MHM (> 1500 μS) and the decline in K_{corr} continued to the January sampling. In sites 8. SM and 9. OA the main decrease in K_{corr} occurred between October and January as in the other sites of the internal system and site 4. LF.

The water levels in all of these sites increased considerably between September and January and it seems likely that the decreases in K_{corr} are due mainly to dilution and possibly flushing of dissolved ions from the sites. The timing of the main

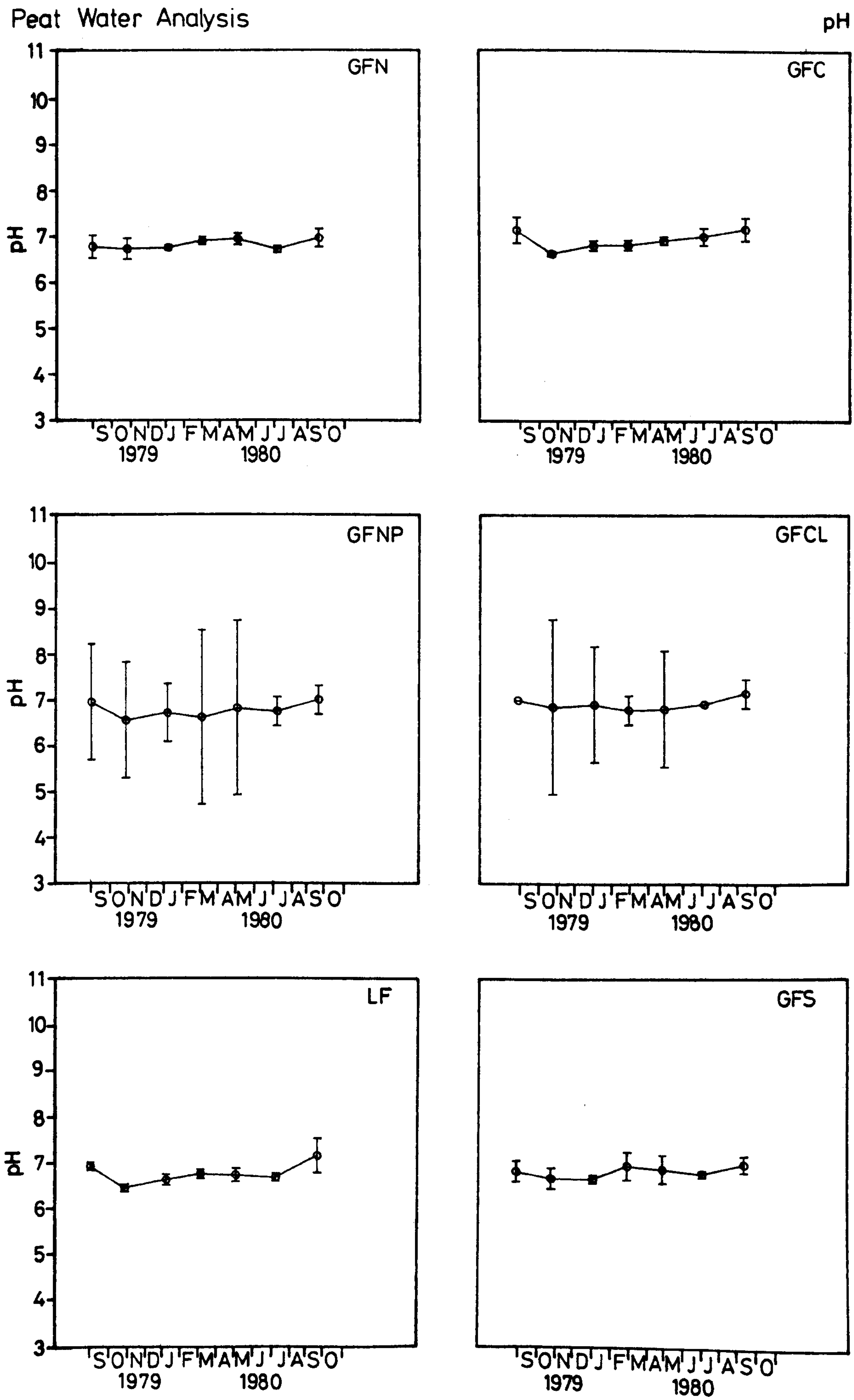
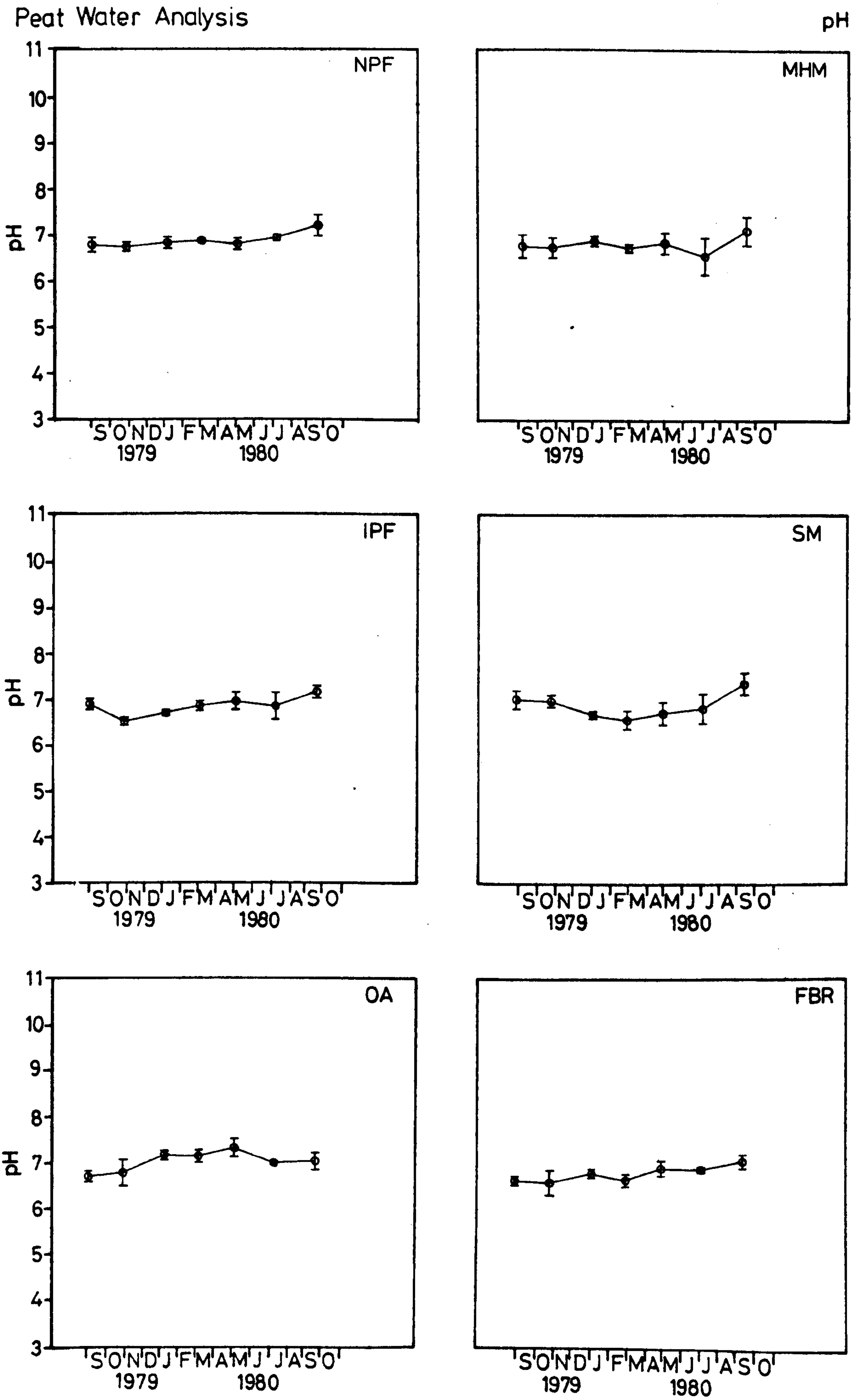
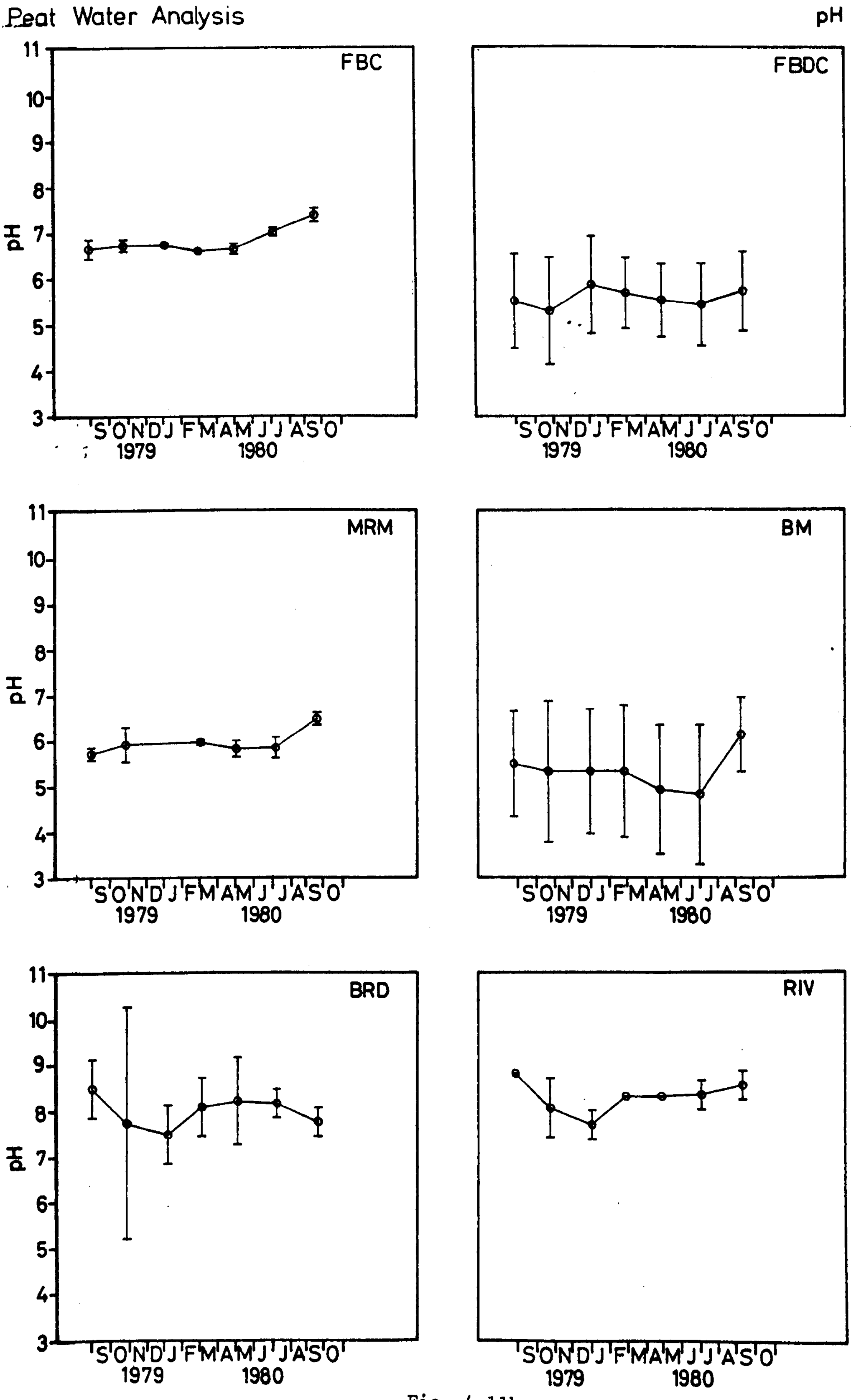

Peat Water Analysis
pH
GFN
GFC
GFNP
GFCL
LF
GFS
pH
11
10
9
8
7
6
5
4
3
S O N D J F M A M J J A S O
1979
1980

Fig. 4.11



Peat Water Analysis
pH
NPF
MHM
IPF
SM
OA
FBR
pH
S O N D J F M A M J J A S O
1979
1980

Fig. 4.11a


Peat Water Analysis
pH
FBC
FBDC
MRM
BM
BRD
RIV
pH
S O N D J F M A M J J A S O
1979
1980
Fig. 4.11b

decrease in conductivity appears to be related mainly to the time when water levels increased most considerably. For instance in sites 8. SM and 9. OA the decrease occurred only when water levels increased well above the peat surface (October 1979-January 1980). In sites 5. NPF and 7. MHM which are close to the River Ant, the increase in water levels between September and October caused the main decrease in conductivity, probably due to flooding by water which was much more dilute than interstitial peat water in these sites (c.f. 16. RIV).

The conductivity subsequently shows an increase in levels in all of these sites as the water levels decreased over the study period, due probably both to concentration of the water by evapotranspiration andequilibrium with ions held in the exchange system of the peat.

The smaller rise in water levels in June 1980 also corresponds with a decrease in conductivity in some sites (e.g. 4. LF, 5. NPF and 6. IPF).

In the three sites with much *Sphagnum* (Sites 12-14) there was much less variation in levels of conductivity than in the sites discussed above although levels did tend to be lower when the water levels were higher, probably due to dilution by rainfall.

The conductivity of the water from the River Ant (16. RIV) and Barton Broad (15. BRD) was relatively constant over the study period exceptfor a dramatic peak in levels in May 1980. This peak was reflected by similar rises in the concentrations of magnesium, sodium and chloride, indicating that an incursion of brackish water up the river must have occurred, extending at least as far as Barton Broad.

Peat Water Analysis

CONDUCTIVITY

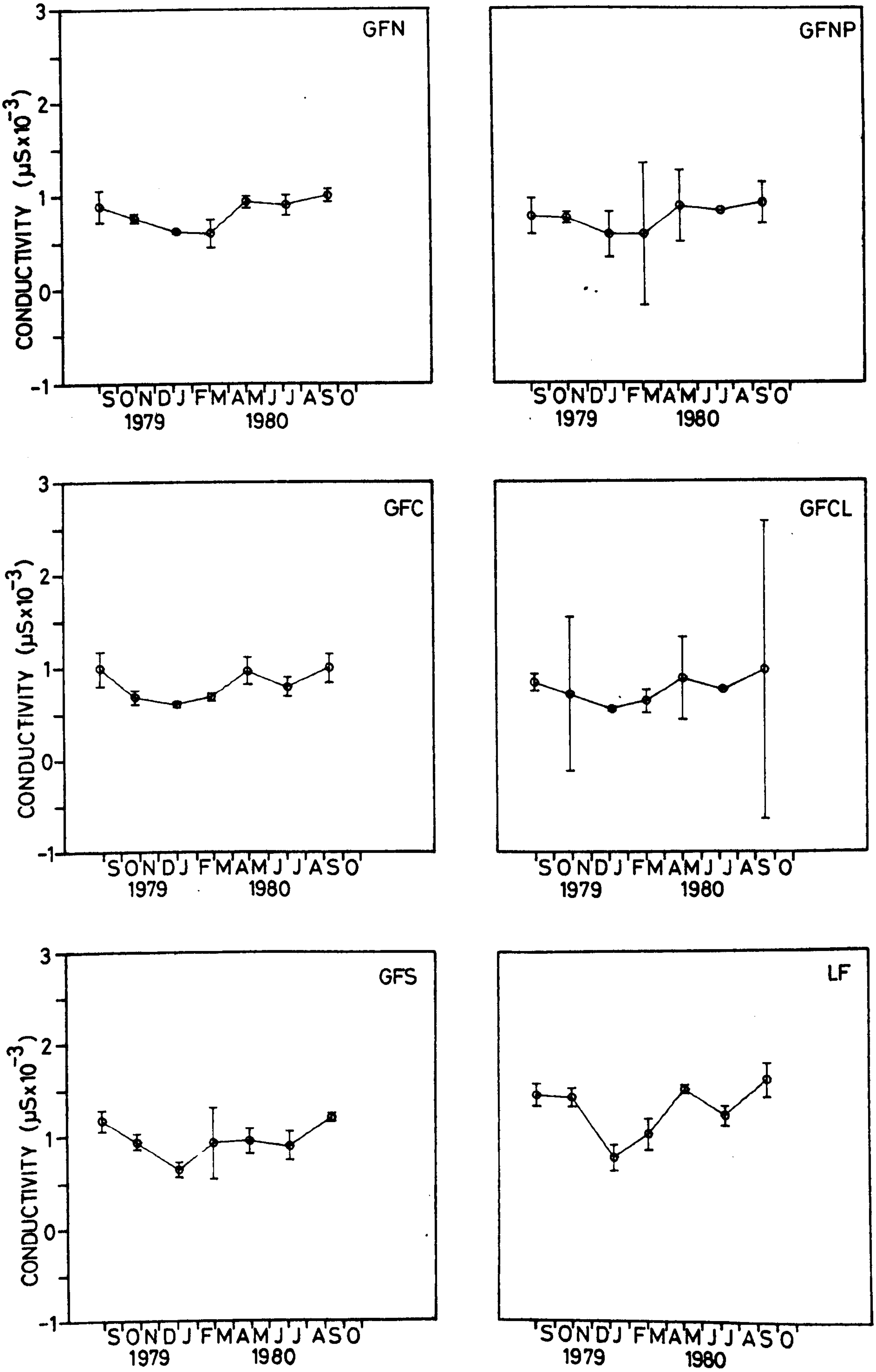


Fig. 4.12

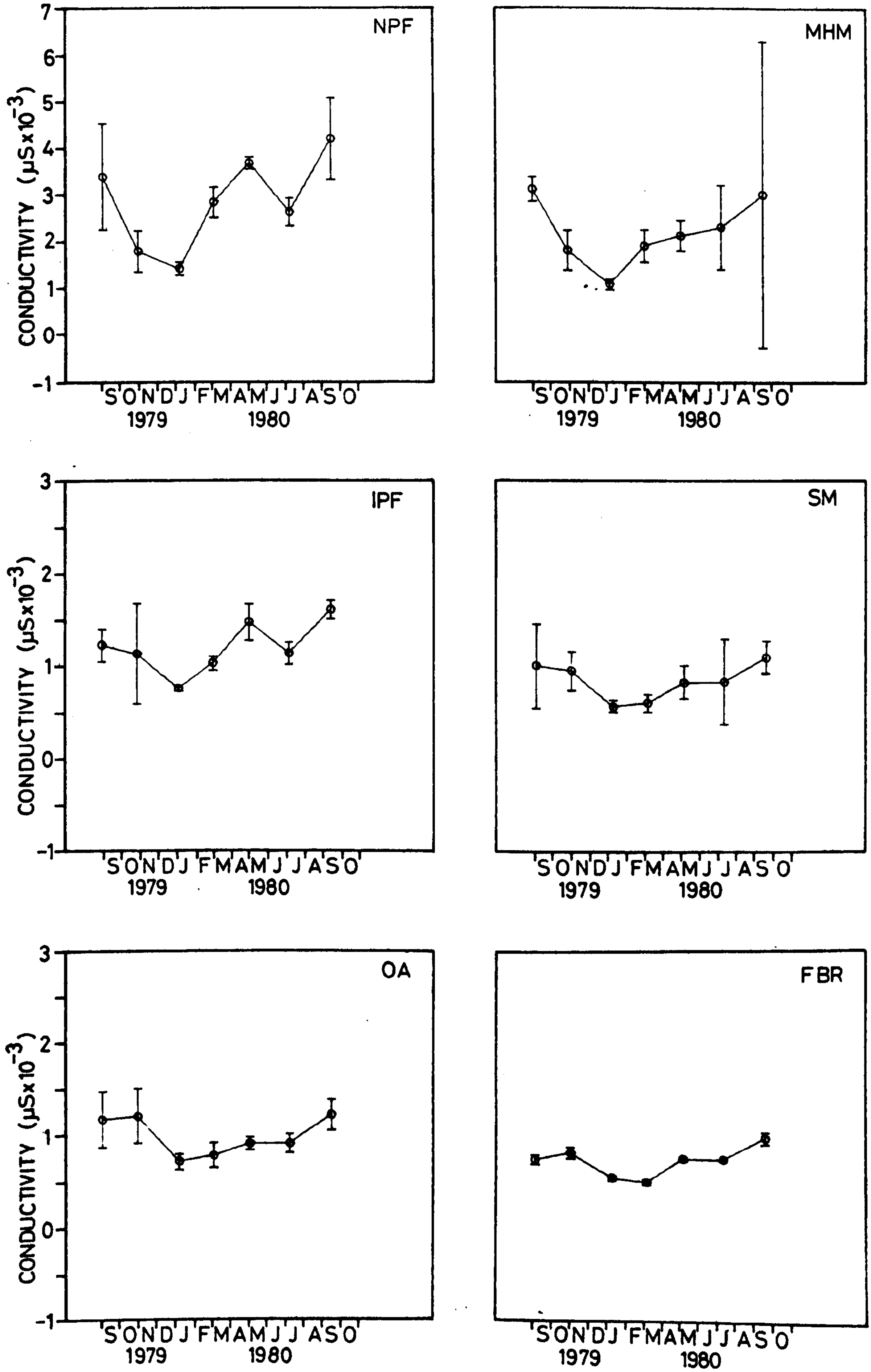

NPF
MHM
IPF
SM
OA
FBR
CONDUCTIVITY (µSx10^-3)
S O N D J F M A M J J A S O
1979
1980

Fig. 4.12a

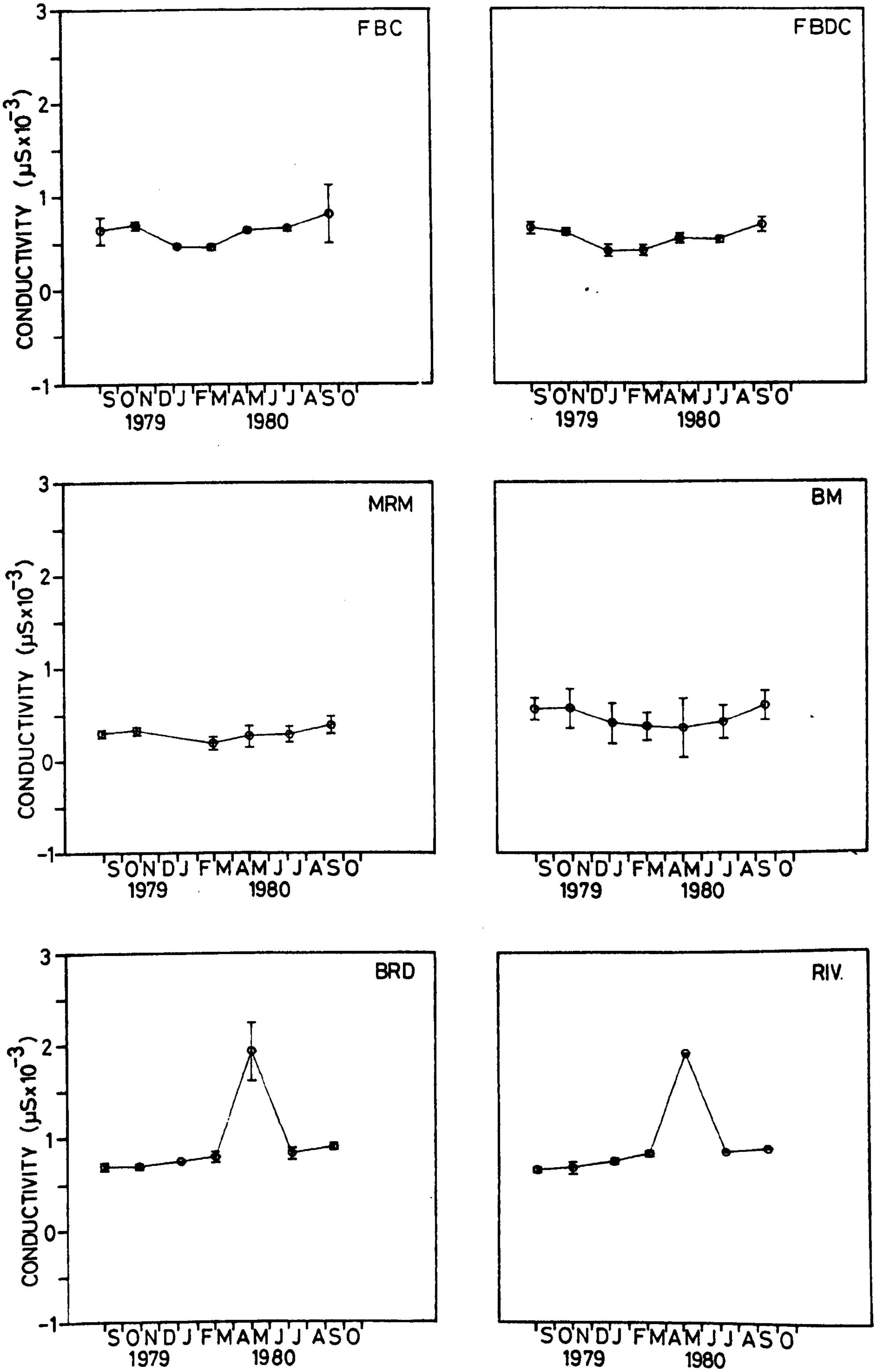

FBC
FBDC
MRM
BM
BRD
RIV.
CONDUCTIVITY ($\mu S \times 10^{-3}$)
3
2
1
0
-1
S O N D J F M A M J J A S O
1979
1980

Fig. 4.12b

A peak in conductivity, and of the ions of high concentration in brackish water was also found in sites 4. LF, 5. NPF and 6. IPF suggesting that brackish water may have entered these sites (4.5.14).

Major cations

The changes in conductivity were reflected very closely by the changes in levels of sodium (Fig. 4.15) and to a lesser extent those of calcium (Fig. 4.13) and magnesium (Fig. 4.14). Calcium and magnesium both increased between September and October 1979 in several of the sites (e.g. 4. LF, 9. OA) the reason for which is not clear. The increase could have been due to release of the cations from exchangeable sites into solution with rising water levels, although this would not account for the rises in levels of magnesium in site 2. GFC where there were already water levels above the peat surface. Release of calcium and magnesium from senescing plant material would be expected over this period, (cf. Planter 1970) but it seems unlikely that this could account for the quite large increases in some of the sites. The rise in calcium in the water from Barton Broad (15. BRD) and the River Ant (16. RIV) could be due to inputs from agricultural liming.

The changes in levels of potassium (Fig. 4.16) were quite different from those of the other major cations, levels generally being higher with higher water levels. Levels in most of the study sites are lower than those found in the broad

Peat Water Analysis

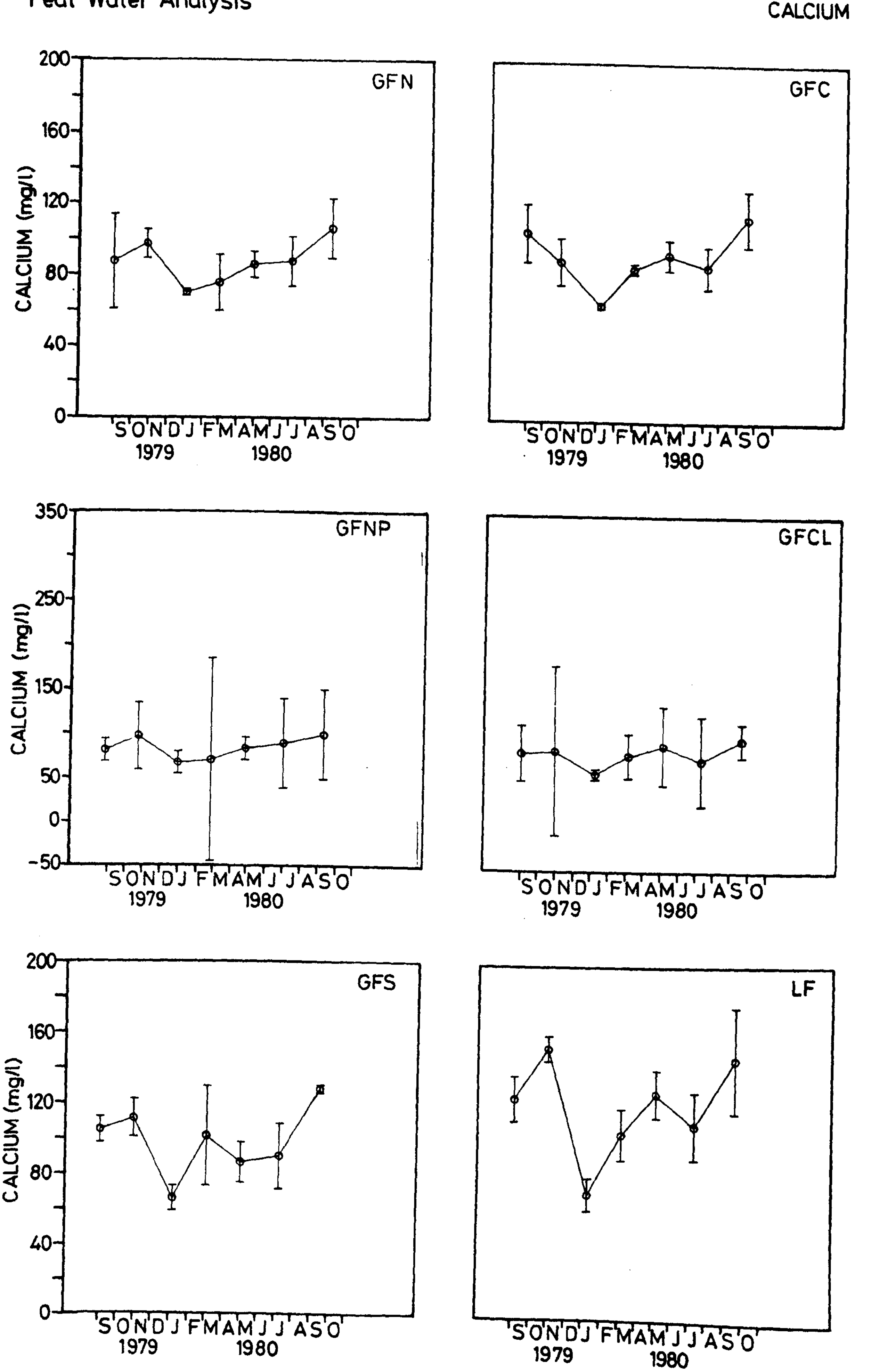
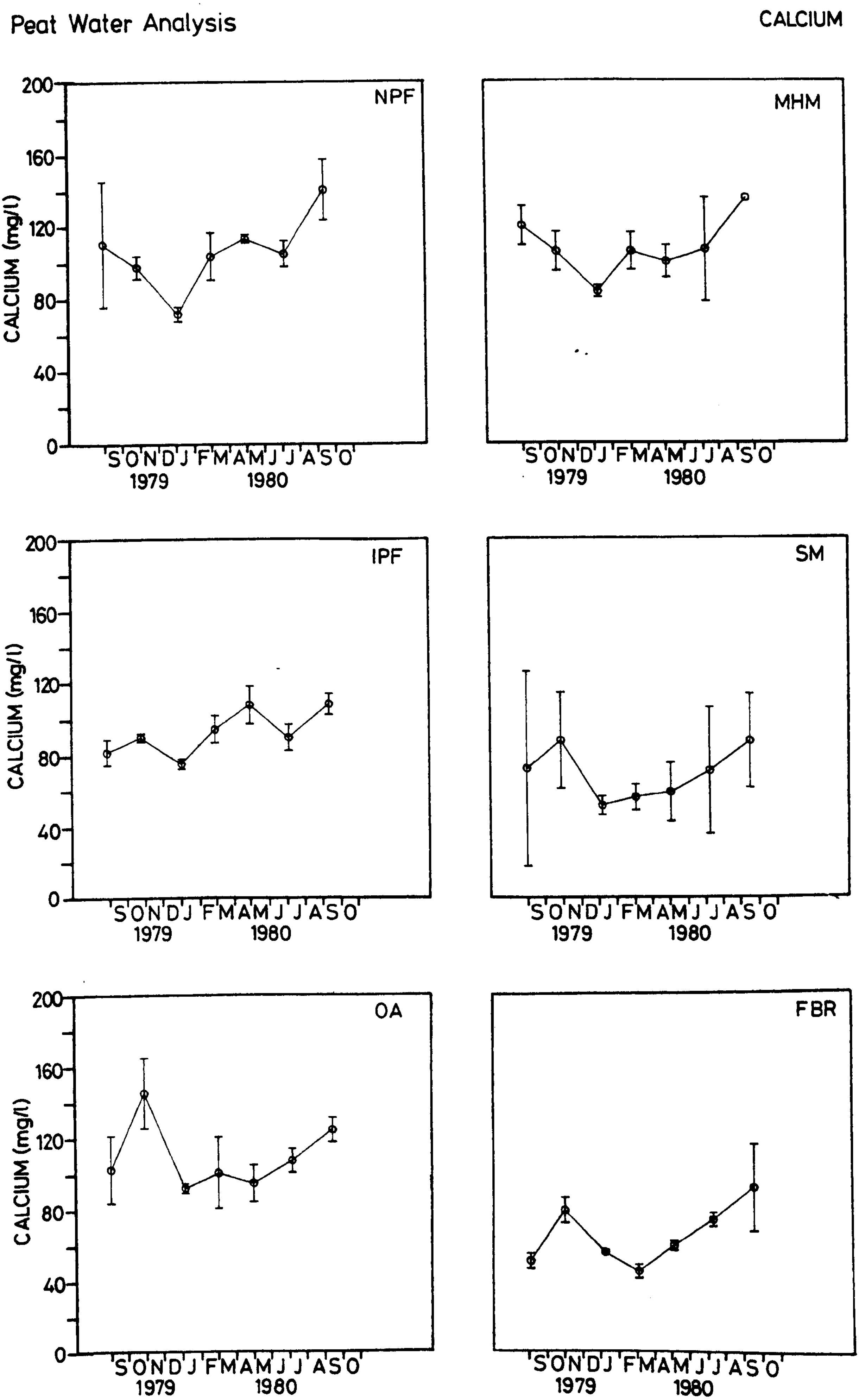


Fig. 4.13



Peat Water Analysis
CALCIUM
NPF
MHM
IPF
SM
OA
FBR
CALCIUM (mg/l)
200
160
120
80
40
0
S O N D J F M A M J J A S O
1979
1980

Fig. 4.13a

Peat Water Analysis

CALCIUM

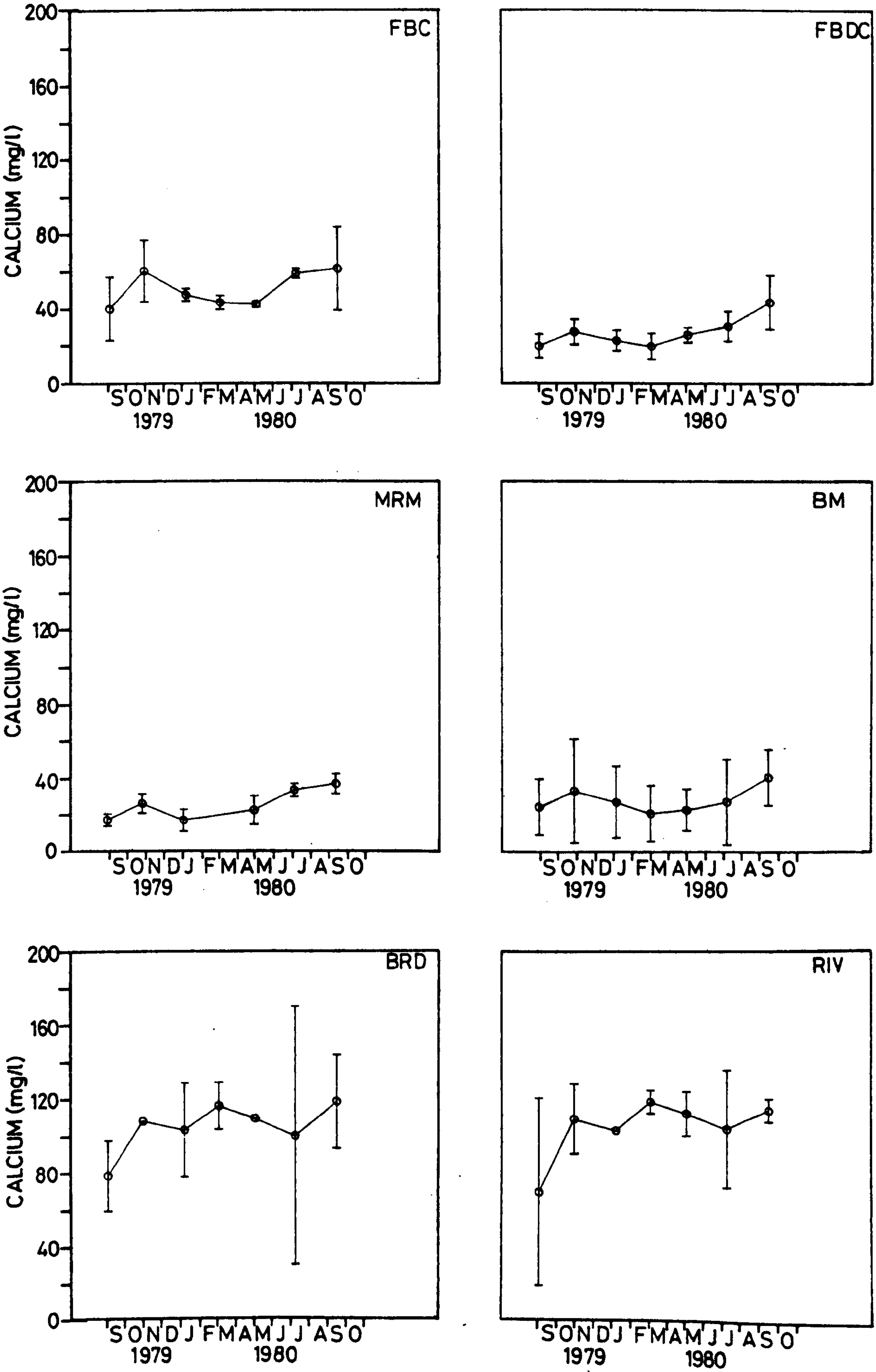


Fig. 4.13b

Peat Water Analysis MAGNESIUM

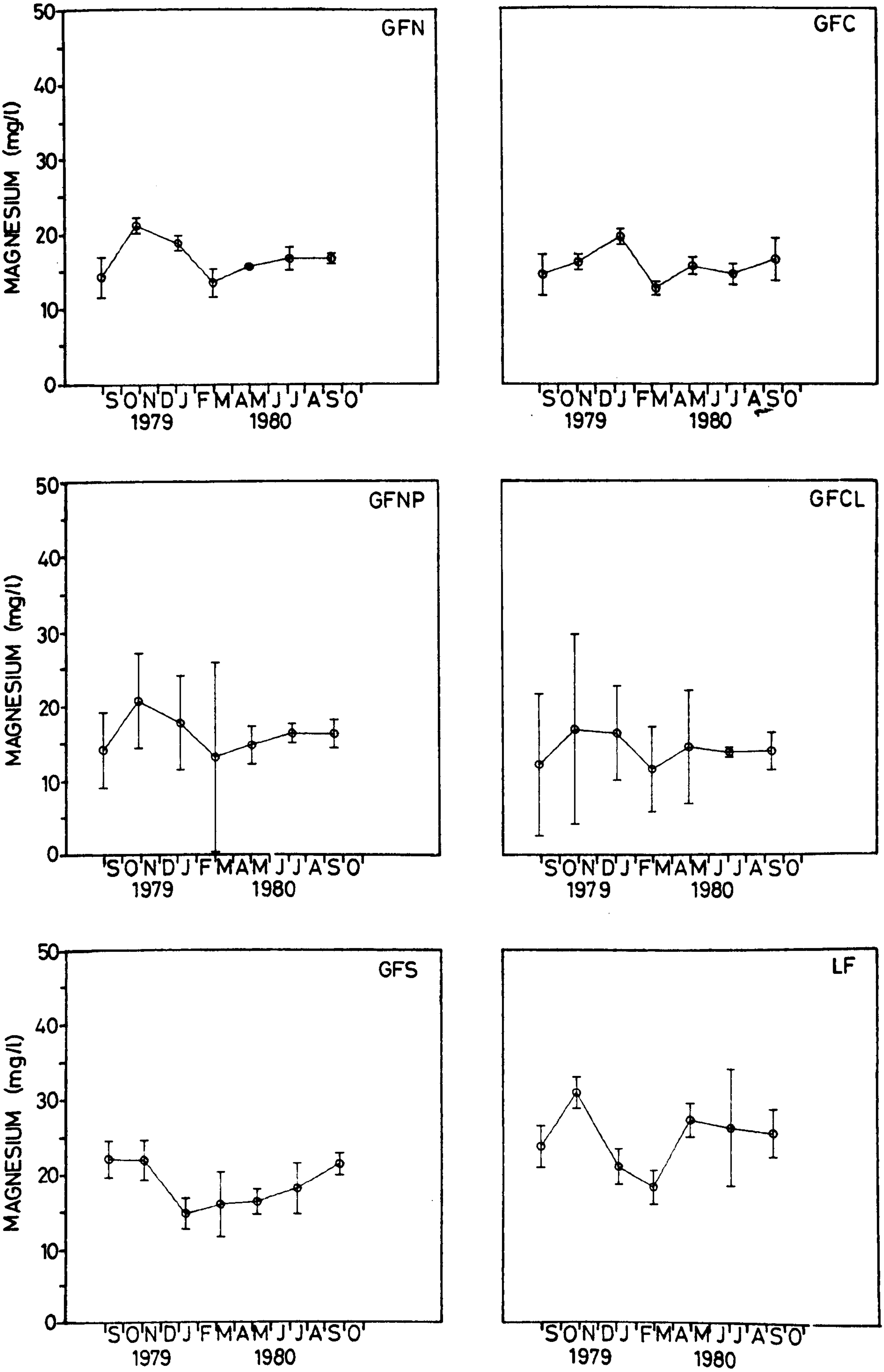


Fig. 4.14

Peat Water Analysis MAGNESIUM

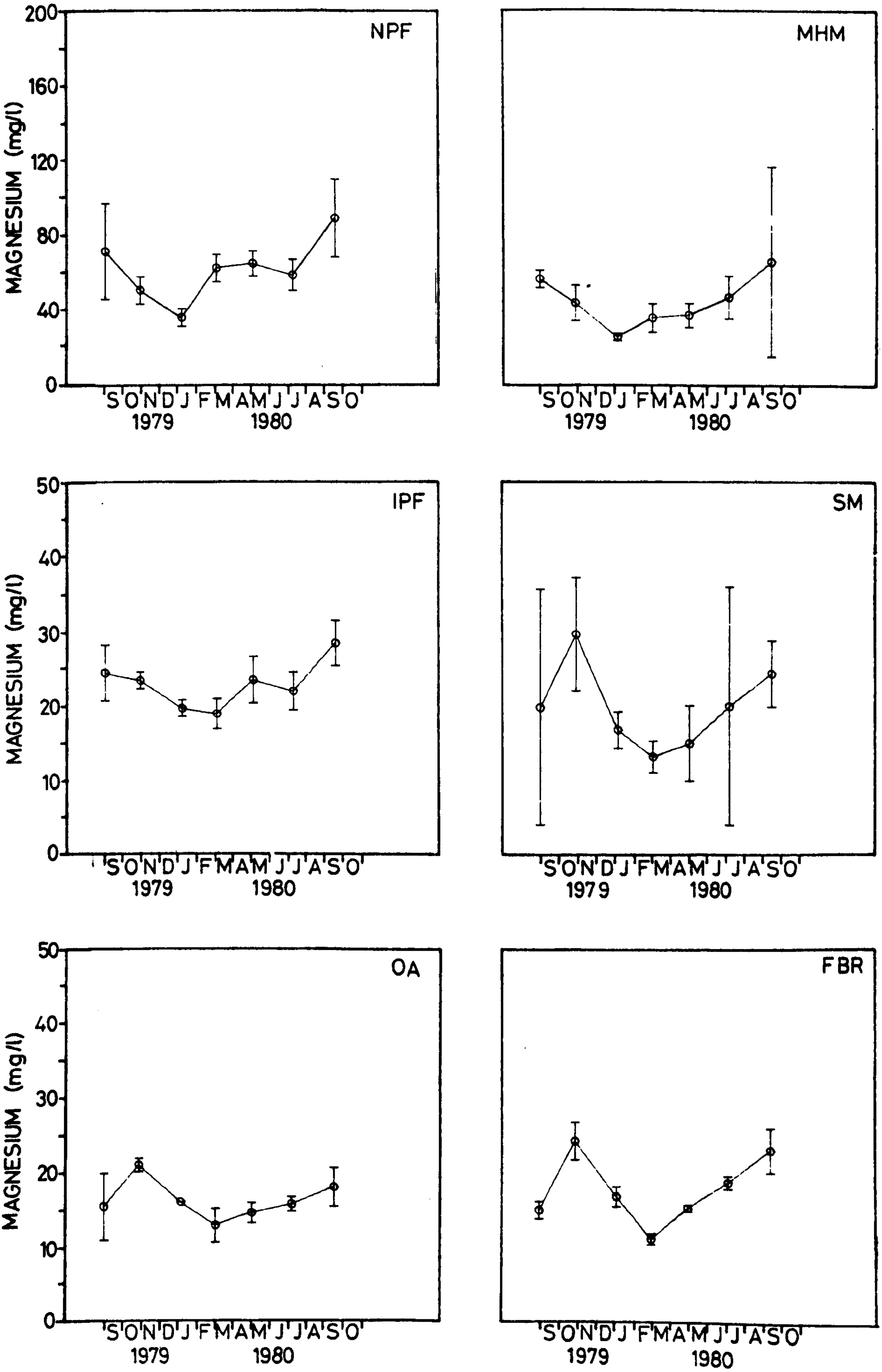


Fig. 4.14a

Peat Water Analysis

MAGNESIUM

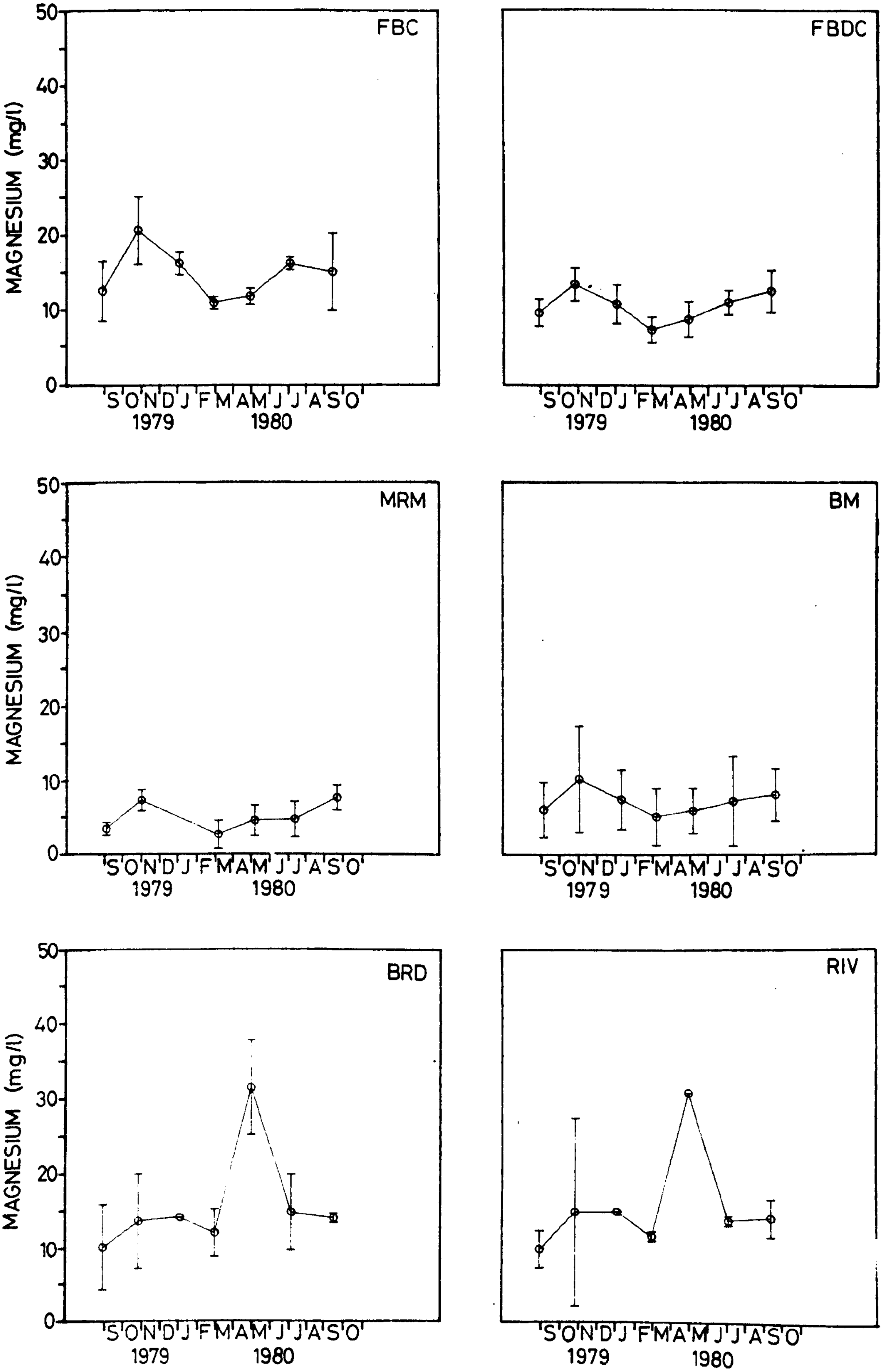


Fig. 4.14b

Peat Water Analysis

SODIUM

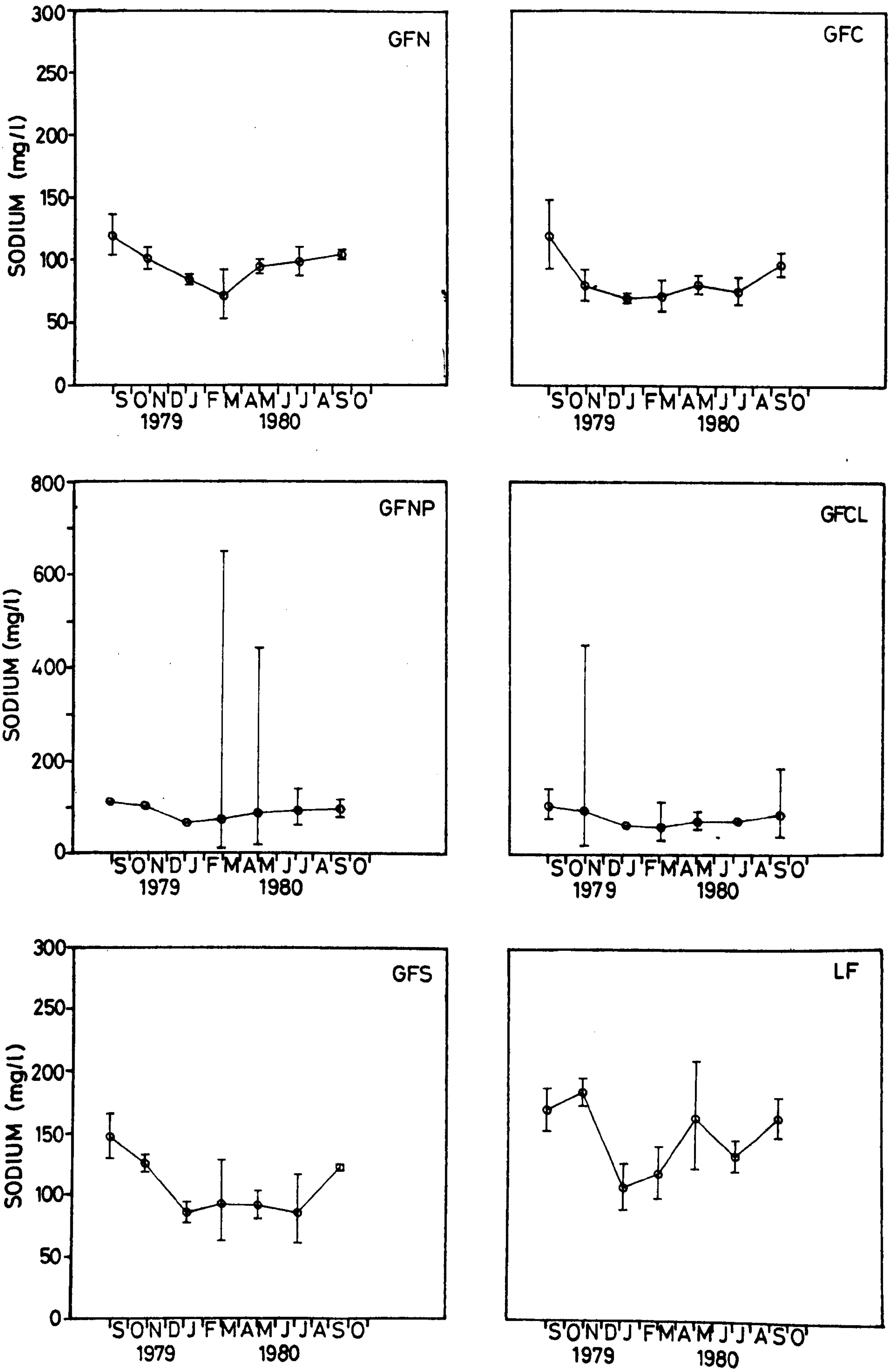


Fig. 4.15

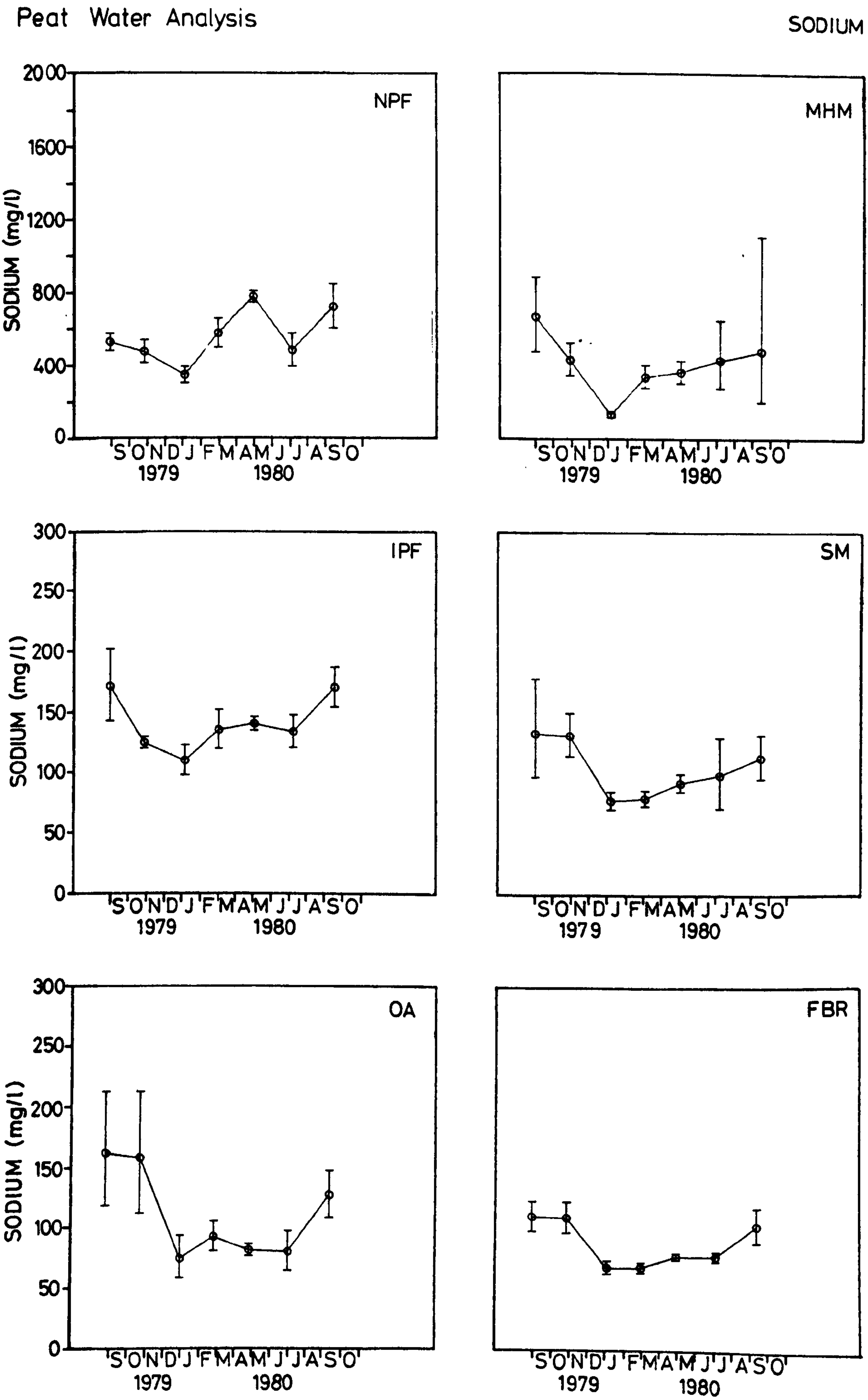

Peat Water Analysis
SODIUM
SODIUM (mg/l)
NPF
MHM
IPF
SM
OA
FBR
S O N D J F M A M J J A S O
1979
1980
0
400
800
1200
1600
2000
50
100
150
200
250
300

Fig. 4.15a

Peat Water Analysis

SODIUM

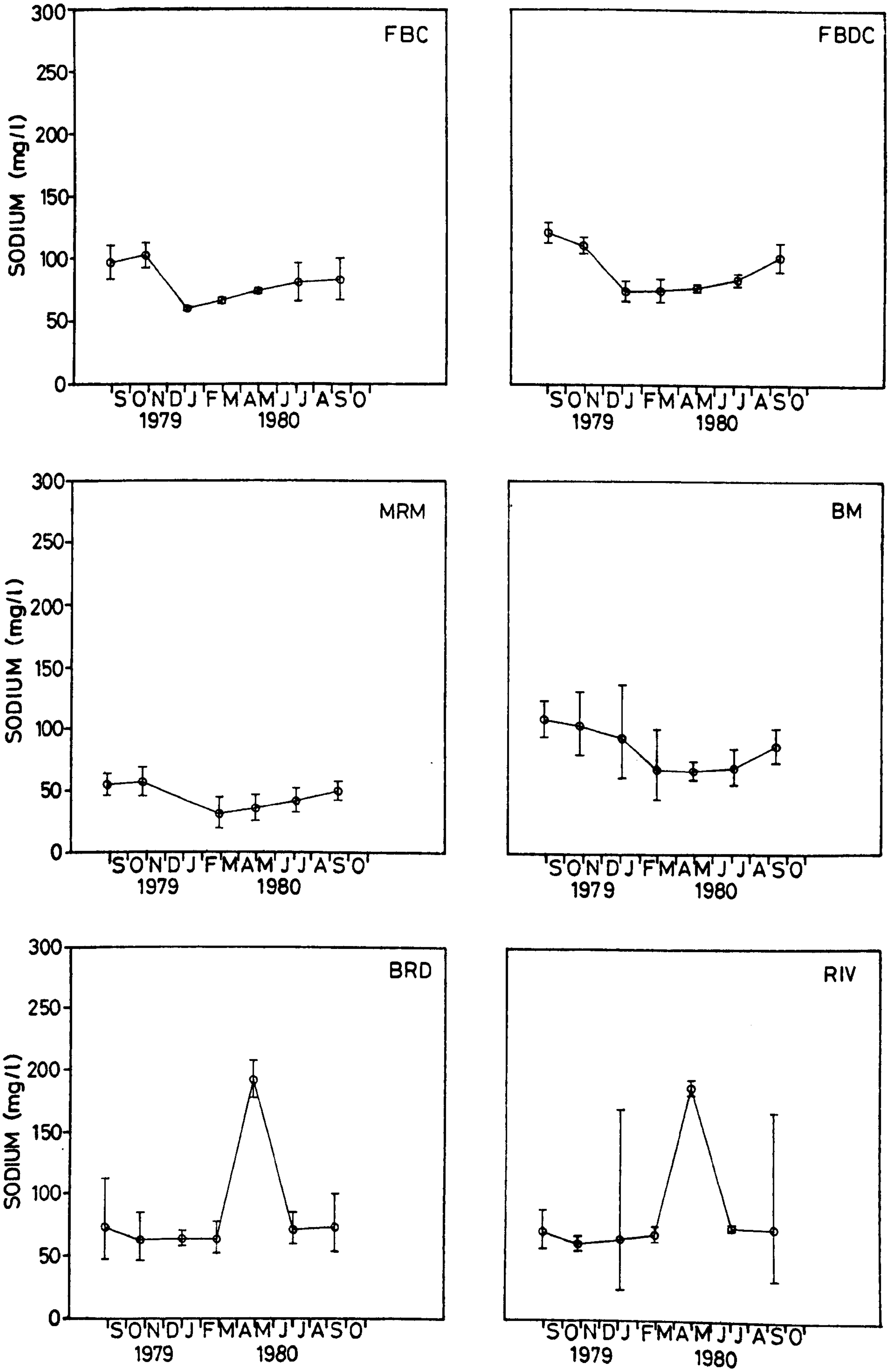


Fig. 4.15b

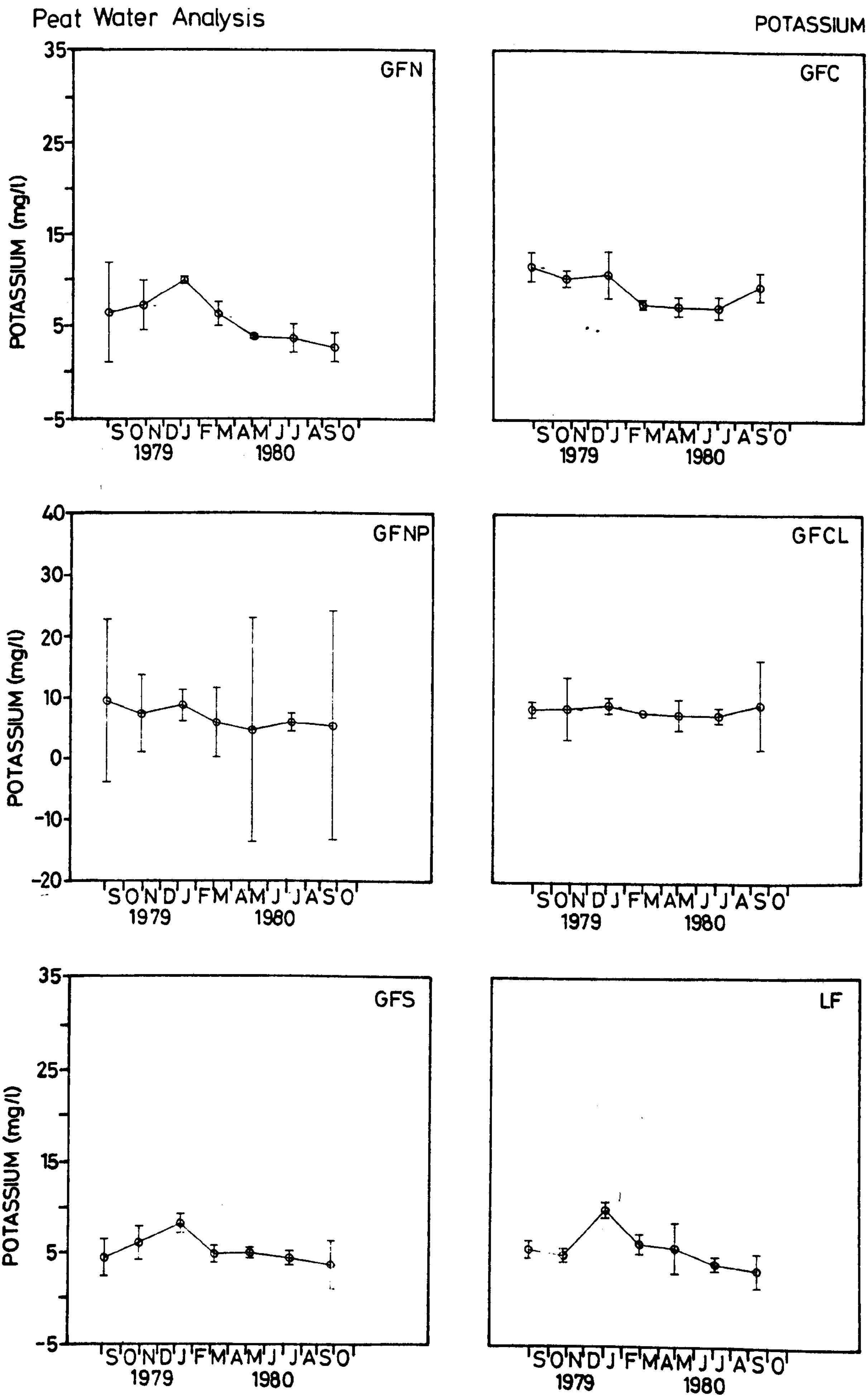

Peat Water Analysis
POTASSIUM
GFN
GFC
GFNP
GFCL
GFS
LF
POTASSIUM (mg/l)
S O N D J F M A M J J A S O
1979
1980

Fig. 4.16

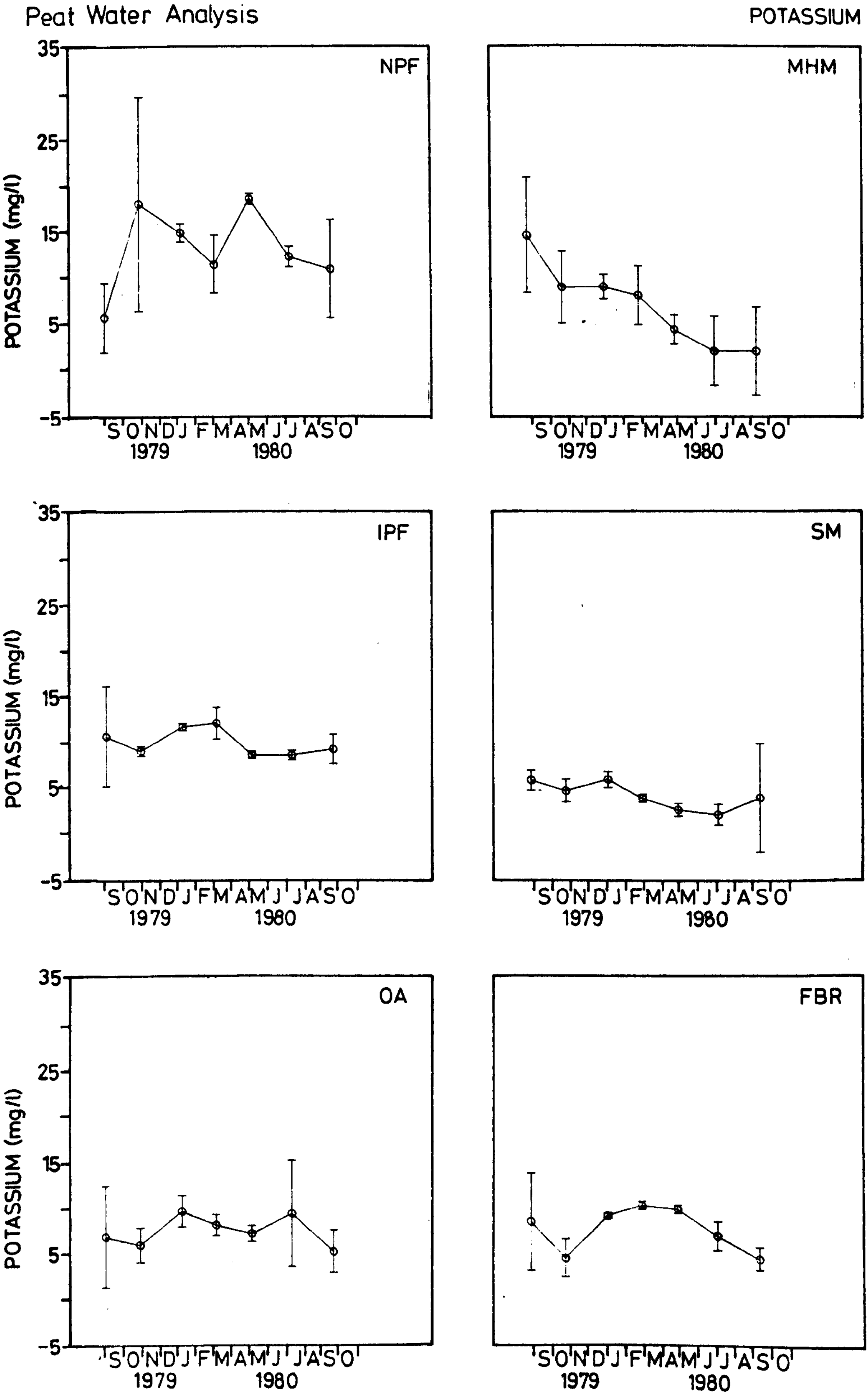
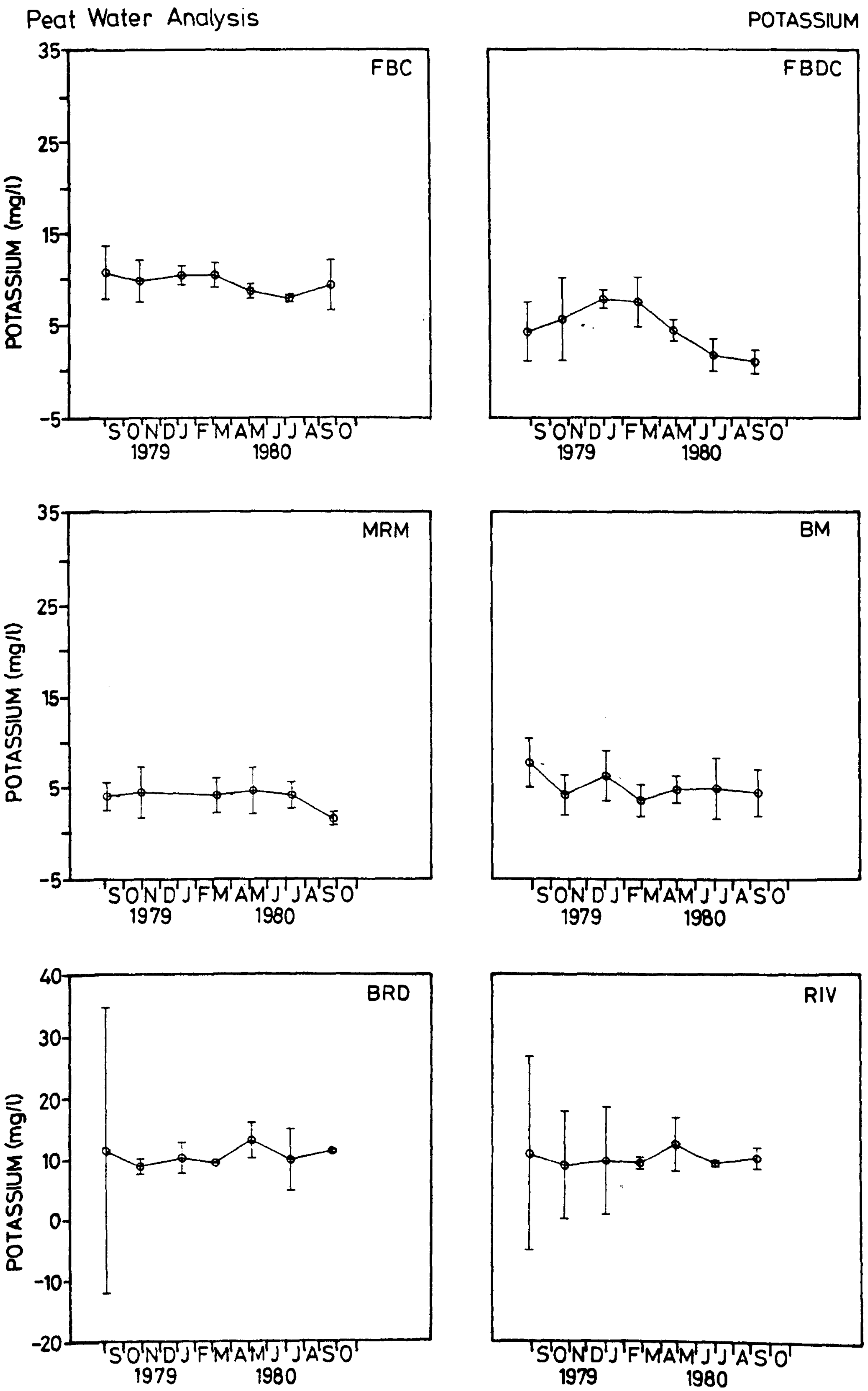

Peat Water Analysis
POTASSIUM
NPF
MHM
IPF
SM
OA
FBR
POTASSIUM (mg/l)
35
25
15
5
-5
S O N D J F M A M J J A S O
1979
1980

Fig. 4.16a



Peat Water Analysis
POTASSIUM
FBC
FBDC
MRM
BM
BRD
RIV
POTASSIUM (mg/l)
35
25
15
5
-5
40
30
20
10
0
-10
-20
S O N D J F M A M J J A S O
1979
1980

Fig. 4.16b

and river water (15. BRD and 16. RIV) and it is probable that at least part of the increase in the winter months was due to flooding by water of higher potassium concentration than that found in the study site over the rest of the year. The river and broad had generally quite constant levels of potassium, a slight rise in May 1980 reflecting the rise in sodium, magnesium, chloride and conductivity.

The increase in levels of potassium between September and January was probably contributed to by leaching from senescent plant material - Planter (1970 found that 10 g of cut *Phragmites* stems increased the concentration of deionised water to 5 mg/l, although elution was very fast, occurring within a few hours. This increase in levels in sites of the external system is probably also contributed to by high levels of potassium in the water flooding the sites.

Levels of potassium decreased in most sites during 1980, probably due to uptake by the vegetation during the growing season. The changes in potassium levels in site 7. MHM were unusual, showing a tendency to decrease over the study period, although there were few significant changes.

Major anions

As already suggested the levels of chloride (Fig. 4.17) reflected those of sodium and conductivity quite closely, decreasing at times of high water levels. Levels of sulphate and bicarbonate were much more variable. Sulphate concentrations were higher at

Peat Water Analysis

CHLORIDE

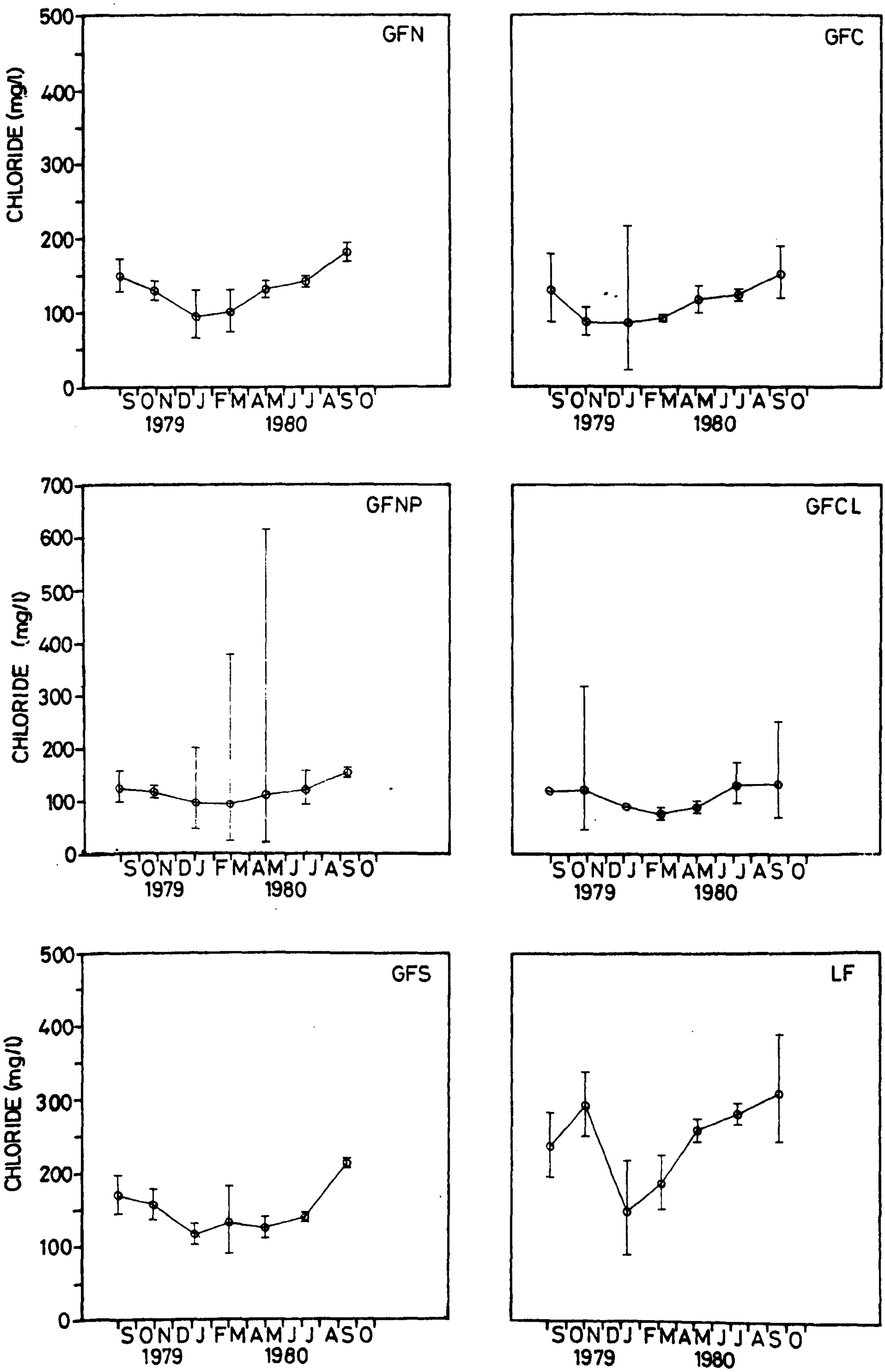


Fig. 4.17

Peat Water Analysis

CHLORIDE

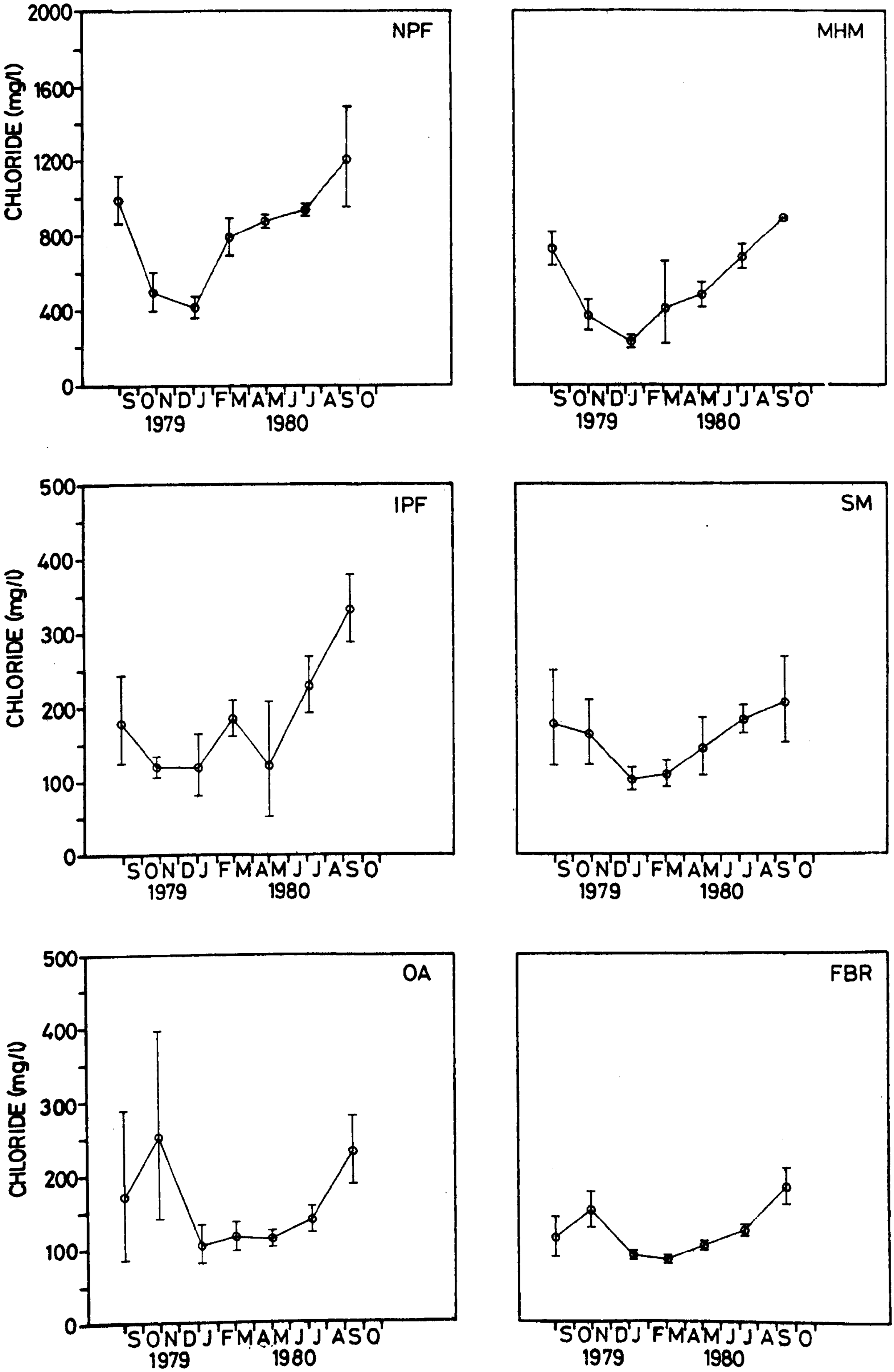


Fig. 4.17a

Peat Water Analysis

CHLORIDE

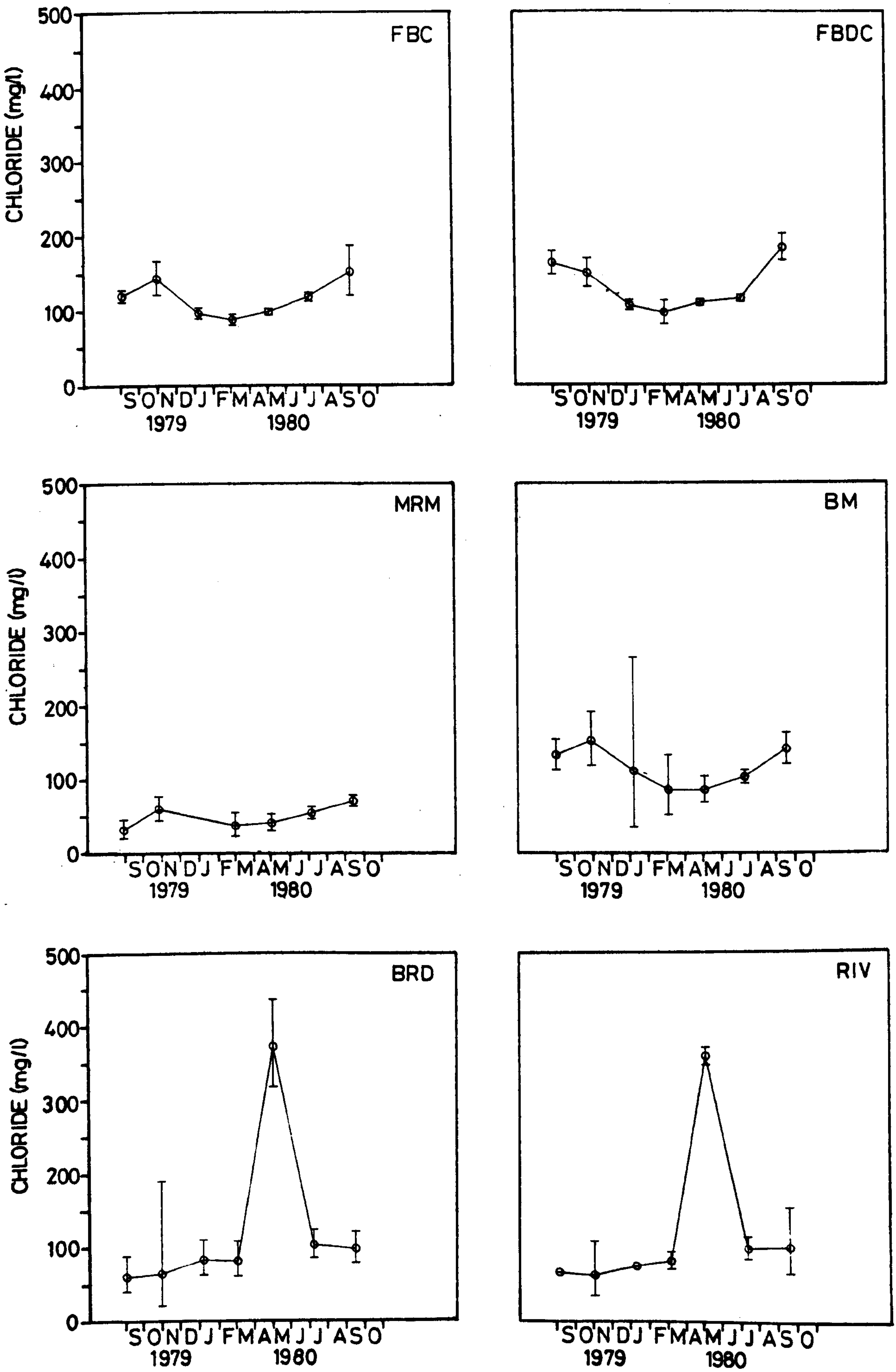


Fig. 4.17b

Peat Water Analysis

SULPHATE

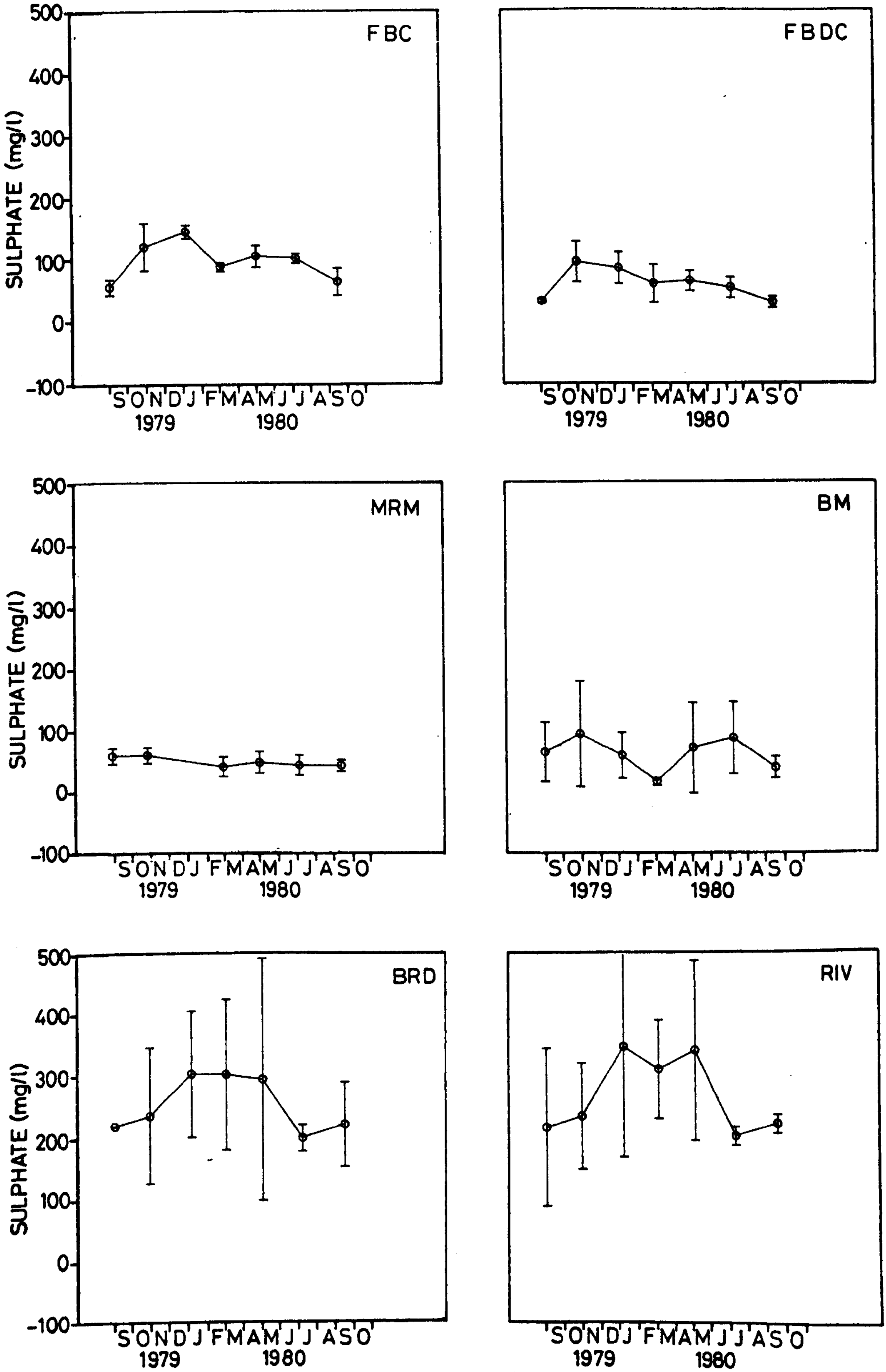


Fig. 4.18

Peat Water Analysis

SULPHATE

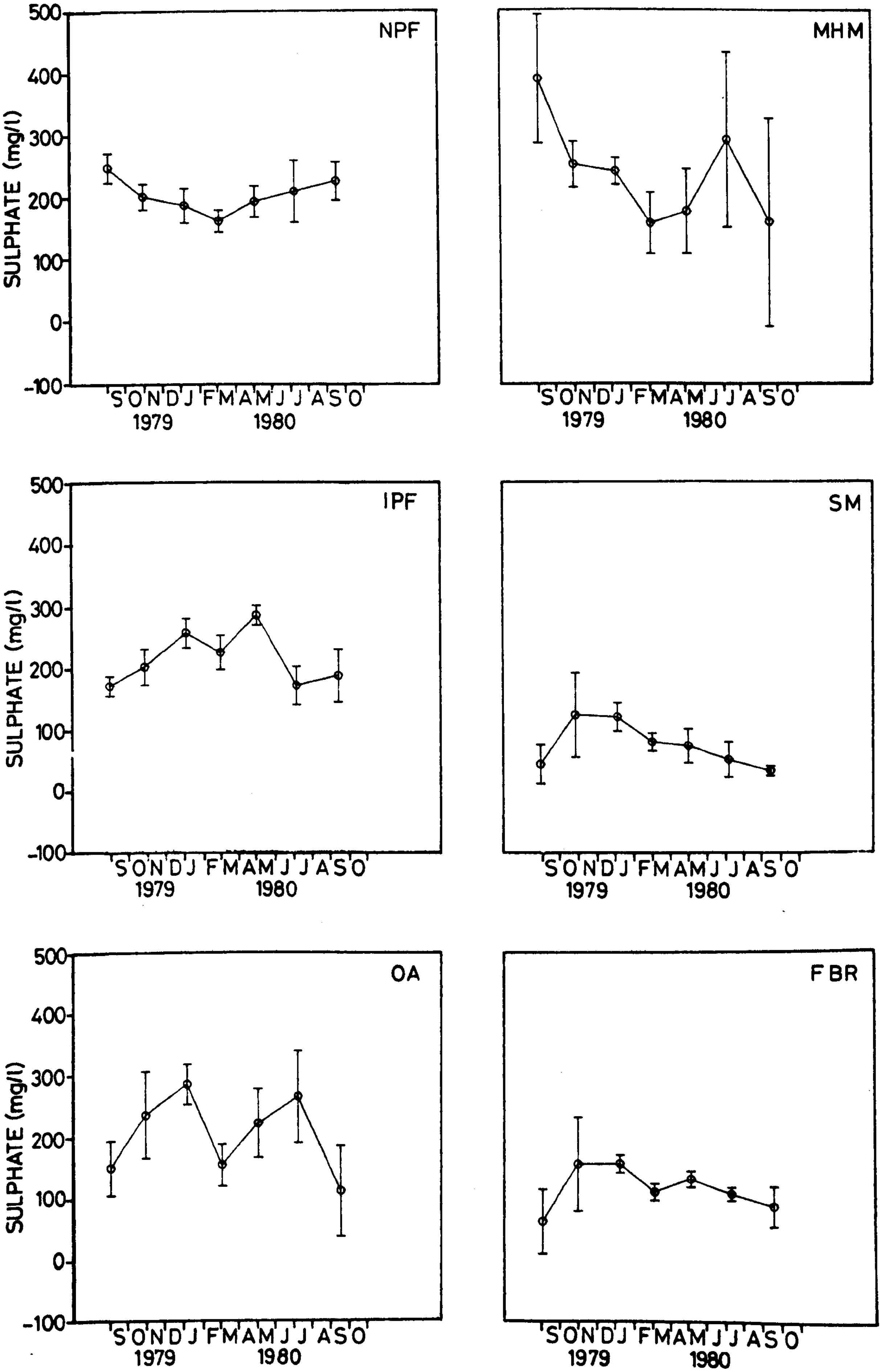


Fig. 4.18a

Peat Water Analysis

SULPHATE

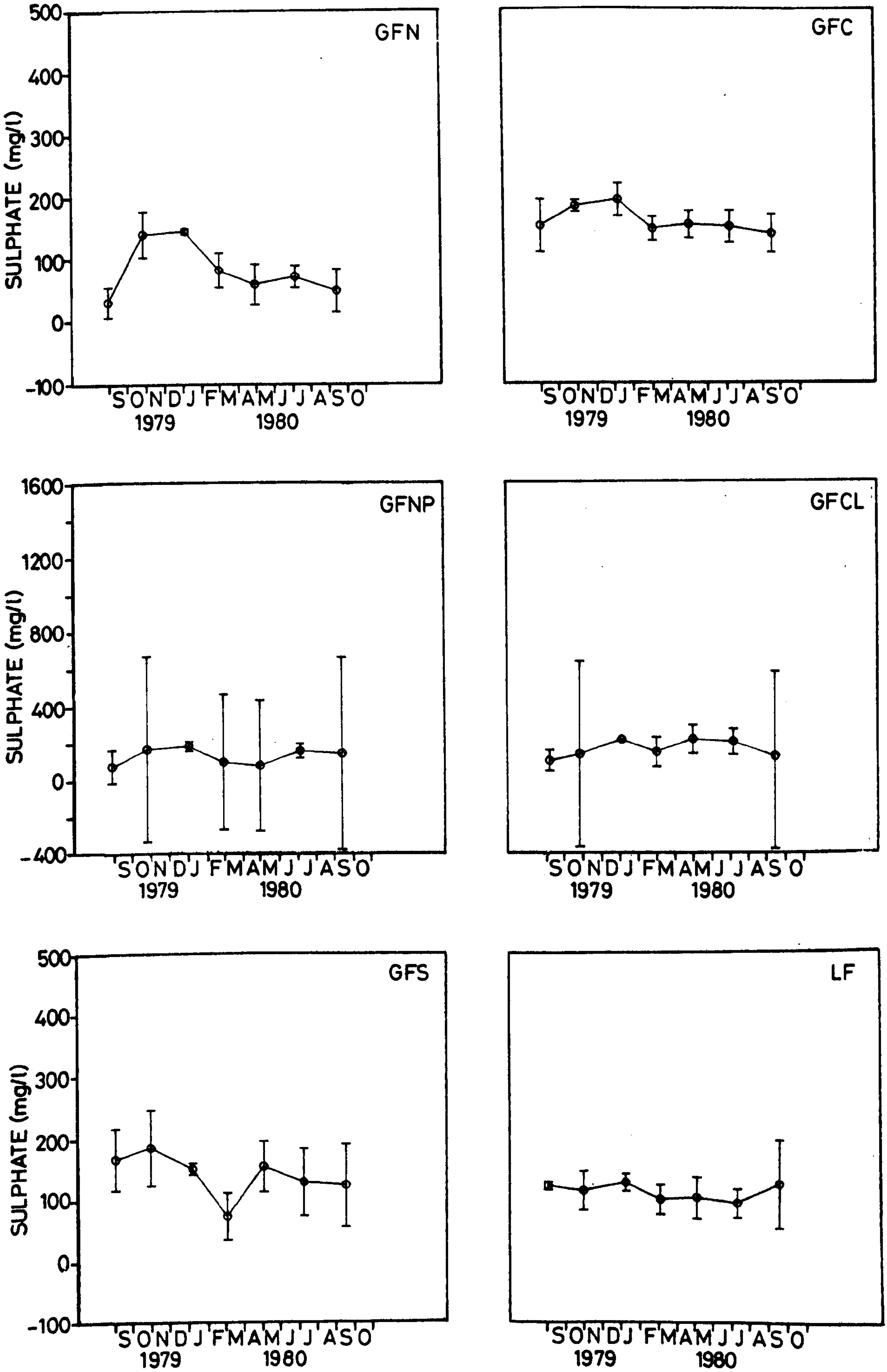


Fig. 4.18b

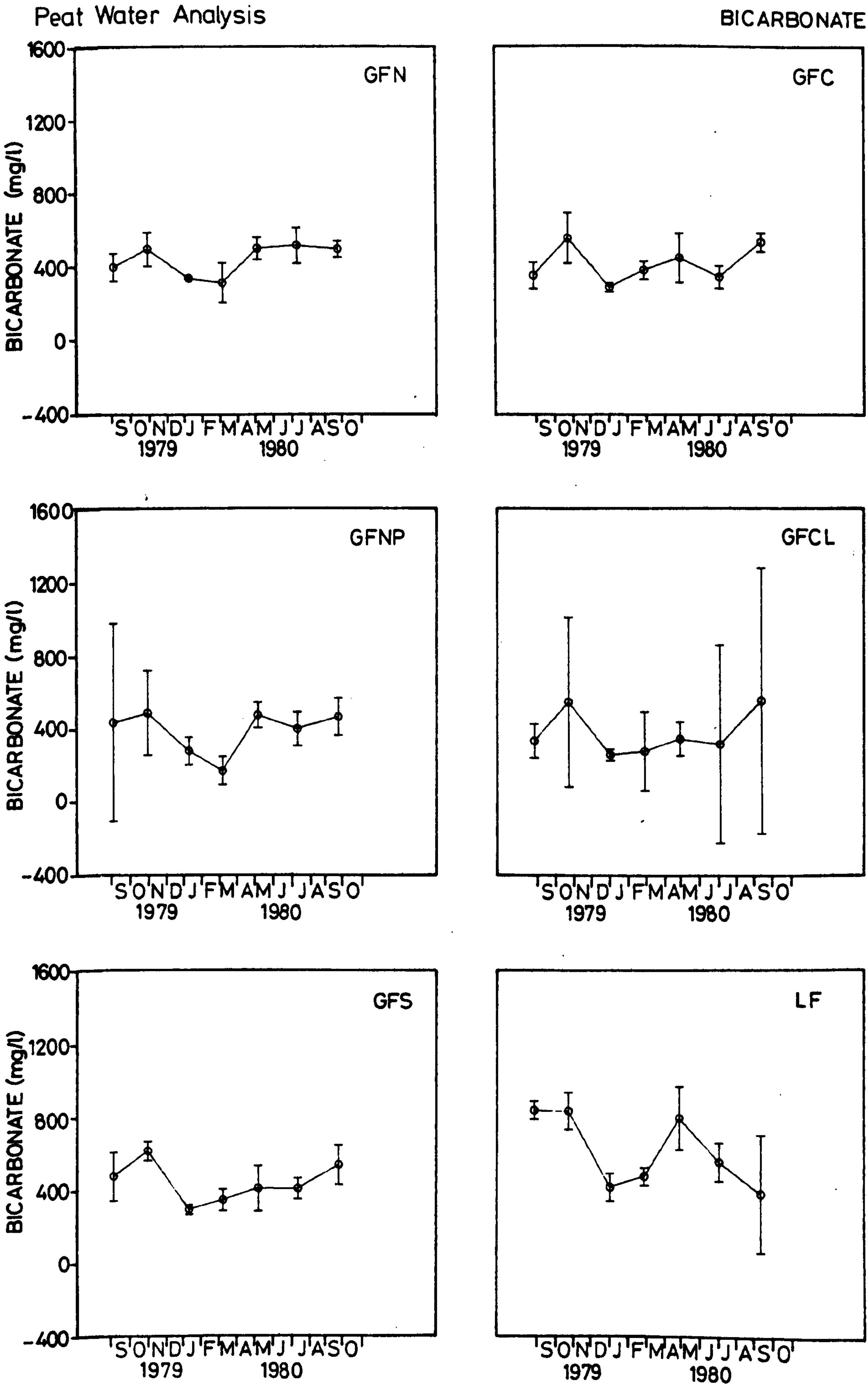

Peat Water Analysis
BICARBONATE
BICARBONATE (mg/l)
1600
1200
800
400
0
-400
GFN
GFC
GFNP
GFCL
GFS
LF
S O N D J F M A M J J A S O
1979
1980

Fig. 4.19

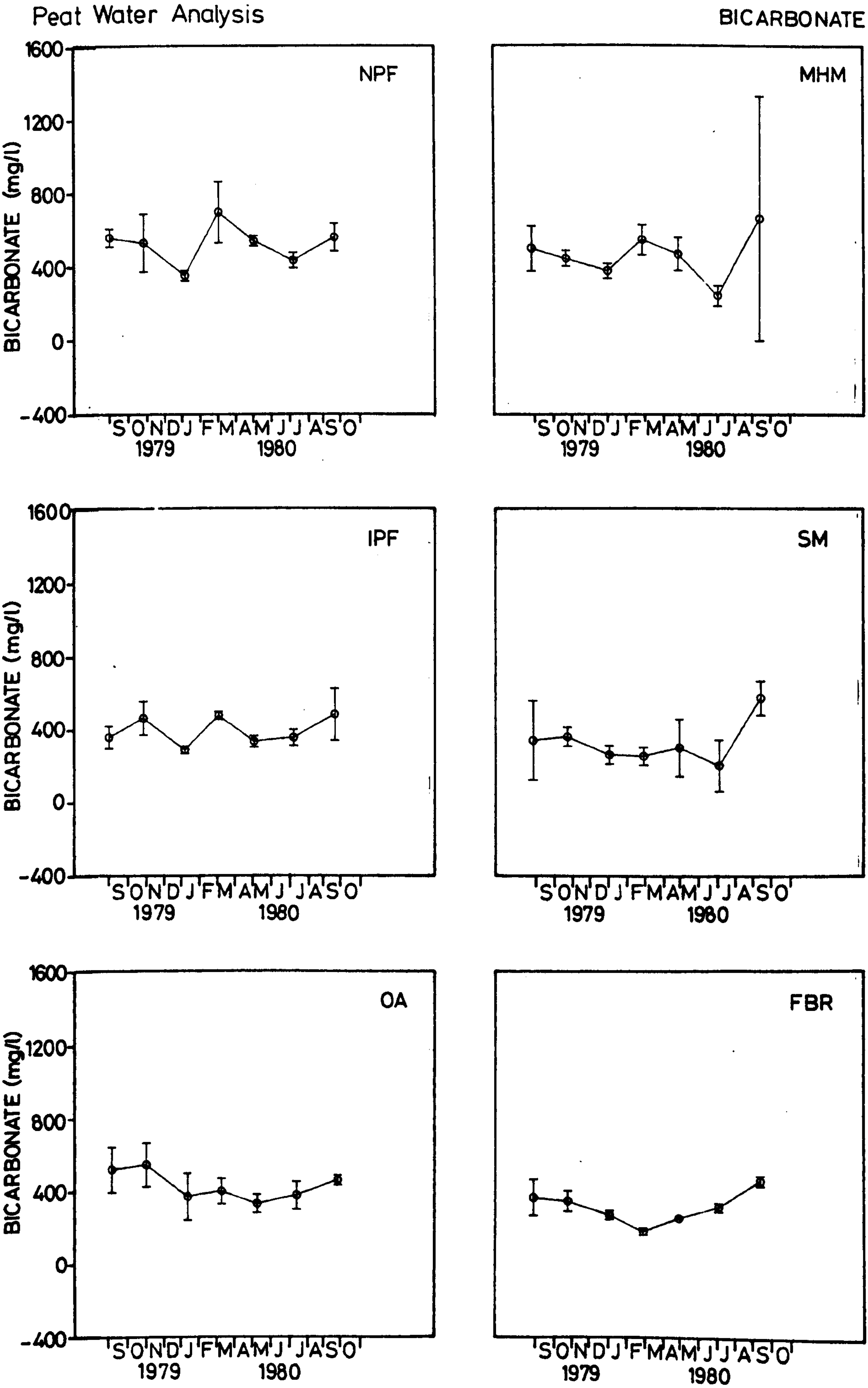
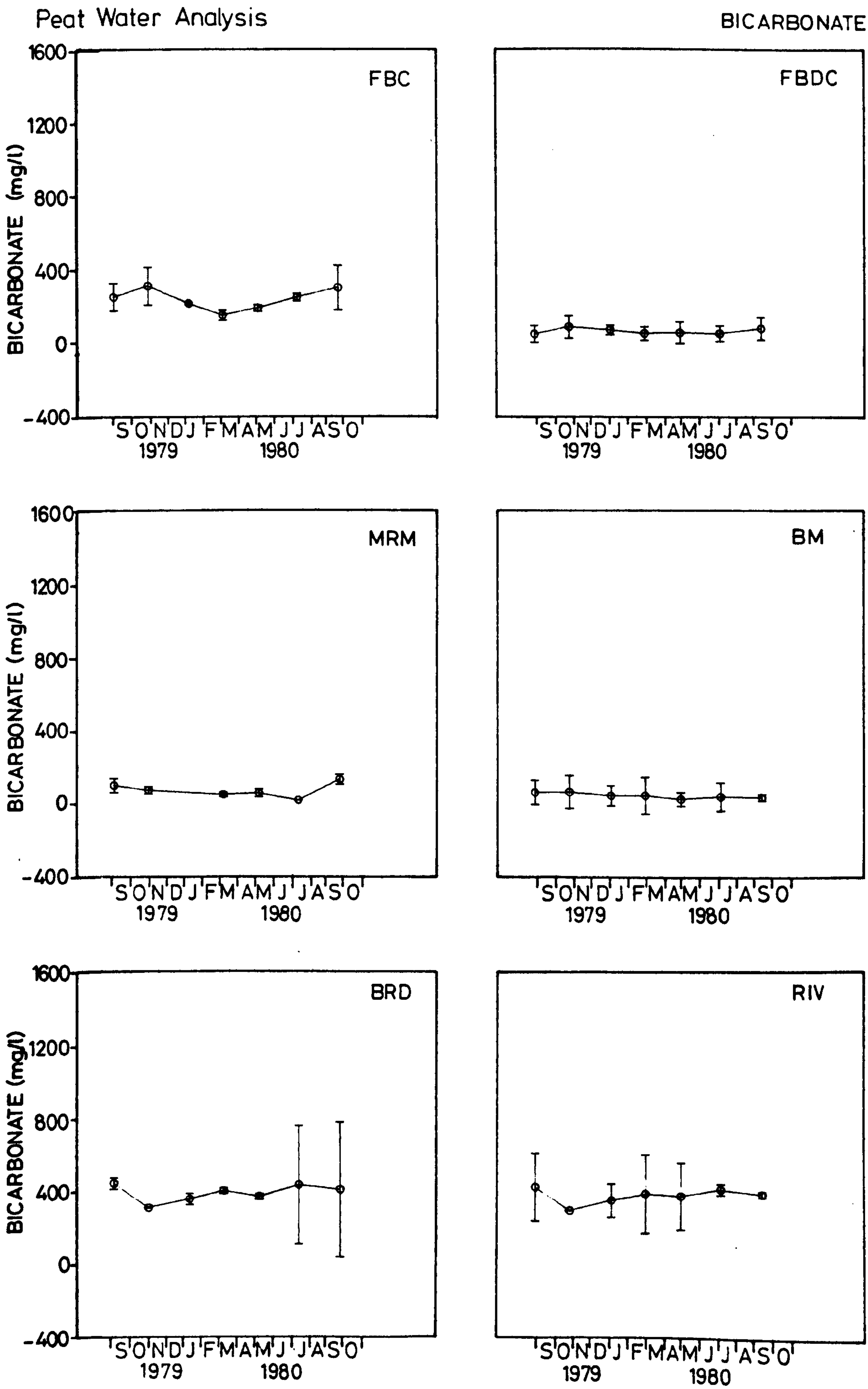

Peat Water Analysis
BICARBONATE
NPF
MHM
IPF
SM
OA
FBR
BICARBONATE (mg/l)
1600
1200
800
400
0
-400
S O N D J F M A M J J A S O
1979
1980

Fig. 4.19a



Peat Water Analysis
BICARBONATE
FBC
FBDC
MRM
BM
BRD
RIV
BICARBONATE (mg/l)
1600
1200
800
400
0
-400
S O N D J F M A M J J A S O
1979
1980

Fig. 4.19b

times of high water level in many sites (Fig. 4.18), possibly due to decreased effects of sulphate reduction and flooding by water of higher sulphate concentration than that usually found in the sites (cf. 15. BRD, 16. RIV). Sites 5. NPF and 7. MHM which had slightly higher sulphate levels than most of the sites have lower levels of sulphate in March perhaps due to dilution effects.

The levels of bicarbonate were generally lower during the winter (Fig. 4.19) possibly due to decreased rates of root respiration of the vegetation while there was little active growth occurring, as well as dilution caused by the floodwater.

4.5.13. Cluster Analysis

Cluster analysis using Ward's method in the Clustan 1C package (Appendix 2) was performed on the mean values of the chemical measurements of the peats and peat waters of the study sites to examine the overall relationship of chemical composition of the peats and peat waters amongst the study sites.

Cluster analysis of peat variables

A dendrogram displaying the classification of the peats from the study sites is shown in Fig. 4.20. The value of the error sum of squares at which the individuals (sample sites) were fused together indicates their degree of similarity.

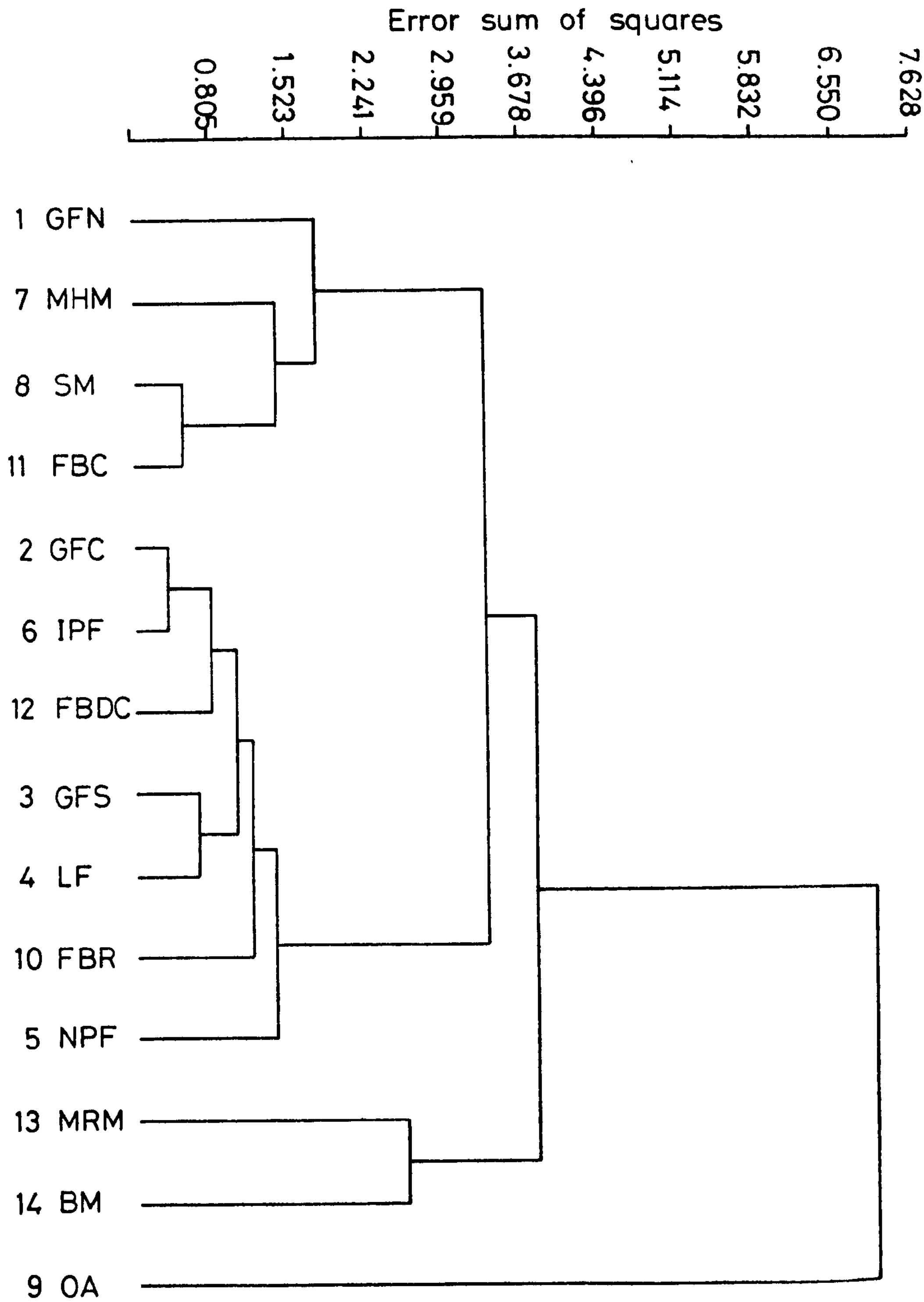


Fig. 4.20. Classification of peats of the study sites using Ward's method, based on the measured chemical attributes.

The sites are segregated into four main clusters, the most isolated of these containing only one site, 9. OA. This site has a very humified peat with high levels of extractable-Ca and digestible-N, P and Fe. The cluster containing sites 13. MRM and 14. BM has low peat pH, low levels of extractable-Ca and Mg and high levels of extractable-K. Sites 1. GFN, 7. MHM, 8. SM and 11. FBC form another cluster with quite high levels of extractable-Ca and Mn and digestible-Fe and Mn. The remaining sites are contained within a cluster which has no particularly distinguishing features and has moderate levels of most of the variables.

Cluster analysis of peat waters sampled on 26.10.79.

Cluster analysis of the peat waters on this sampling occasion generated three main clusters (Fig. 4.21). The sites which had very high levels of sodium, magnesium, sulphate and chloride (5. NPF and 7. MHM) were in one cluster which was fused to the other cluster at a high value of the error sum of squares. The three acidic *Sphagnum* sites form another cluster with low levels of most of the variables measured.

The third main cluster is very large, containing all of the remaining sites, but this has several quite different clusters within it. Four of these are quite different and will be discussed here. Sites 4. LF and 9. OA are the least similar to the other sites within this main cluster and had high levels of calcium, bicarbonate, sodium and chloride. Of all the sites

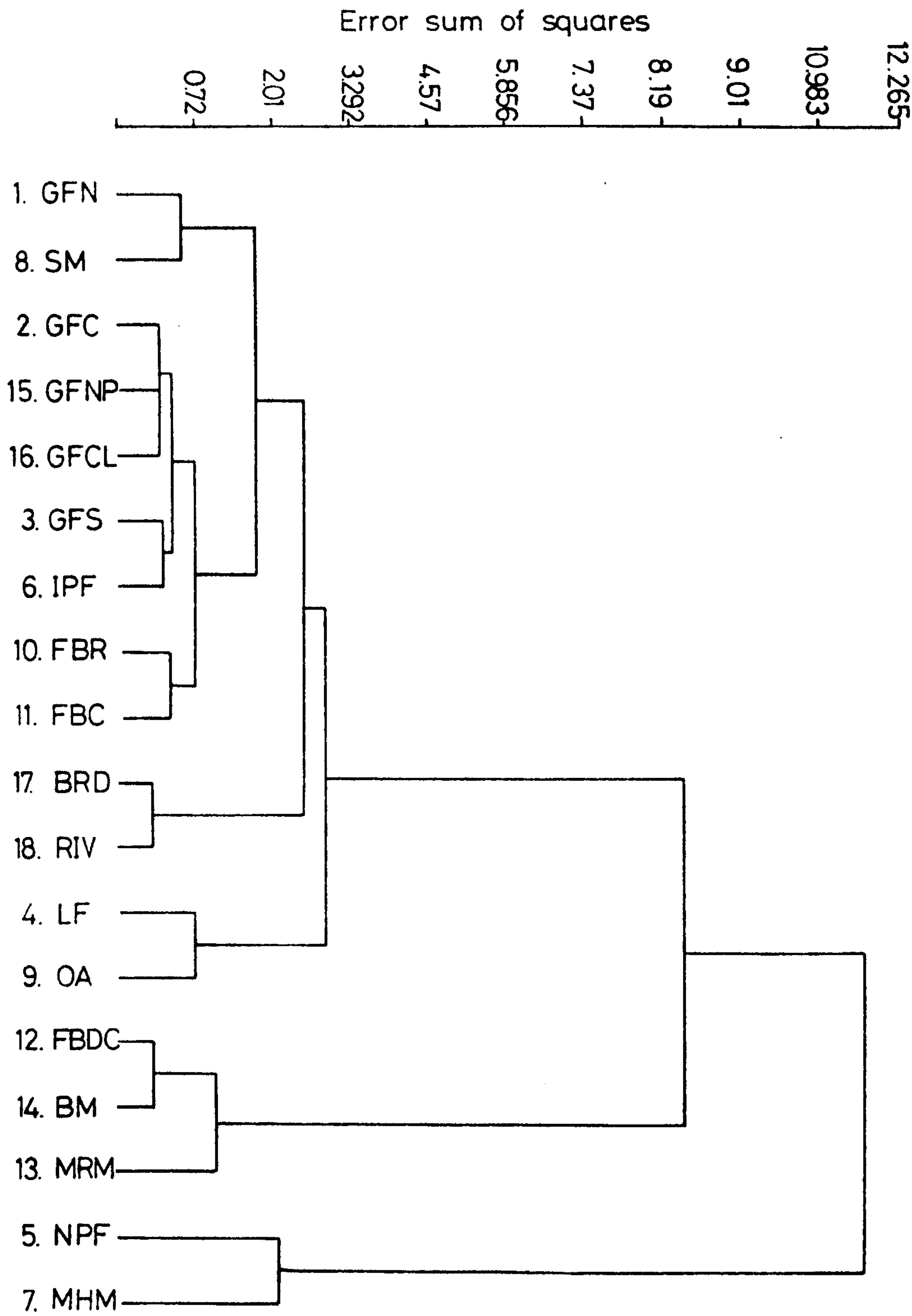


Fig. 4.2 1. Classifications of peat waters of the study sites sampled on 26 October 1979 using Ward's method, based on the measured chemical attributes.

the waters from the Broad (15. BRD) and the River Ant (16. RIV) were the most similar having high pH and low levels of Na and Mg compared to other sites within this main cluster. Sites 1. GFN and 8. SM had quite high levels of Fe and Mn and moderate levels of most other variables. The remaining sites had low levels of Fe and Mn and moderate levels of the other variables.

Cluster analyses of peat water chemical analysis on different sampling occasions.

Cluster analyses performed on chemical variables measured in the peat waters in September 1979 and July and September 1980 segregated the sites on a similar basis to that described above for October 1979. This was not the case for the other sampling times in January, March and May 1980 (e.g. Fig. 4.22). The main difference between the clustering of the sites at these times during the winter and spring period and those during summer and autumn is that the two sites with brackish water influence (sites 5. NPF and 7. MHM) are found in different clusters. The chemical composition of the peat waters from site 7. MHM is more similar to that of other sites with quite humified sedge peats on these occasions. This is due to the lower levels of sodium, magnesium, sulphate and chloride in sites 5. NPF and 7. MHM probably caused by dilution of the peat waters (4.5.12). The relatively high levels of Fe and Mn in site 7. MHM and site 8. SM for instance, are probably more important in the separation of the study sites at these times.

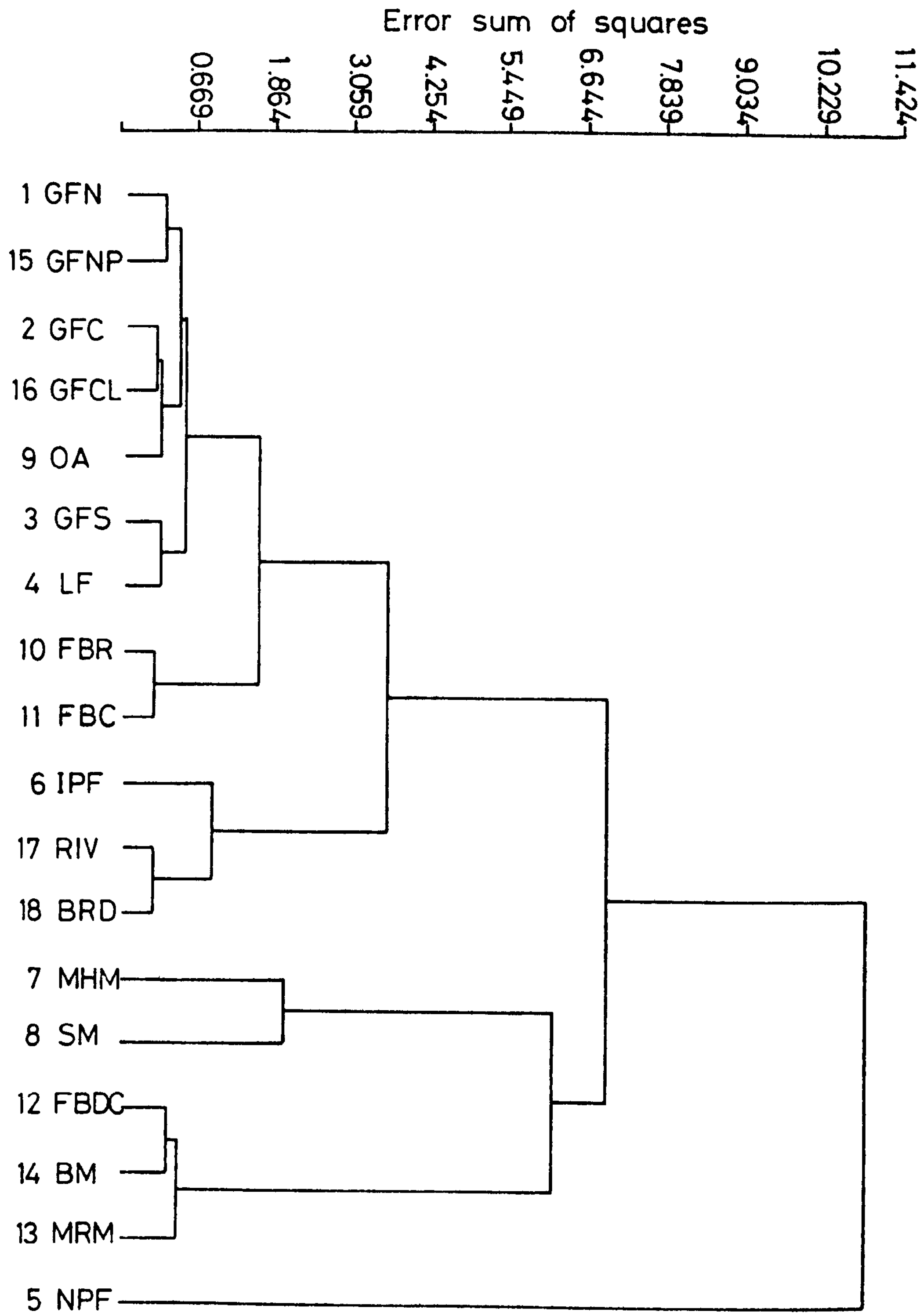


Fig. 4.22. Classification of the peat waters of the study sites sampled on 26 March 1980 using Ward's method, based on the measured chemical attributes.

It seems more informative to consider the chemical differences between sites at times when the influence of dilution by flooding is less, i.e. in summer or autumn when water levels are generally lower.

4.5.14. Discussion

The influence of brackish water

As the distinction between fresh and brackish water is somewhat arbitary (Price and Gunter 1964), the term brackish water will be used here to refer to water directly influenced by the salinity of the sea.

The waters of the Thurne Valley, in particular, those of Horsey Mere, are very saline having mean chloride concentrations in excess of 1000 mg/l (Anglian Water Authority 1975), probably caused by percolating of ground water from the coastal dunes (Pallis 1911b). The River Ant catchment is much further from the coast and unlikely to be influenced directly in such a way.

As early as 1911 there was published data concerning periodic increases in the salinity of the River Ant (Gurney 1911; Innes 1912). These increases in the salinity occurred at times of abnormally high tides, raising the salinity of Barton Broad in one case from normal levels of chloride of about 5 to above 30 grains/gallon ($\simeq$ 70-430 mg l^{-1}) (Innes 1912). Increased levels were still detectable at least eight days after the main increase in salinity (Gurney 1912). The abnormal tides occurred due to normal high tides coupled with strong onshore winds, particularly north-westerlies (Gurney 1912).

The increased levels of chloride measured in Barton Broad and the River Ant in May 1980 were between 360 and 375 mg l^{-1} and may have been higher on previous days as it is not certain that the samples were collected during the maximum extent of the brackish water incursion.

The levels of sodium, magnesium and chloride in sites close to the lower reaches of the River Ant (sites 5. NPF, 7. MHM) reach much higher levels than those detected in the broad or river in the present investigation or by Innes (1912). For instance, chloride concentrations were on some occasions in excess of 1000 mg/l, sodium concentrations above 750 mg/l and magnesium concentrations above 80 mg/l. While it is not impossible that such levels could be reached in the river and broad water during extremely high tides, it seems likely that the very high levels of ions found in the peat waters of these two study sites are due to concentration of the ions within the sites. This could possibly be due to periodic inundation by brackish water followed by increases in the concentration of these ions due to evapotranspirative losses. However, the contribution of other factors to these high levels of some ions was suggested by further studies (5.6.2.). The high levels of sodium and magnesium will replace other cations (e.g. calcium) on the cation exchange sites of the peats, as they are present in such high concentrations in solution.

Site 9. OA is situated very close to the edge of Barton Broad and yet does not have as high concentrations of sodium, magnesium and chloride as sites 5. NPF and 7. MHM., although levels in the broad increased as much as those in the river during May 1980. This study site is situated on more elevated peat and usually has water levels well below the peat surface (4.4.2) and will be more isolated hydrologically from the effects of brackish water which seem to occur in the two sites discussed above. Other sites of the external system are probably isolated from the effects of abnormally high tides by their distance from dykes with a free connection to the broad. Brackish floodwater will be diluted by the water already in the study site and will probably tend to 'pond back' water in the peats, rather than flood across the peat surface, decreasing the effects of the brackish water incursion.

Innes (1912) noted that the salinity of water entering Barton Broad from the upper River Ant was less than that of the water draining from the broad into the lower reaches of the Ant, during normal tidal conditions. He suggested that this was probably due to salt derived from the 'sub-soil' of Barton Broad or due 'to salt left on the reeds by sea fogs'. While neither of these suggestions can be discussed it seems likely that a large proportion of the increased salinity of the lower River Ant which he noted could be due to the gradual leaching of 'salt' from the large area of marshes surrounding Barton Broad.

The relationship between the vegetation and the chemical composition of the peats and peat waters

The *Betulo-Dryopteridetum cristatae* and *Betulo-Myricetum Sphagnum* var. community types, which both contain much *Sphagnum* occur in acidic areas with dilute peat waters. The peats also have low levels of extractable-Ca and Mg in the areas investigated. Such observations are compatible with many analyses from mire systems throughout Europe of the chemistry of *Sphagnum* dominated communities (e.g. Bellamy 1972). These areas contain many species which normally grow in more base-rich peats (e.g. *Juncus subnodulosus, Cladium mariscus*) but these species have their main rooting zone below the superficial *Sphagnum* peat where higher pH and higher levels of most major cations and anions are found (5.6.3.).

Other areas with more characteristic rich-fen and swamp vegetation (c.f. Wheeler 1980a) have higher pH values (> 6.0) and higher levels of most major cations and anions. The areas in which levels of sodium, magnesium, chloride and sulphate were very high (4.5.14) support both *Cladium* and *Phragmites* dominated vegetation. The same is true of areas of flood plain mire around Hickling Broad where levels of sodium and magnesium in the peat waters have been found to be as high as 800 mg/l and 150 mg/l respectively (Wheeler & Giller 1982c). The vegetation of the *Phragmites-Typha angustifolia* community at Site 5. NPF has strong floristic similarities to the vegetation of some *Phragmites* and *Agrostis stolonifera* communities of coastal salt marshes (Adams 1981, in litt.). These areas often have sparse stunted shoots of *Phragmites* but were formerly good reed beds (P. Neave, pers. comm.). Flooding of *Phragmites* beds by sea water can cause severe damage to the reed, the shoots are short and sparsely distributed until the salt is flushed out (Haslam 1968). *Phragmites* can tolerate quite high salinity (Ranwell *et al.* 1964) but inundation of fresh water biotopes by brackish water could cause depauperate reed growth such as that found in the *Phragmites*-*Typha angustifolia* communities of the study area. Such flooding of reedbeds at Wheatfen, Surlingham in the Yare valley caused failure of the reed crop (E.A. Ellis, pers. comm.).

If the growth of *Phragmites* was suppressed it is possible that *Agrostis stolonifera* would be able to grow more vigorously as light penetration would be greater (6.2.). The dense carpets of *A. stolonifera* could then be important in prolonging poor *Phragmites* growth. Dense carpets of litter have been shown to prevent bud initiation in *Phragmites* (Haslam 1972). However, such communities with poor reed growth are found elsewhere where there is little influence of brackish water such as at study sites 3. GFS and 6. IPF and in some areas within the internal system. There is also evidence that conditions in the reed beds were formerly more saline (5.6.5.).

The suggestion that poor growth of *Phragmites* may be caused by very reducing conditions in the substrate has been investigated (Boorman & Fuller 1981). To examine whether the conditions in the peat were particularly unfavourable for reed growth in the *Phragmites-Typha angustifolia* communities measurements of redox potential and sulphide concentration were made in a small area within Neatishead Poor's Fen (5 a) NPF) where *Phragmites* growth was more vigorous than in the main study site (5. NPF). The levels of redox potential and sulphide concentration were very similar in these two areas (4.5.8., 4.5.9) and not unusual when compared with measurements in the other study sites (e.g. 2. GFC). As concluded by Boorman and Fuller (1981) the presence of very reducing conditions does not directly seem to be causing poor *Phragmites* growth.

The *Peucedano-Phragmitetum cicutetosum* study site (3. GFS) has many more associated species (Table 2.2) than the other study sites with poor reed growth (sites 5. NPF and 6. IPF). The chemical composition of the peats and peat waters at this site was very similar to that of the *Phragmites-Typha angustifolia* study site in Irstead Poor's Fen (6. IPF) (3.5.12) and it appears that other factors must be important in determining the differences in vegetation between these sites. Similarly the *Cicuto-Phragmitetum* study site (10. FBR) did not differ markedly in overall chemical composition from other *Phragmites* dominated study sites (3. GFS, 5. IPF) and yet was quite floristically rich and supported good reed growth.

A quite interesting comparison is that between the two swamp community study sites 10. FBR and 11. FBC. The former is *Phragmites* dominated and the latter dominated by *Cladium* with virtually no *Phragmites*. The sites are situated on opposite sides of Fenside Inner Broad only 40 m apart. These two sites have quite similar chemical composition of the peat waters, although the chemical characteristics of the peats varied. The *Phragmites* dominated site (10. FBR) had slightly higher levels of extractable nitrogen and digestible nitrogen and phosphorus and the *Cladietum marisci* site (11. FBC) had higher levels of extractable calcium and manganese and digestible iron and manganese. It seems likely that these differences may be at least partly due to the differing macrofossil composition of the peat (3.5.14). The differences in the chemical composition of the peat do not seem great enough to determine such large differences in the composition of the vegetation.

The *Peucedano-Phragmitetum-schoenetosum* study sites (7. MHM and 8. SM) had some similarities in chemical composition of the peats and peat waters. Both of these study sites had relatively high levels of all measured fractions of iron and manganese. Site 7. MHM had much higher levels of sodium and magnesium, for instance, probably due to the effects of brackish water incursions which did not seem to cause much difference between the vegetation of these two *Peucedano-Phragmitetum schoenetosum* sites. Expressions of this community type often contain much *Molinia caerulea*. This is probably related to the low summer water levels causing higher redox potentials in these areas and corresponding low sulphide concentrations allowing growth of this species (4.4.2., 4.5.8., 4.5.9).

The *Peucedano-Phragmitetum caricetosum* site 1. GFN also has many of the chemical characteristics of the *schoenetosum* subassociation mentioned above and also contains much *Molinia caerulea*. This site seems to have many similarities in the chemical composition of the peats and peat waters to site 8. SM (4.5.13). The wetter *caricetosum* study site (2. GFC) does not have high levels of dissolved and extractable iron or manganese and had high sulphide concentrations and correspondingly low redox potential below the peat surface. Site 2. GFC has much higher water levels than site 1. GFN (4.4.2) but has quite similar floristic composition, except for the occurrence of swamp and aquatic species and the lack of *Molinia caerulea* in site 2. GFC. While the chemical composition of these two sites does differ in some ways as mentioned above the two sites do have quite similar levels of the major cations and anions, nitrogen and phosphorus. The two subsites 1 a) GFNP and 2 a) GFCL of the *caricetosum* study sites which represent particularly floristically rich areas do not seem to differ significantly from the corresponding study site in the chemical composition of the peat waters.

The *Osmundo-Alnetum glutinosae* site (9. OA) had a much more humified peat than the other sites examined and correspondingly high levels of many chemical constituents in the peat. *Phalaris arundinacea*, a species suggested as a good indicator of fertility (Pringle & van Ryswyk 1965) occurs here as does *Urtica dioica*, a nutrient demanding species. There are correspondingly relatively high levels of extractable nitrogen and phosphorus in the peat. The *Peucedano-Phragmitetum typicum* study site (4. LF) also had relatively high levels of extractable phosphorus and nitrogen and was dominated by *Juncus subnodulosus*. This study site had high levels of calcium in the peat waters and contained many species also found in other *Peucedano-Phragmitetum* subassociations (e.g *Epipactis palustris, Sium latifolium*).

Generally although some correlations can be made between the community types and the chemical composition of the peats and peat waters no adequate explanation of the differences in the vegetation of the high pH fen sites is provided. Definite conclusions about the differences in chemical composition between community types cannot be drawn when considering so few examples. Wheeler and Giller (1982c) examined the peat water chemistry of many more areas throughout the Broadland flood plain mires. This work tended to support those differences between community types found in these analyses.

4.5.15. Conclusions

The main factors which determine the differences in chemical composition of the peats and peat waters of the study area.

The differences in the hydrology of the study sites seem to have an over-riding influence on the peat and peat water chemical composition of the study sites examined. The influence of hydrology operates in two main ways, by influencing the quality of water entering the sites and through the different extent of lowering of the water levels affecting the oxidation and humification of the peat.

1) Vertical hydrological isolation

The height of the peat surface relative to prevailing water levels affects the susceptibility of the study sites to flooding (4.4.2.). This has allowed acidic, oligotrophic conditions to develop in areas now dominated by *Sphagnum* (4.5.1., 4.5.7). The height of the peat surface in the alder carr site (9. OA) adjacent to Barton Broad seemed to provide some isolation from the possible effects of brackish water. This was also true of site 7. MHM which is situated very close to the River Ant, but to a lesser extent (4.5.12).

2) Spatial hydrological isolation

The spatial distribution of the study sites influences the levels of many chemical variables measured within the peats and peat waters of the sites. This occurs by influencing the quality of the water which floods into the sites and is most obvious in relation to the influence of brackish water (4.5.12).

3) Dilution during times of high water

The levels of many ions in the peat waters were much lower during times of high water (4.5.12).

4) Water levels below the peat surface

Water levels below the peat surface allow more oxidising conditions to develop in the peat (4.5.10). This results in greater degrees of humification of the peat which influences the amount of exchangeable and digestible fractions of chemical constituents within the peat. This is most evident in relation to the very humified nature of the peat in the alder carr site (9. OA) e.g. 3.5.3., 3.5.4). The occurrence of more oxidising conditions in the peat will also influence the chemical state of some chemical constituents. For example, bacterial transformations will affect the form and amount of the extractable nitrogen (4.5.4) and the forms of sulphur compounds (4.5.11) and the degree of oxidation will influence the solubility of iron and manganese (4.5.6).

5) Other factors

The macrofossil composition of the peat appears to be important in causing differences in the level of various constituents in the peat (4.5.6.) and also the proportions of constituents in dissolved or extractable form (4.5.7). Clays underlying the surface peat also seem to have some effects on levels of chemical variables (4.5.7). The levels of potassium in the peat waters appear to be more influenced by leaching from senescent vegetation and uptake by the vegetation during times of active growth (4.5.12).

Some correlations between the vegetation and the peat and peat water chemistry of the study sites can be made but an adequate explanation for the distribution and variation in the vegetation is not provided by the chemical factors measured.

CHAPTER 5

FURTHER INVESTIGATIONS OF THE RELATIONSHIP BETWEEN THE VEGETATION AND THE CHEMISTRY OF THE PEATS AND PEAT WATERS

5.1. INTRODUCTION

Included in this chapter are a number of separate investigations in various parts of the study area.

These investigations were designed to examine the relationship between the levels of chemical consituents of the peats and peat waters in the fens with levels found in the waters of the dyke system and the River Ant, the chemical stratification of the peat waters and detailed small scale variations in surface peat and peat water chemistry. Investigations of chemical stratification were restricted to an examination of the peat waters as the upper 80 cm of peat could not easily be sampled in many areas.

5.2. METHODS

In order to examine the chemical stratification of the peat waters, water samples were taken at 10 cm intervals up to 150 cm below the peat surface. The samples were taken with a sampling device which was a modification of a design of Dr G van Wirdum[1] (Appendix 2). Small samples of water (≃ 60 ml) were taken at increasing depths to limit mixing of the peat waters to a minimum. Preliminary analyses indicated that the surface peat waters were much more dilute than those within the peat and so the sampler was rinsed with surface water between the

1. Research Institute for Nature Management, Kasteel Broekhuizen, Leersum, The Netherlands.

collection of successive samples. Samples of surface peat waters for chemical analysis were taken from shallow holes dug into the peat (≃ 20 cm deep) unless otherwise stated and peat samples were taken from 10-20 cm below the peat surface. Analytical methods are given in Appendix 2.

Transects were levelled at a time of high water levels (3.2). Vegetation recording was on the basis of shoot frequency percentage occurrence in 25 sub-divisions of a 50 x 50 cm quadrat. In many cases the sampling sites are the same as those described in Table 4.1. The relative heights of the peat surface are indicated by the relative height of the peat and chemical profiles in subsequent figures to allow comparison of cation levels at corresponding heights.

5.3. THE INFLUENCE OF FLOODING BY RIVER WATER ON THE CHEMISTRY OF THE FENS.

5.3.1. Analysis of nitrogen and phosphorus in surface waters

A series of water samples was collected along the transect described below (5.3.2) on 2 February 1979. The water level at this time was well above the peat surface in most areas of the fen and samples were taken from the standing water. The levels of ammonium-nitrogen (NH_4-N), nitrate and nitrite nitrogen ((NO_2+NO_3)-N) and soluble reactive phosphorus (PO_4-P) in the water samples were analysed to see if there was any evidence of eutrophication of the fens by water from Barton Broad. The results are summarised in Table 5.1.

Table 5.1. Mean levels of pH and dissolved-N and P of surface water samples (2 February 1979) n.d. = not detectable.

	pH	PO_4-P	(NO_2+NO_3)-N	(mg/1)
Barton Broad	6.8	0.025	0.91	
Hundred Stream	6.8	0.042	1.12	
Osmundo-Alnetum	6.8	0.052	0.9	
Salix-carr	6.7	0.044	n.d.	
Cladietum	6.65	0.045	n.d.	
P.-P. caricetosum	6.6	0.026	n.d.	
P.-P. schoenetosum	6.25	0.017	n.d.	

No NH_4-N was detectable in any of the samples and (NO_2+NO_3)-N was detectable (> 0.02 mg l^{-1}) only in samples from Barton Broad, the Hundred Stream and the *Osmundo-Alnetum* community adjacent to the Hundred Stream. The very low levels of nitrogen found in the surface waters from all other areas are possibly due to dilution, denitrification and absorption by the underlying peat. The level of PO_4-P was low in all of the samples (< 0.07 mg l^{-1}). Higher levels of PO_4-P were found in the waters overlying the marshes than in the water from Barton Broad, except in the *Peucedano-Phragmitetum caricetosum* community of Great Fen and the *P.-P. schoenetosum* community of Sedge Marshes. The higher levels found in the waters overlying the marshes may be due to release of phosphorus from the peats.

5.3.2. Analysis of chemical variables along a transect from Barton Broad to Great Fen

Peat water samples were collected from sampling tubes (4.3.) and peat samples from 10-20 cm below the peat surface on 29 April 1979. At this time the water level was roughly 5-10 cm below the peat surface in most parts of the transect (which was close to transect F-G, Fig. 3.1) except between 0 and 100 m.

Levels of nitrogen and phosphorus (Fig. 5.1) in the peat waters were very low, in fact undetectable in many samples from areas furthest from the broad. There were high levels of nitrogen in two water samples (135 m, 175 m) which may represent contamination of the samples. Detectable levels of nitrogen and phosphorus were found in all of the peat extracts. Almost all of the nitrogen present was in the form of NH_4-N presumably due to the quite high water levels creating reducing conditions in the peat.

Levels of nitrogen and phosphorus in peat extracts were consistently high in the *Osmundo-Alnetum* and *Salix* carr communities as were levels of dissolved and extractable calcium, magnesium and sodium (Fig. 5.2., 5.3.). This is probably a reflection of the humified nature of the peats beneath these communities combined with the effects of periodic inundation by water from the broad. Levels of dissolved and extractable phosphorus were high in the *Peucedano-Phragmitetum typicum*

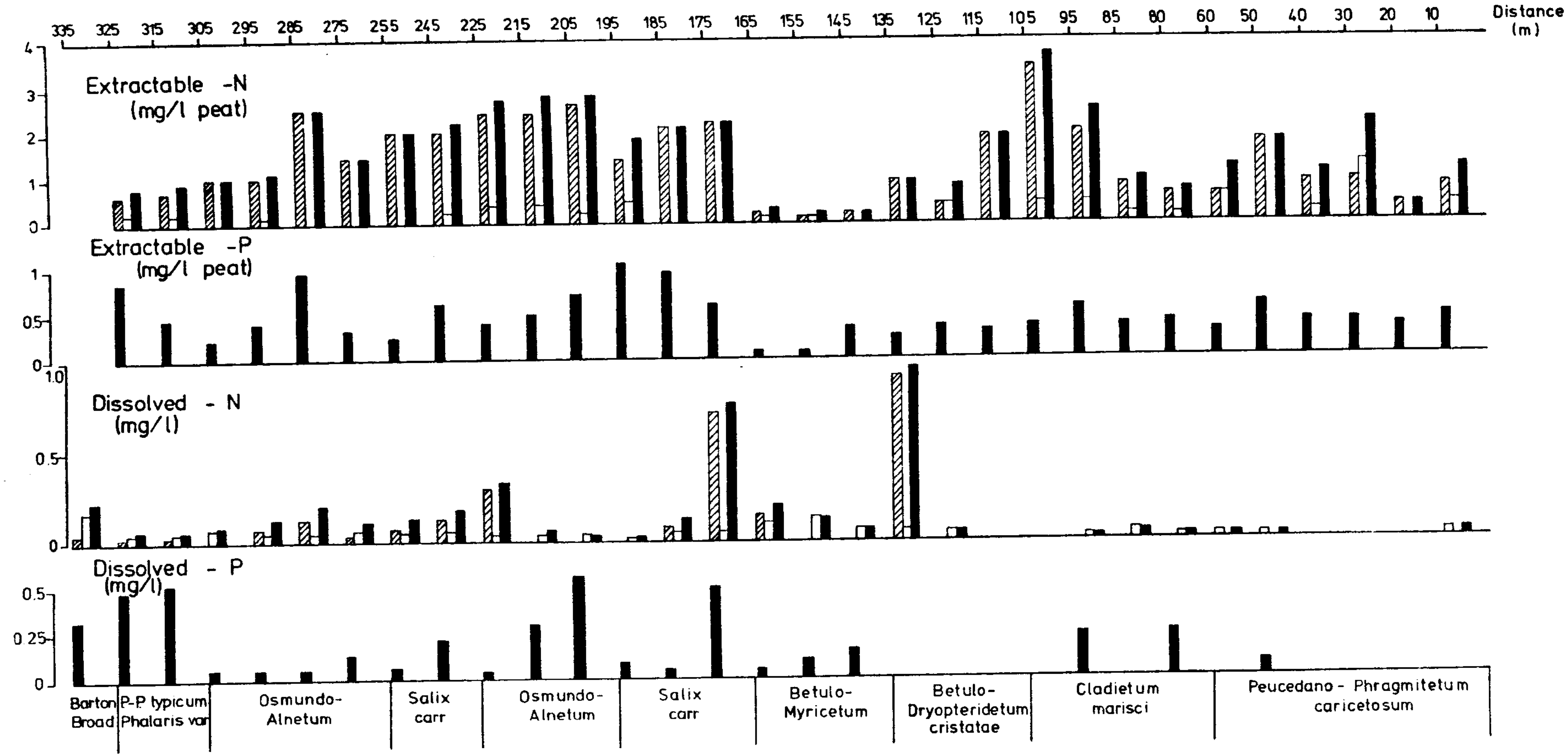


Fig. 5.1. Concentrations of nitrogen and phosphorus in peats and peat waters along a transect from Great Fen to Barton Broad (NH_4-N, ▨ ; (NO_2+NO_3)-N, □ ; $(NH_4+NO_2+NO_3)$-N, ■).

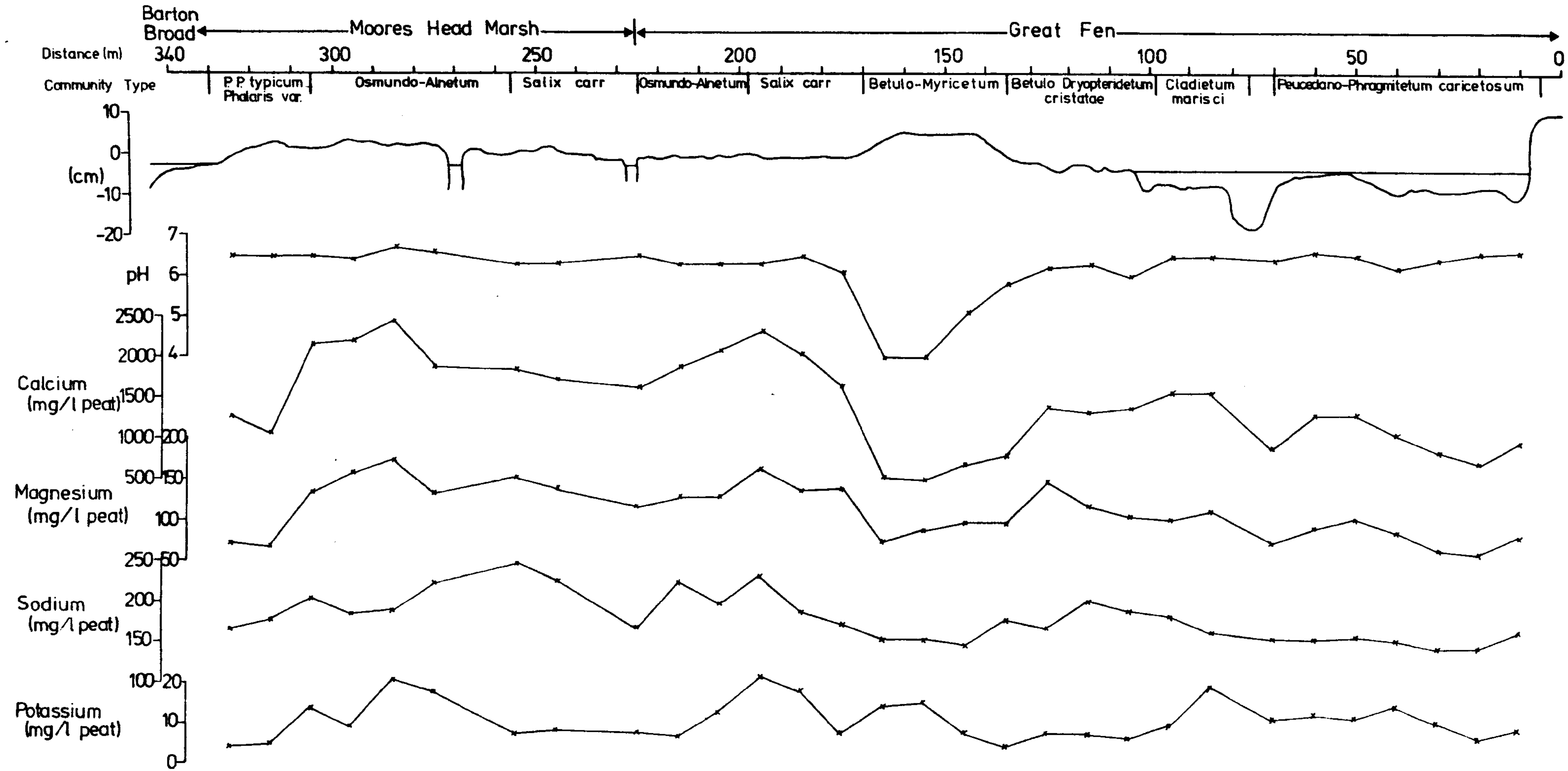


Fig. 5.2. Levels of pH and major cations in the peats along a transect from Great Fen to Barton Broad.

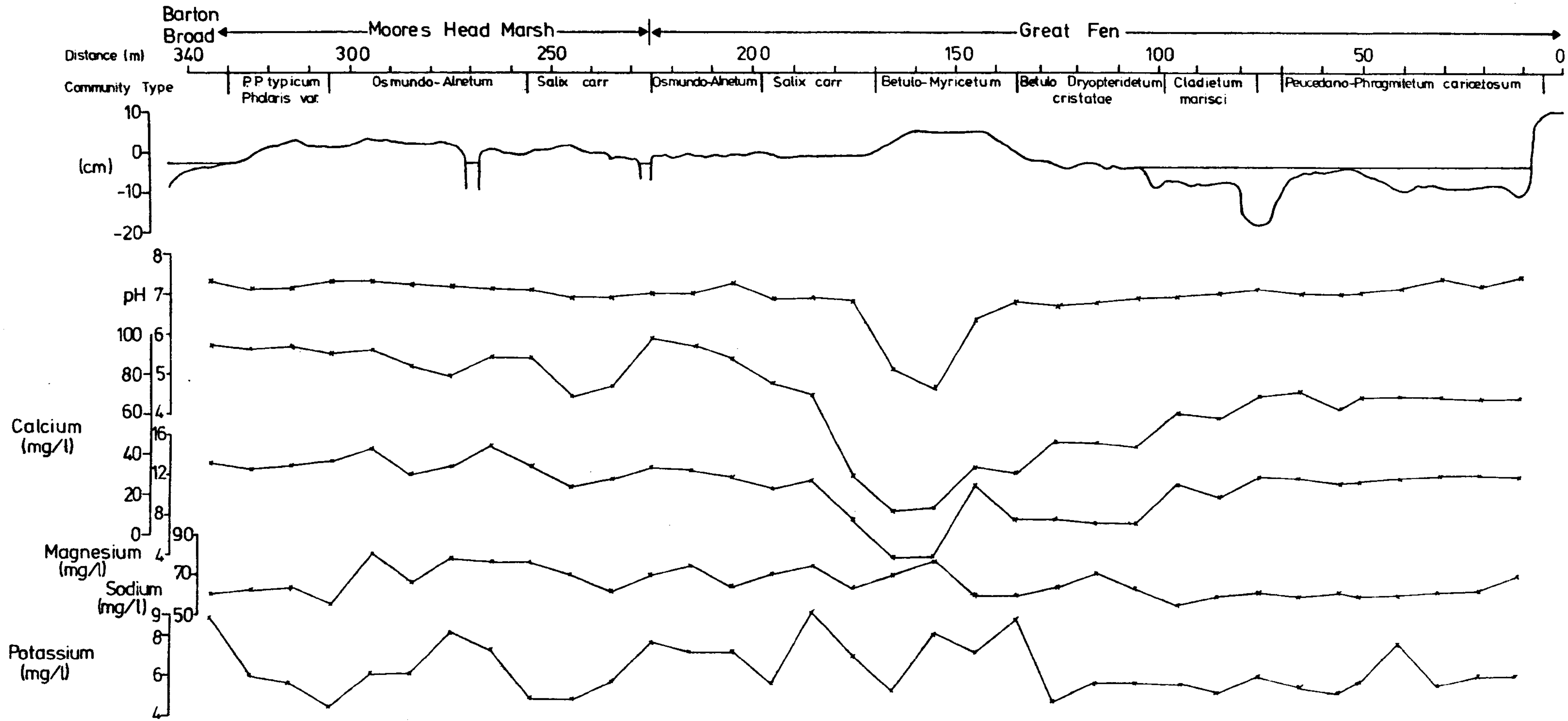


Fig. 5.3. Levels of pH and major cations in peat waters along a transect from Great Fen to Barton Broad.

Phalaris var. community indicating some enrichment by broad water. Levels of major cations in the peat waters were similar in the *Phalaris* var. to those in the adjacent carr communities, but levels of extractable calcium and magnesium were lower, probably due to the less humified nature of the peat in this herbaceous fen community.

The levels of most variables measured were lower in the peat and peat waters beneath the *Betulo-Myricetum* community than in other areas. There is quite a deep *Sphagnum* peat underlying this community and it is likely that the isolation of the area from inundation (4.4.2) together with the acidifying effects of *Sphagnum* spp. (Clymo 1964) have led to the low pH and low levels of cations found in the peat. The *Betulo-Dryopteridetum cristatae* community which has a shallow surface layer of *Sphagnum* peat (Fig. 3.5) had levels of most variables which were intermediate between those of the *Betulo-Myricetum* community and the open herbaceous communities of Great Fen.

Generally the herbaceous communities of Great Fen had lower levels of most chemical constituents than those found beneath the fen carr communities in areas of high pH, perhaps due to their comparative isolation from floodwater from the broad coupled with the less humified nature of the peat. Levels of potassium and sodium were higher if more variable beneath the fen carr communities than in the herbaceous communities. The quite high levels of nitrogen and phosphorus found in the *Cladietum marisci* community compared to those in the *Peucedano-Phragmitetum caricetosum* community may be due to the close proximity of the *Cladietum* to a duck-decoy.

5.4. CATION LEVELS IN THE DYKES AND FENS

5.4.1. Levels of cations in waters from the dykes

Inputs of ground drainage water to the study area are likely to occur mainly via the dyke system and directly from Barton Broad and the River Ant (4.4.1). To examine the major cation levels of the dyke waters in relation to the study sites 140 samples of dyke water were collected on 16-17 August 1981 and analysed for pH, Ca, Mg, Na and K. Some surface water samples were also collected from the marshes to allow a comparison with levels in the dykes. At this time water levels in the dyke system were relatively low (4.4.1).

Levels of calcium, magnesium and potassium (Figs. 5.4., 5.5., 5.7) were high in the north-eastern corner of the study area where land drainage water enters the dyke system. Lower levels were found towards the more central parts of the internal system, especially around Sedge Marshes. Levels of sodium seemed to show a reverse trend, being higher in the more central areas of the internal system. Very high levels of calcium were found around Mill Dyke Marsh. This marsh is close to the former course of the River Ant, and the higher levels are probably due to the influence of underlying clays (3.4).

In the external system levels of all the major cations were generally higher in the more central areas, being lower where the dykes are close to the River Ant and Barton Broad. Levels are also relatively low in the dyke at the southern margin of Great Fen (North) which carries water draining through the sluice from the internal dyke system.

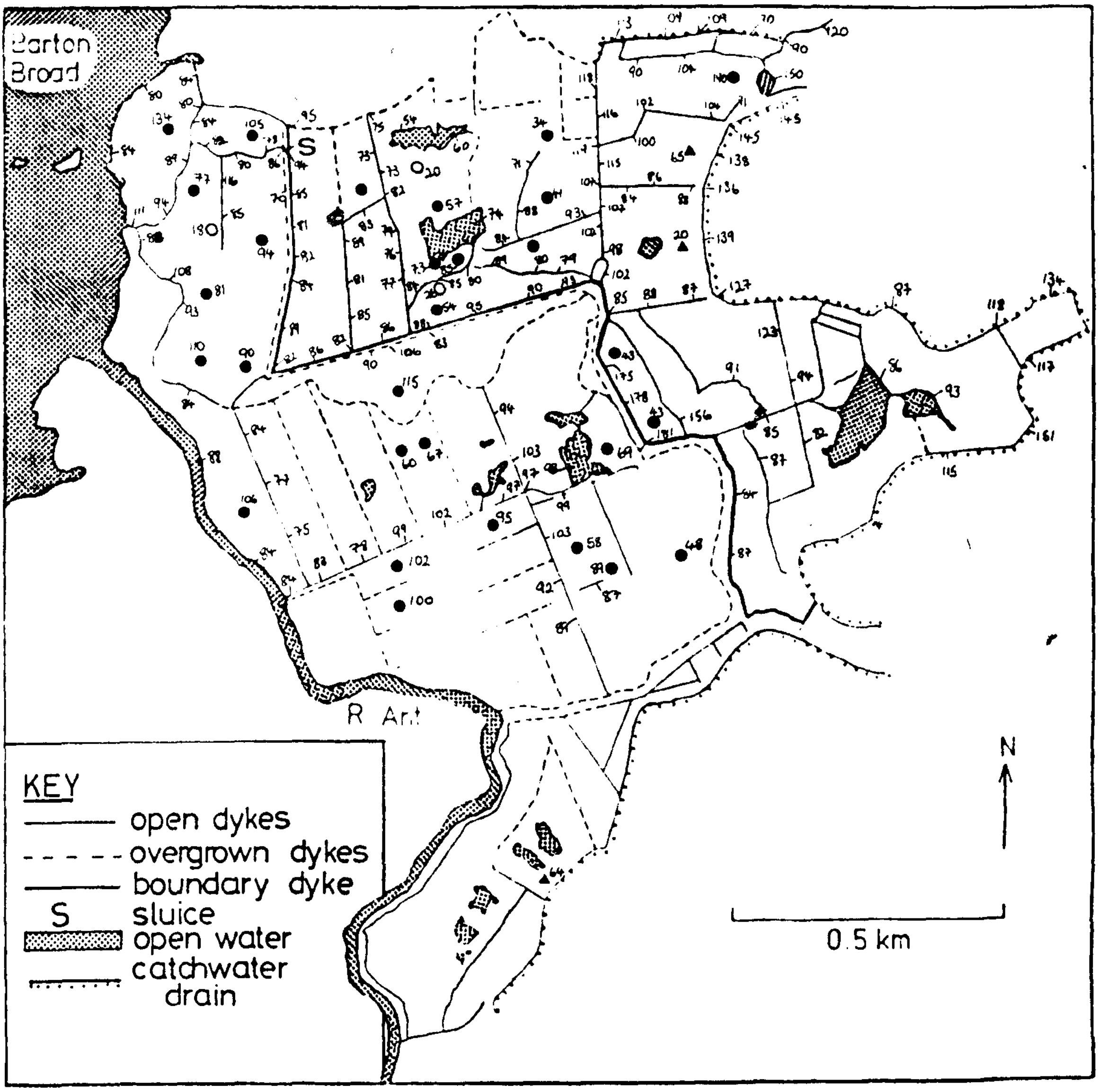


Fig. 5.4. Calcium concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (○) and other fen (●) communities.

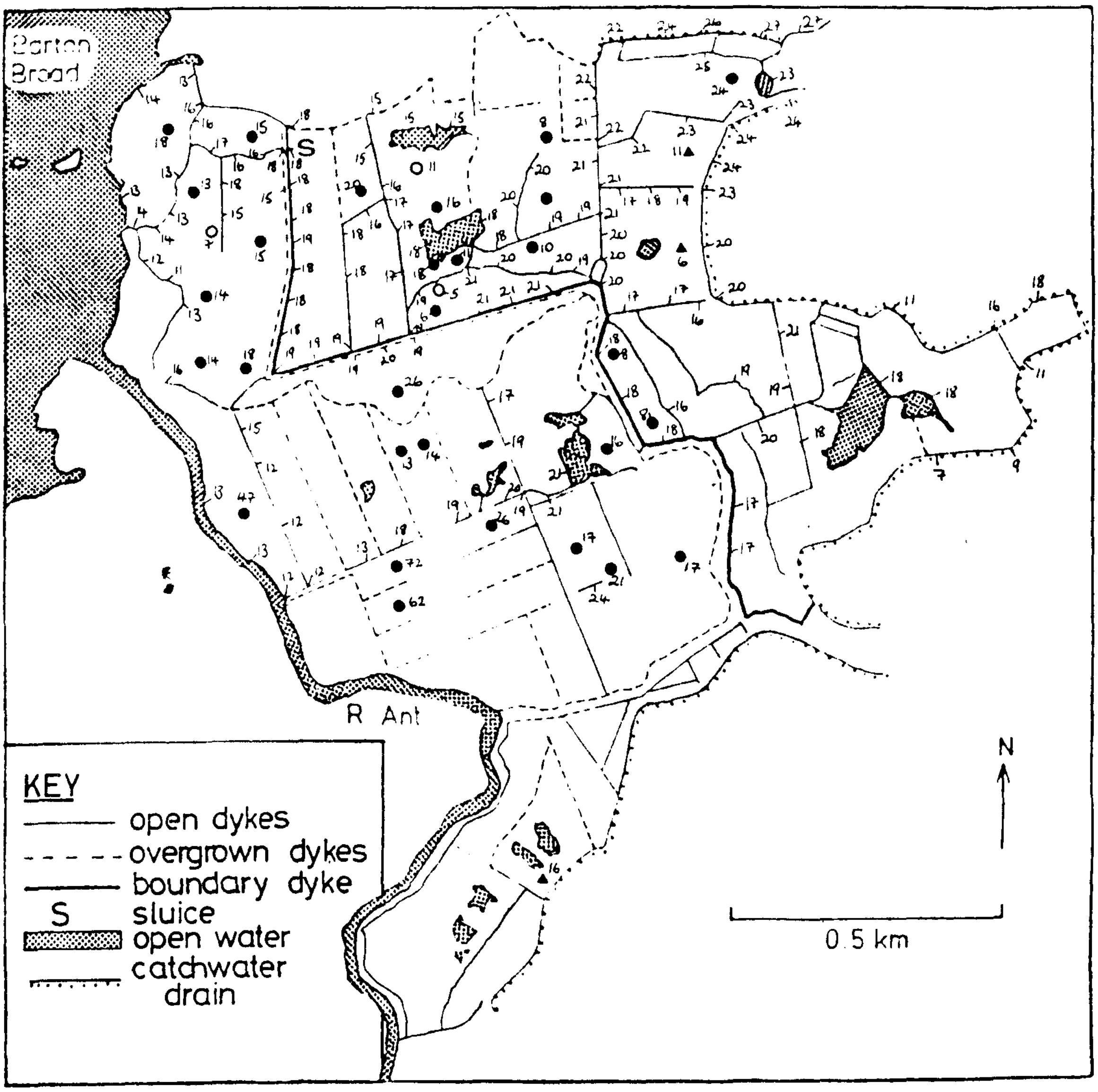


Fig. 5.5. Magnesium concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (O) and other fen (●) communities.

5.4.2. The sources of the major cations in relation to the fens

The main sources of the major cations in the study area will be from precipitation and ground water drainage into the system. The concentrations of the major cations in rainfall are usually very low (Gorham 1957) and it therefore seems likely that ground water is the main source of the cations. There may also be some input from wind blown material especially of lime or agricultural fertilizers from the adjacent arable land.

The concentrations of the major cations in the River Ant system will normally be dependent on the geology of the catchment area together with some addition from agricultural runoff, except in the case of abnormally high tides. The upper reaches of the River Ant drain areas of chalky boulder clays which will contribute to the quite high concentrations of calcium found in the river and broad water (≃ 100 mg/l).

The internal system rarely receives water input from the external system at the present time and the main source of the major cations is likely to be directly from land drainage water. The catchment area of the internal dyke system is underlain by Norwich Brickearth, an acidic substratum (1.4). The high levels of calcium, magnesium and potassium found in the waters draining into the internal system are probably derived principally from agricultural fertilization (most of the surrounding land is used for arable farming).

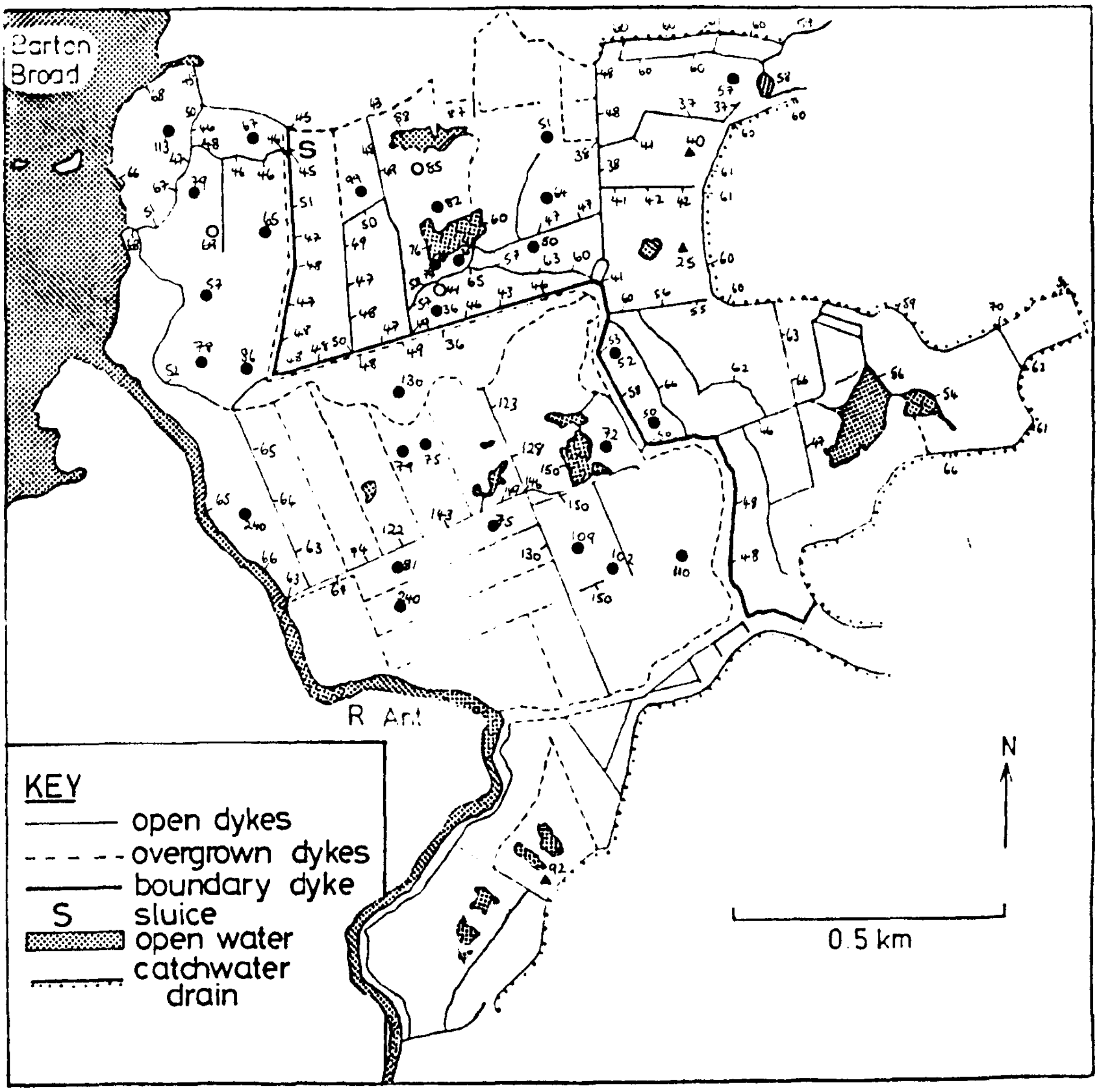


Fig. 5.6. Sodium concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (O) and other fen (●) communities.

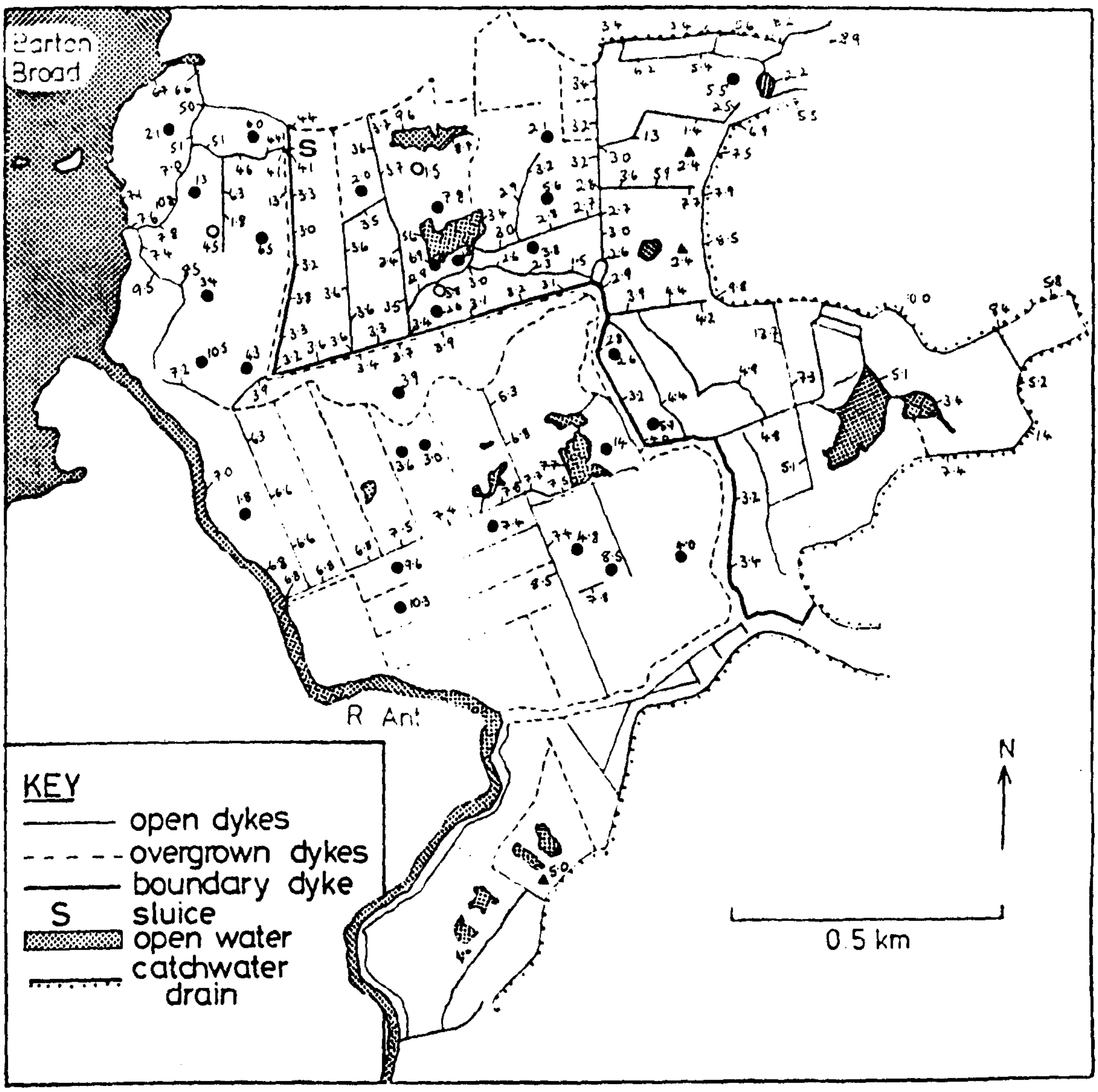


Fig. 5.7. Potassium concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (O) and other fen (●) communities.

Levels of calcium, magnesium and potassium were generally lower towards the central areas of the internal dyke system. This is presumably due both to dilution of the inflowing drainage waters by direct precipitation and to absorption of the cations by the peat and vegetation.

Levels of all the major cations in the dyke waters were higher in the central area of the external system around Irstead Poor's Fen, where they are above those prevailing in the broad and river. These high levels are probably due to the distance of the dykes from the river causing lower rates of flushing of the cations whose concentrations had been previously raised by incursions of brackish water. In areas closer to the river, mixing of the water in the dykes with that in the river will occur with the result of lowering the levels of cations in the dykes. Several samples from the dykes around Moores Head Marsh and Great Fen had higher levels of all the cations measured. These however, were taken from dykes with very shallow water (< 10 cm deep) where little mixing of the water with other areas can occur allowing very localised conditions to become established.

The levels of cations in the dyke waters at this time do not reflect the levels found in the surface peat waters from the fens in all cases. The levels in the dyke waters at times when the peat surface is flooded will probably have greater influence on the levels of cations in the peat waters. This is especially true in the case of brackish water influence (4.5.14). The levels of cations in the peat waters will also be affected by the amount held in exchangeable form in the peats within each study site which will probably depend to some extent on conditions which prevailed at previous times (e.g. the possible influence of estuarine clay in site 4. LF), as well as on the humification and macrofossil composition of the peat (4.5.8).

Some correlations between levels of cations in the dyke water surrounding the study sites and those of the peat waters can be made. The dykes of the central area of the internal system had relatively low concentrations of calcium, which were reflected by the quite low levels found in the surface waters from the fens. Levels of calcium were low in areas of fen isolated from the dykes, for instance in Middle Marsh and parts of Irstead Poor's Fen. Sodium and magnesium levels were generally higher in the surface waters of the fens of the external system except in some areas isolated from the dykes or near the sluice where flushing of these ions by water drainigg from the internal system may occur. Levels of sodium in the peat waters were particularly low in the marshes near to the north-eastern corner of the internal system.

Levels of potassium were generally higher in the dyke waters of the external system than in the internal system but this is not reflected in the levels in the surface waters from the fens which were in general similar. The levels of sodium and potassium were quite high in Fenside Outer Broad. This is probably related to a septic tank overflow from nearby cottages (Wheeler & Giller 1982b) and may contribute to the quite high levels of potassium found in study site 11. FBC (4.5.7).

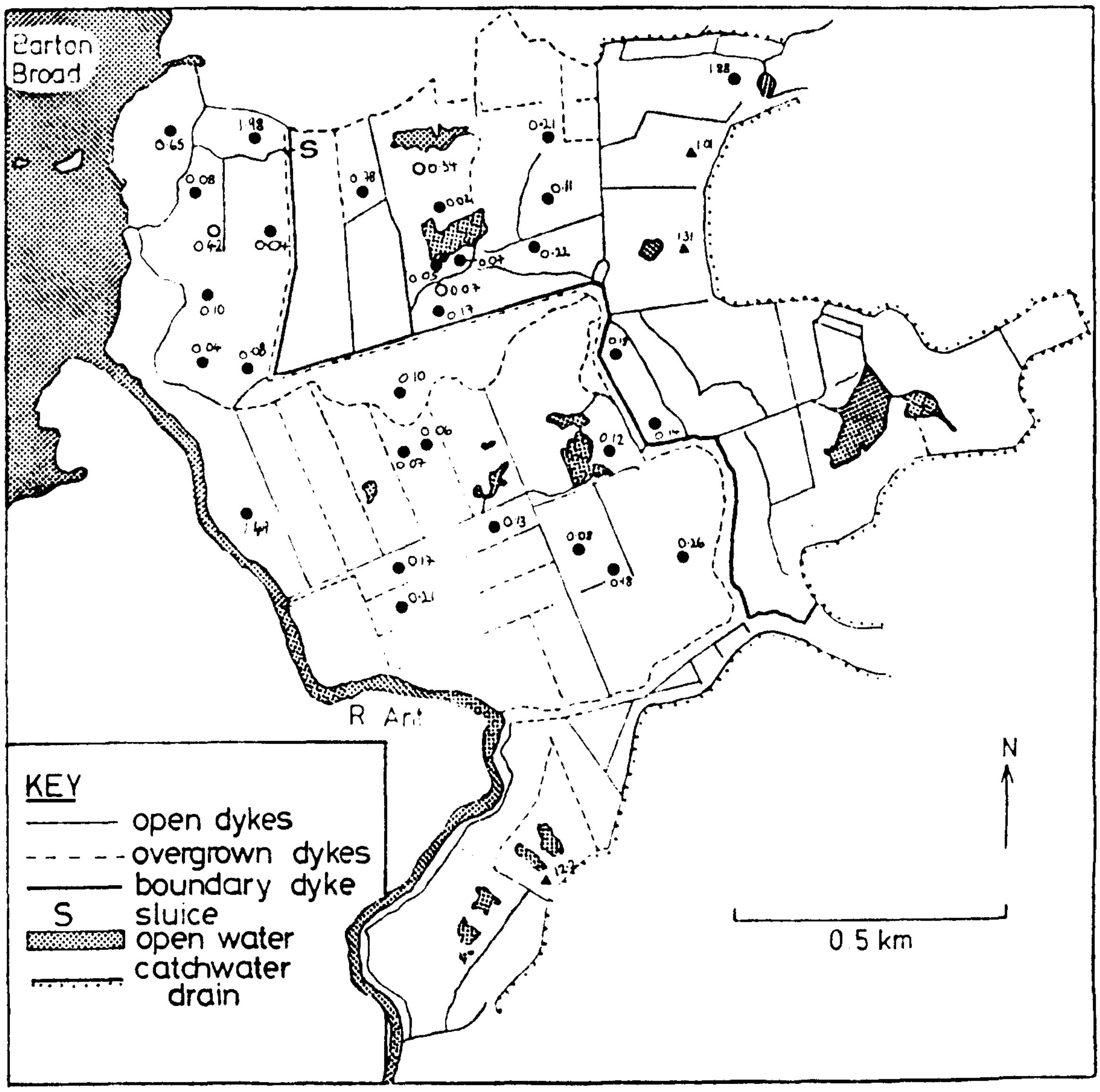


Fig. 5.8. Iron concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (○), and other fen (●) communities.

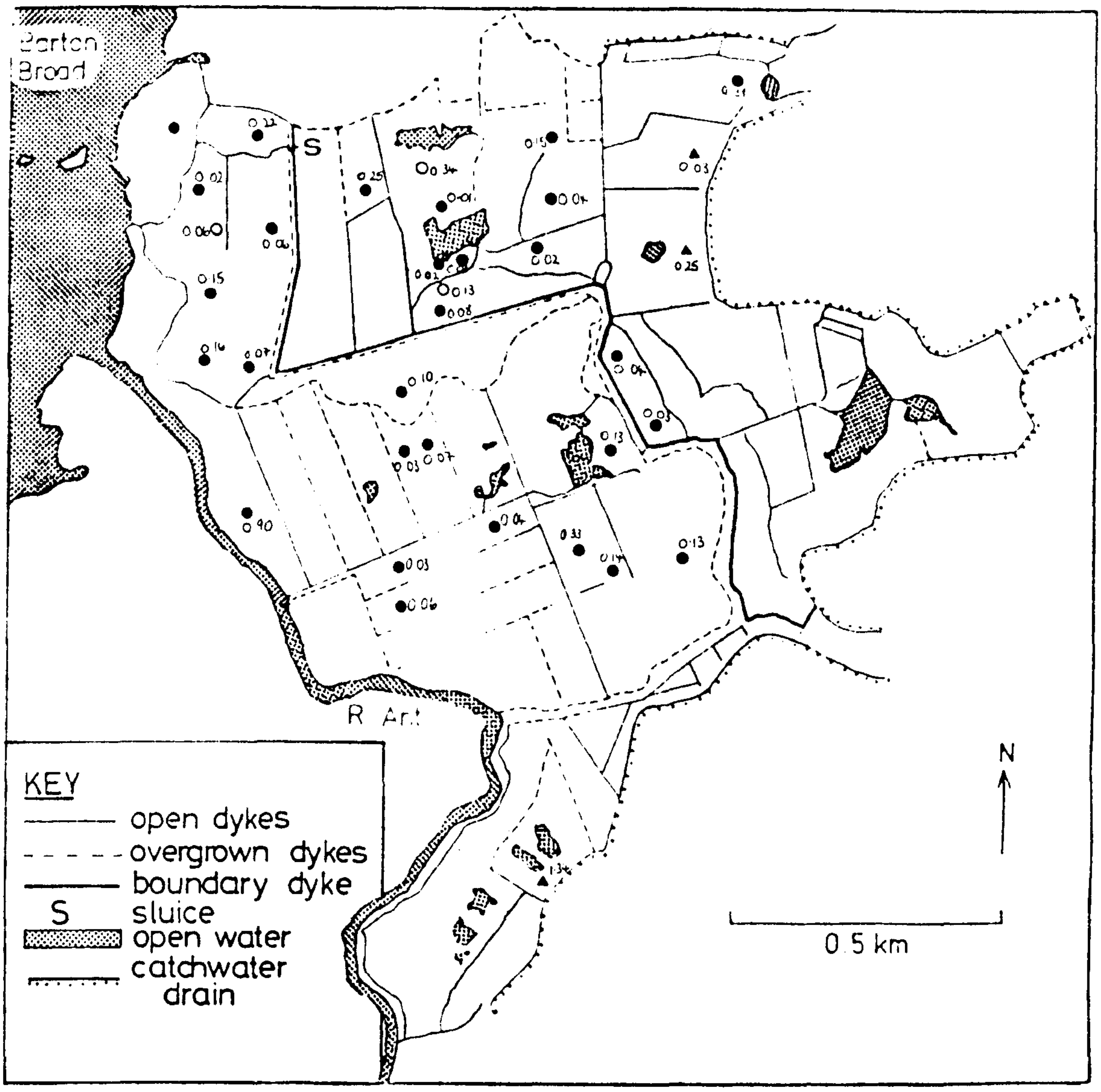


Fig. 5.9. Manganese concentrations (mg/l) in dyke waters and surface peat waters from *Potentillo-Caricetum* (▲), *Sphagnum* (O) and other fen (●) communities.

Levels of iron and mangnese were very low in all the dyke waters (< 0.10 mg/l). High levels of these cations are found in marginal areas of the fens probably due to the influence of the mineral subsoil where the peats are more shallow.

5.5. FURTHER STUDIES IN SELECTED COMMUNITIES

5.5.1. Investigations in Great Fen

Chemical stratification of the peat waters

The results of analyses of peat waters collected on 5 July 1981 in sites 1. GFN, 2. GFC and 3. GFS are shown in Fig. 5.10. Surface water samples had low levels of calcium, magnesium and sodium. This was also the case in many other sites examined. In site 1. GFN levels of all of the cations measured decreased in the lower samples (depth > 80 cm) while in site 3. GFS levels were much higher, if more variable, with increasing depth below the surface. The higher levels of cations in the lower depths of site 3. GFS correspond to the horizons in which the *Phragmites*/clay was found and it seems likely that this clay which was probably laid down during the Romano-British marine transgression (3.4) is the main source of these high concentrations. Sites 1. GFN and 2. GFC were not underlain by *Phragmites*/clay and do not have increasing cation levels with depth. Levels of potassium were consistently quite high in site 2. GFC and levels of all of the cations were very constant at depths below 20 cm. The reason for these constant levels is not clear, but could be related to better mixing possibly due to higher rates of vertical or horizontal water movement. No direct evidence for such water

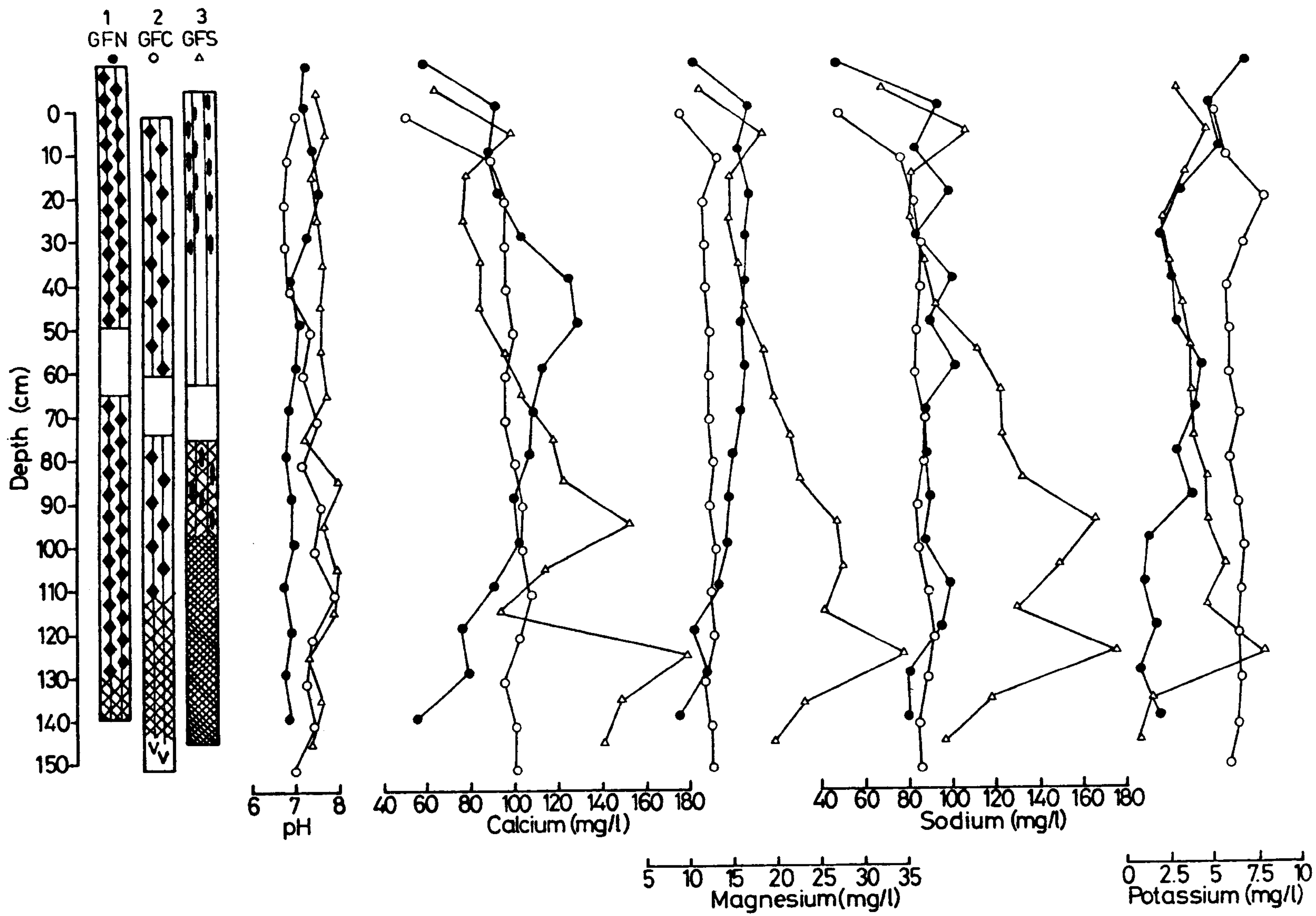


Fig. 5.10. Chemical analyses of peat waters from the upper 150 cm of peat in some study sites in Great Fen. A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

movement has been found (4.4.4).

The results of chemical analyses of peat waters at different depths in the *Betulo-Myricetum Sphagnum* var. community of central Great Fen (site 14. BM) are shown in Fig. 5.11. Unfortunately pH readings were not taken on these samples. Levels of all the major cations were quite constant at depths of 80 cm or more. Above this horizon the concentrations of calcium and magnesium decreased markedly in the *Sphagnum* peat. The concentrations of sodium were lower only within the surface 20 cm of peat, while the level of potassium increased in the surface 20 cm. Sodium levels are perhaps lower in the very surface layers due to leaching by rainfall while potassium levels are probably high due to the recycling from below by the vegetation and, especially at the time of year of sample collection, due to leaching from the abundant tree litter.

An examination of small scale variation in vegetation, water depth and surface water chemistry in central Great Fen.

The vegetation quadrat recording and water sampling were carried out at 3 m intervals across the central areas of Great Fen along a transect on 30 July 1981 which had been previously levelled at a time of high water. Changes in composition and shoot frequency of the vegetation along the transect are shown in Fig. 5.12.

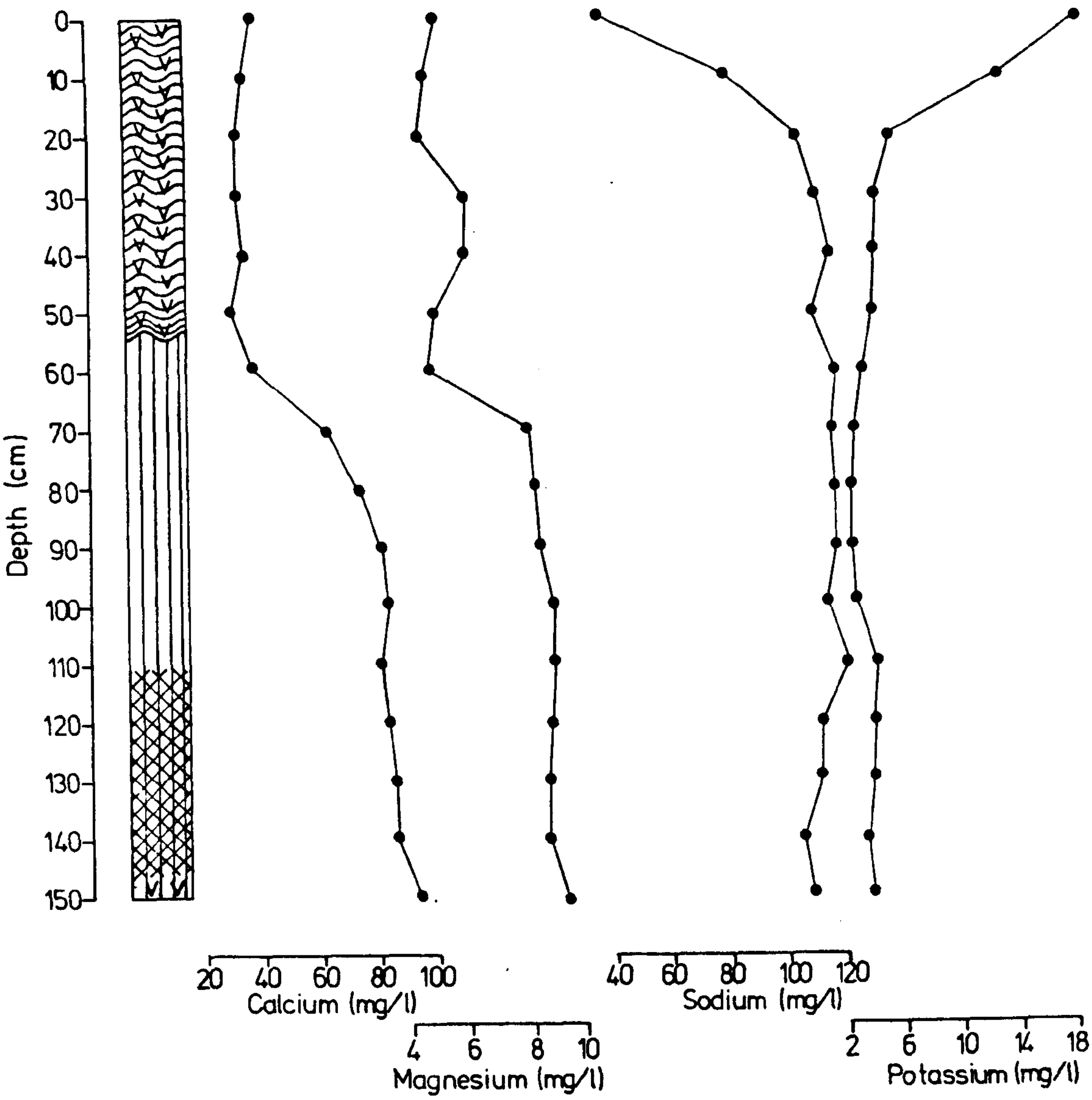


Fig. 5.11. Chemical analyses of peat waters from the upper 150 cm of peat in study site 14. BM. A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

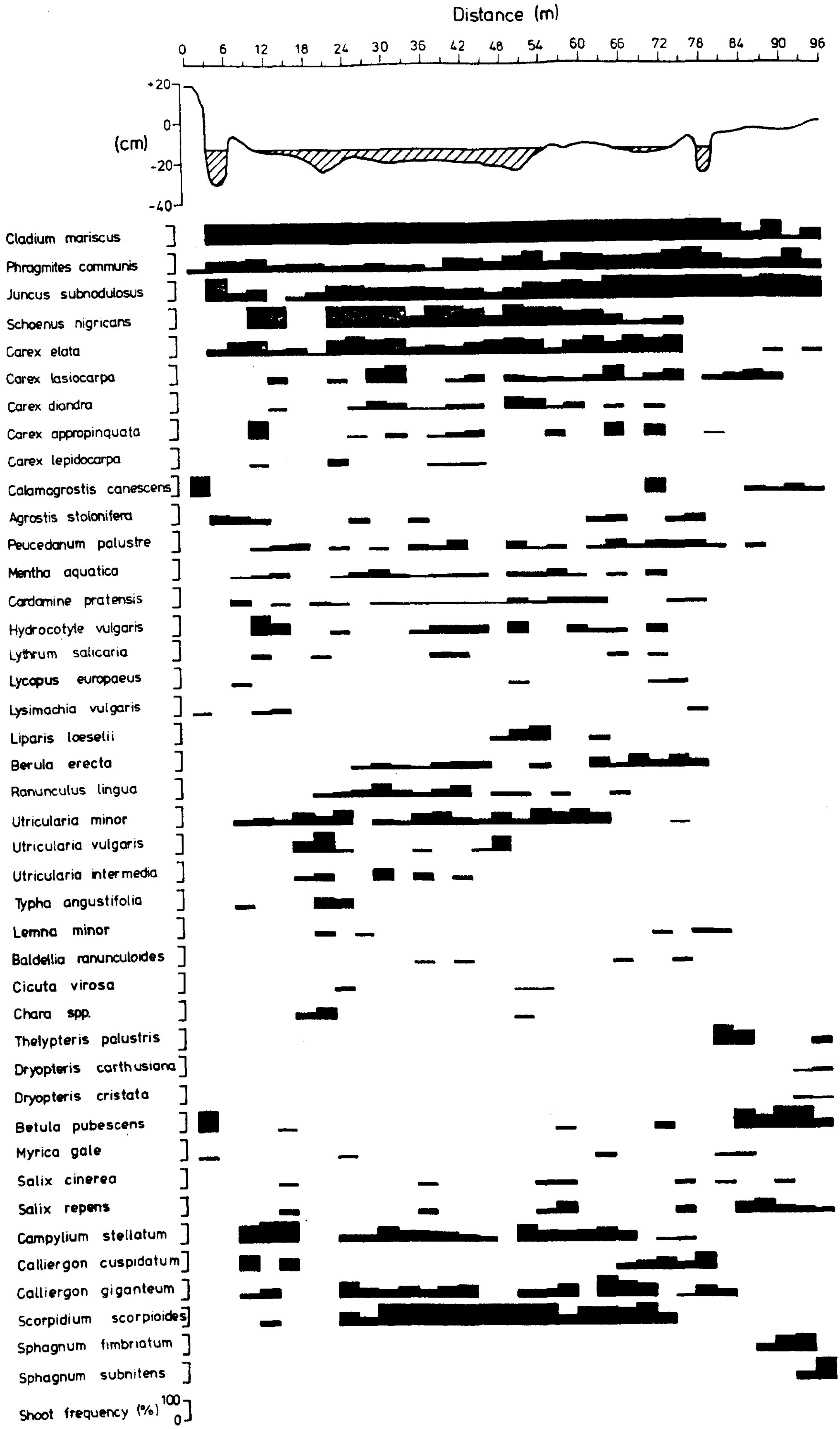


Fig. 5.12. Species composition and shoot frequency along a short transect in Great Fen. Additional species are given on the following page.

Additional species with distance along transect (m) and shoot frequency (%) in parentheses in the case of vascular plants:

Anagallis tenella 12 (44), 39 (24); *Carex pseudocyperus* 30 (12); *Epilobium palustre* 6 (8), 72 (12); *Epipactis palustris* 12 (68); *Eupatorium cannabinum* 0 (4), 12 (12); *Lemna trisulca* 18 (20), 24 (4); *Juncus articulatus* 21 (20), 33 (8); *Oenanthe fistulosa* 36 (24), 69 (20); *Pyrola rotundifolia* 90 (40).

Aulacomnium palustre 87; *Brachythecium rutabulum* 54, 63, 69; *Bryum pseudotriquetrum* 36, 60; *Calliergon cordifolium* 66; *Calypogeia muellerana* 84, 87, 90; *Camplyium elodes* 35, 57; *Chiloscyphus pallescens* 69, 72: *Eurhynchium praelongum* 48, 54, 60, 63, 66, 72; *Fissidens adianthoides* 12, 57; *Lophocolea bidentata* 90; *Mnium hornum* 90; *Pellia neesiana* 9; *Plagiothecium undulatum* 90; *Polytrichium commune* 87; *Pseudobryum rostratum* 72, 75; *Riccardia multifida* 9, 51, 57, 58, 75; *R. pinguis* 9, 21, 54, 63; *R. sinuata* 75.

The dry rond supported a vegetation of *Betula pubescens* with *Calamagrostis canescens*. The herbaceous vegetation of the open fen (6-75 m along the transect) is a good example of the *Peucedano-Phragmitetum caricetosum Menyanthes* var. *Ranunculus lingua* sub. var. (2.4). This community is dominated by *Cladium mariscus* with much *Schoenus nigricans*, *Juncus subnodulosus*, *Phragmites communis* and *Carex elata* and a dense carpet of *Scorpidium scorpioides*, *Calliergon giganteum* and *Campylium stellatum*. Fine leaved sedges such as *Carex diandra* and *C. lasiocarpa* are also quite constant in this vegetation. *Carex lasiocarpa* is found in the *Betulo-Dryopteridetum cristatae* community (84-96 m along the transect) which has much *Betula pubescens* with *Sphagnum fimbriatum*, *S. subnitens*, *Dryopteris carthusiana* and *D. cristata*. The presence of *Carex lasiocarpa* with much *Cladium*, *Phragmites* and *Juncus subnodulosus* in this community suggests that it has perhaps developed over the *Peucedano-Phragmitetum caricetosum*.

The peat surface in the fen was at a relatively higher level from 54 m along the transect being highest underneath the *Betulo-Dryopteridetum cristatae* although the rise in level was quite sligr.t (≃ 20 cm). At the time of levelling the water level was continuous above the peat surface, except for the rond which was well above the water level. The *Sphagnum* hummocks in the *Betulo-Dryopteridetum cristatae* community were quite tall (20-30 cm high above the firm peat surface) and were not generally in contact with the flooding water. The distribution of some species along the transect shows some correlation with the relative height of the peat surface. *Calamagrostis canescens*, *Betula pubescens* and *Calliergon cuspidatum* are found in areas above the water level at the time of sampling, while aquatic and swamp species such as *Utricularia* spp., *Lemna minor*, *Typha angustifolia* and *Cicuta virosa* were found in areas where the peat surface was below the prevailing water level.

Changes in the chemical composition of peat waters along the transect are shown in Fig. 5.13. There was little variation in pH along the transect. The levels of all the major cations tended to decrease with distance along the transect perhaps indicating oligotrophication in the areas where the peat surface is slightly more raised and less susceptible to flooding. It has already been shown (4.5.12) that levels of the major cations are normally lower at times of high water levels, due to dilution effects. The reverse trend with water level is found here within the *Peucedano-Phragmitetum caricetosum* community, supporting the hypothesis that oligotrophication is taking place in the areas with a more raised peat surface.

5.5.2. Investigations in Little Fen and Neatishead Poor's Fen

Chemical stratification of the peat waters

The results of chemical analyses of peat waters from the surface 150 cm of peat in Little Fen (site 4. LF) collected on 5 June 1981 are shown in Fig. 5.14. The pH was quite high

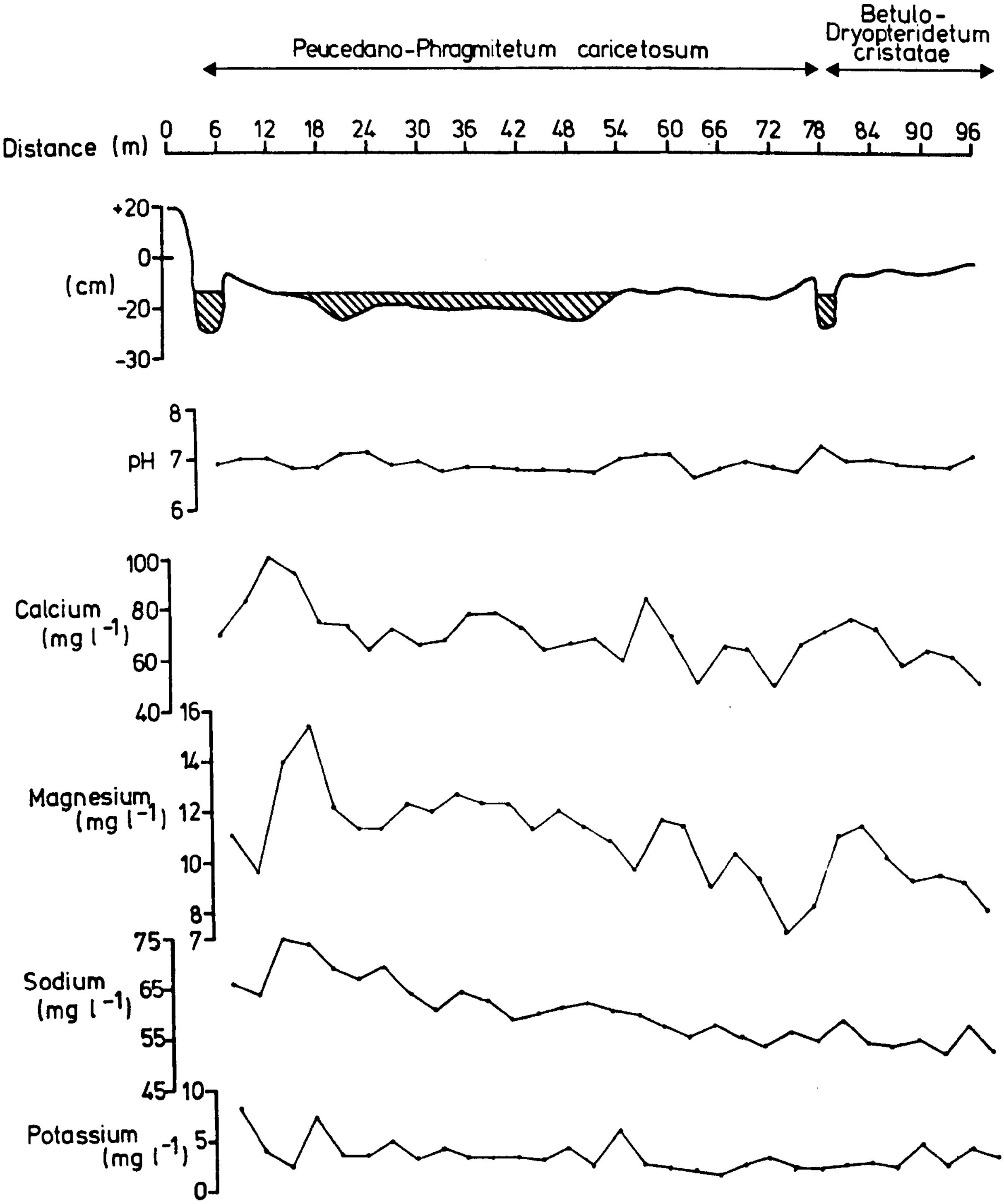


Fig. 5.13. Variation in pH and major cation levels in surface peat water samples taken along the transect shown in Fig. 5.12.

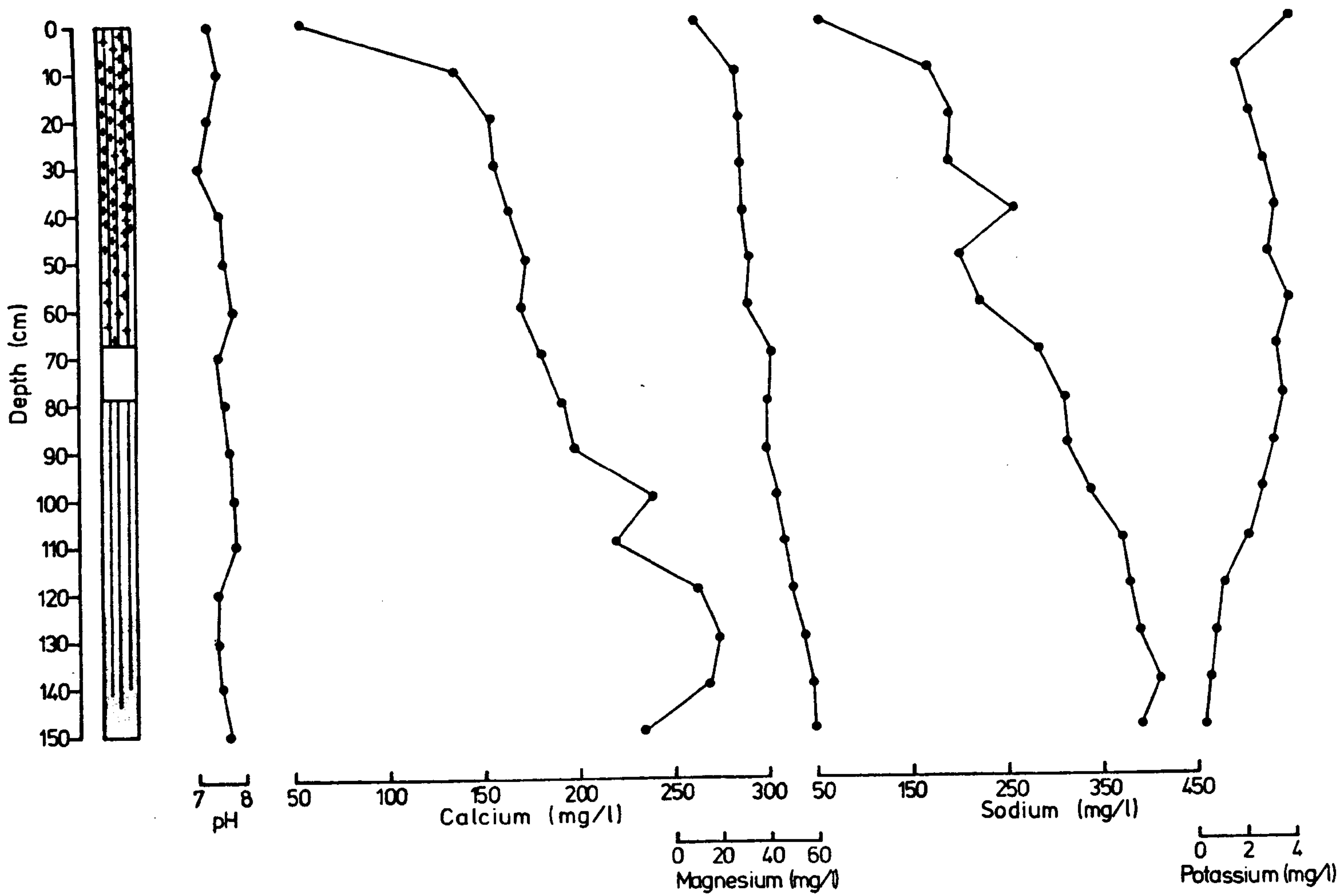


Fig. 5.14. Chemical analyses of peat waters from the upper 150 cm of peat in study site 4. LF. A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

(between pH 7 and 8) at all depths. The surface waters were quite dilute as found in the analyses from Great Fen. Levels of calcium, magnesium and sodium increased markedly with depth, especially in the lower depths (> 100 cm). This is probably due to the influence of the underlying clay as the levels (Ca^{++} > 250 mg l^{-1}, Mg^{++} > 55 mg l^{-1} and Na^{+} > 375 mg l^{-1}) are higher than those measured in brackish water entering the study site (4.5.12). The level of potassium was highest in the surface water sample and was very low in water from the clay horizons.

Samples were only obtainable from the upper 80 cm in Neatishead Poor's Fen (5. NPF). Levels of all the major cations increased to very high levels in the samples from lower horizons (Fig. 5.15), demonstrating the strong influence of the underlying *Phragmites*/clay.

5.5.3. Investigations in Irstead Poor's Fen

Vegetation recording and sampling of the surface peat waters was carried out at 1 m intervals along a 10 m transect in Irstead Poor's Fen on 10 October 1980. This transect is the same as that shown in Fig. 3.1. An open pool at 0 m along the transect contained *Cladium mariscus* with *Utricularia vulgaris* and Chara spp. (Fig. 5.16). Immediately adjacent to the pool was a *Betulo-Dryopteridetum cristatae* community (4.4.2; IPF *B.-D. c*) which, although it covered such a small area, contained most of the species characteristic of this community type with much *Sphagnum fimbriatum* and *S. squarrosum*. There was a narrow

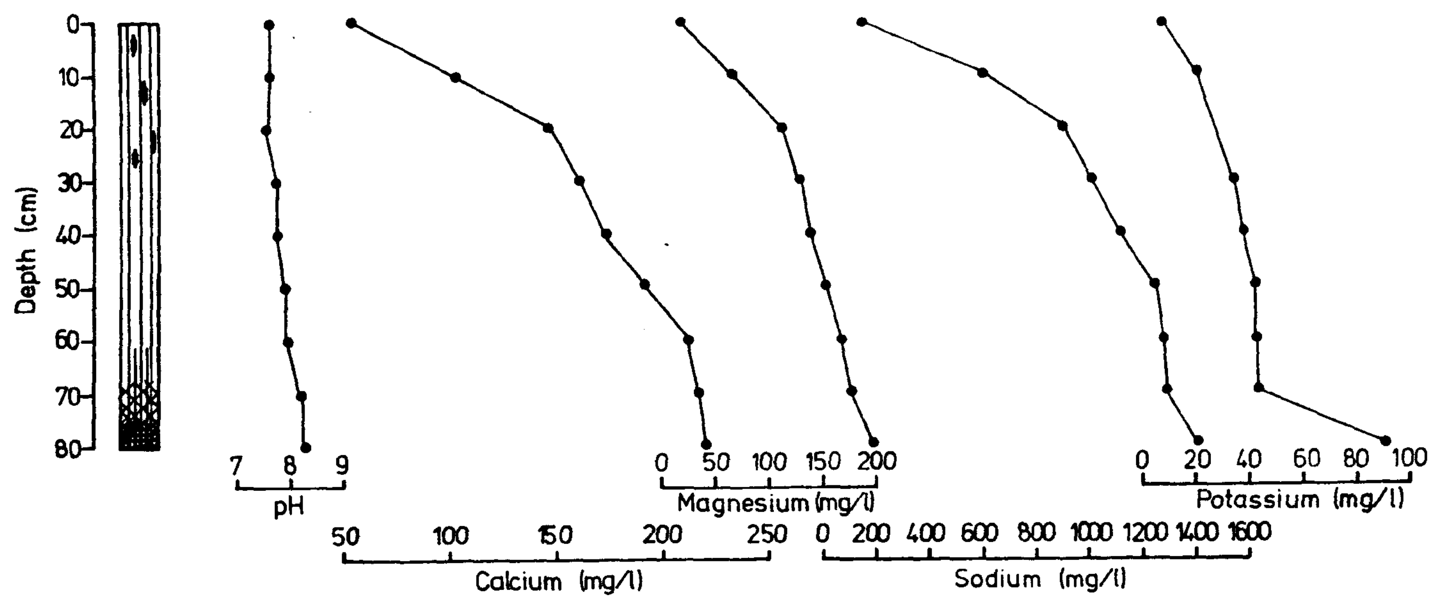


Fig. 5.15. Chemical analyses of peat waters from the upper 150 cm of peat in study site 5. NPF. A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

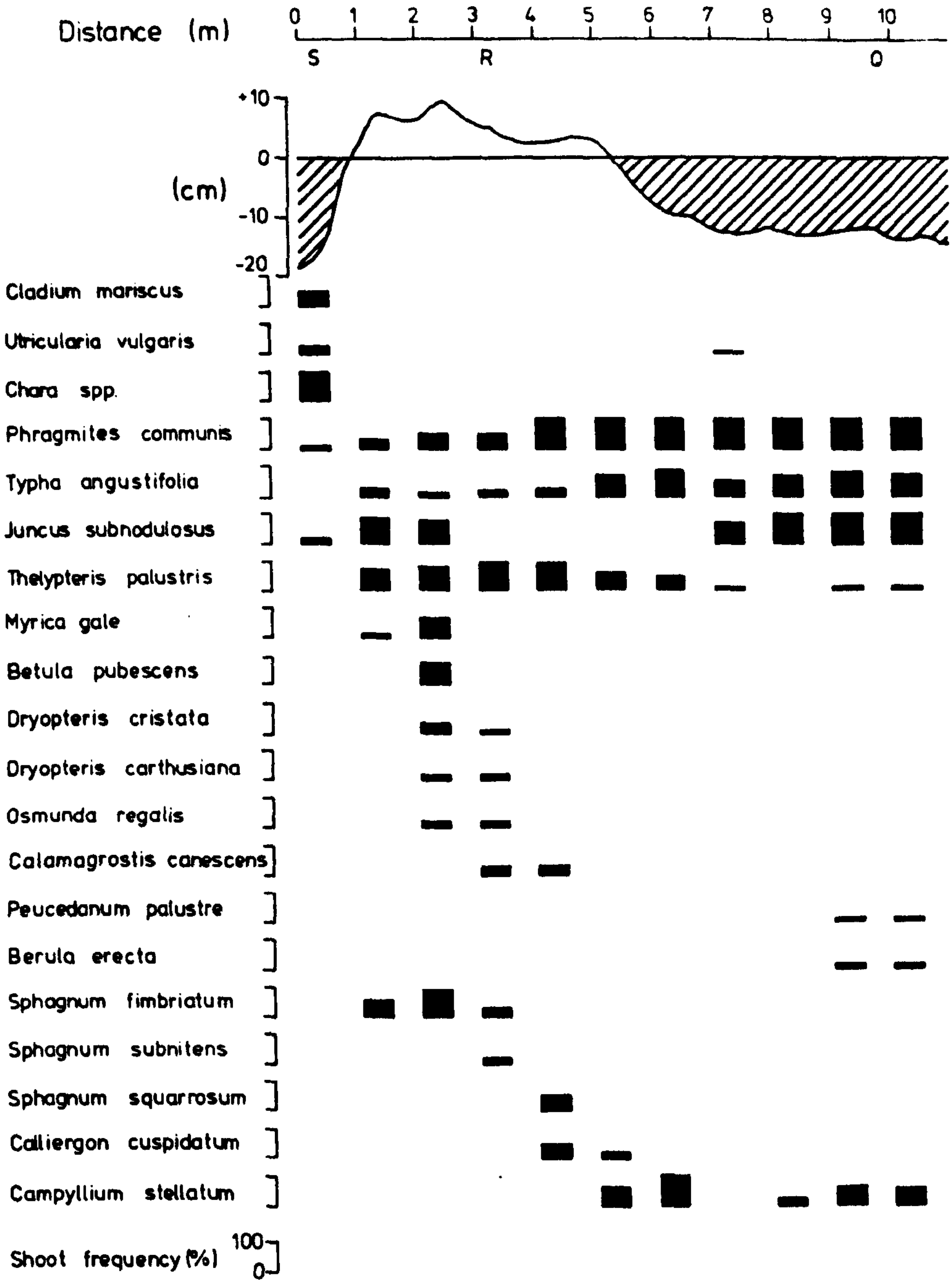


Fig. 5.16. Species composition and shoot frequency (%) along a short transect in Irstead Poor's Fen.

transition zone from this community to the adjacent species-poor fen community. This transition zone (4-6 m along the transect) had much *Calliergon cuspidatum* and *Sphagnum squarrosum* and occupied the shallowly sloping margin of the *Betulo-Dryopteridetum cristatae* community. *Phragmites* and *Typha angustifolia* were co-dominants of the species-poor fen community (= site 6. IPF) which occurred between 6 and 10 m along the transect. *Calamagrostis canescens* was present only in the area with a more elevated peat surface.

The water level at the time the transect was levelled (18 October 1980) was quite high and yet the peat surface in the *Betulo-Dryopteridetum cristatae* community was not flooded (4.4.2). The results of chemical analyses of the surface waters along the transect are shown in Fig. 5.17. Levels of all the variables were much lower in the *Betulo-Dryopteridetum cristatae* community than in the surrounding vegetation. The level of potassium was highest in the part of the *Betulo-Dryopteridetum cristatae* where *Betula pubescens*, *Myrica gale* and *Salix cinerea* were present which could be due to leaching from the falling tree litter.

Levels of all the variables measured were very constant in the surface waters where there was standing water above the peat surface.

Peat water samples were collected on 18 October 1980 from the upper 150 cm of peat in the open pool with *Cladium* (S), in the *Betulo-Dryopteridetum cristatae* community (R) and in

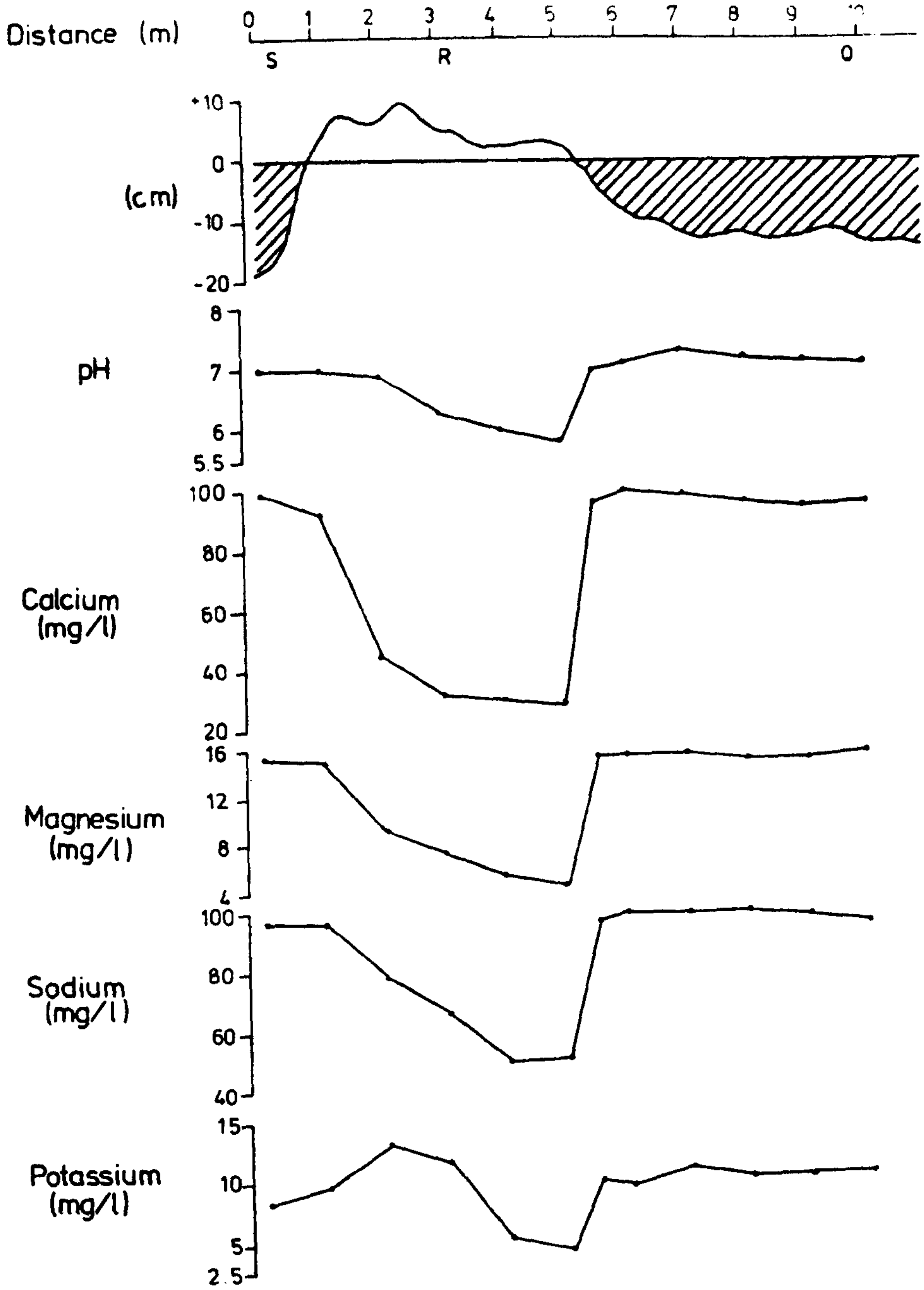


Fig. 5.17. Variation in pH and major cation levels in surface peat waters collected along the transect shown in Fig. 5.16.

the *Phragmites-Typha* community (Q) and the results of chemical analysis of these waters are shown in Fig. 5. 18 . Investigations of the hydrology and stratigraphy in this area (4.4., 3.3) had revealed the presence of a semi-floating raft of vegetation. Living rhizomes could be felt extending down from this peat raft into the peat slurry found beneath the raft. Samples were collected from the water surface in the *Cladium* community as the vegetation raft was very mobile and moved when the sampler was inserted. Calcium levels were lowest in the surface 10 cm of peat in the *Betulo-Dryopteridetum cristatae* community. Otherwise levels of calcium were quite constant beneath all three areas, showing a slight tendency to decrease in the lowest samples from the *Cladium* and *Phragmites-Typha* communities. The levels of magnesium were much higher in the samples from the underlying *Phragmites/Juncus* peat and decreased through the zone of unsamplable deposits to lower levels (< 30 mg l^{-1}) in the surface peat. The lowest level was found in the surface water from *Sphagnum* peat.

Levels of sodium followed a similar pattern to magnesium levels, being highest in the underlying peat and indicating an increasing effect of dilution towards the surface peat. Levels were lower between 30 and 80 cm below the peat surface in the samples underlying the *Cladietum marisci* than in samples from corresponding depths from the other two communities. This could be due to the very thin surface peat raft allowing better mixing of the surface waters with the underlying layers. In the

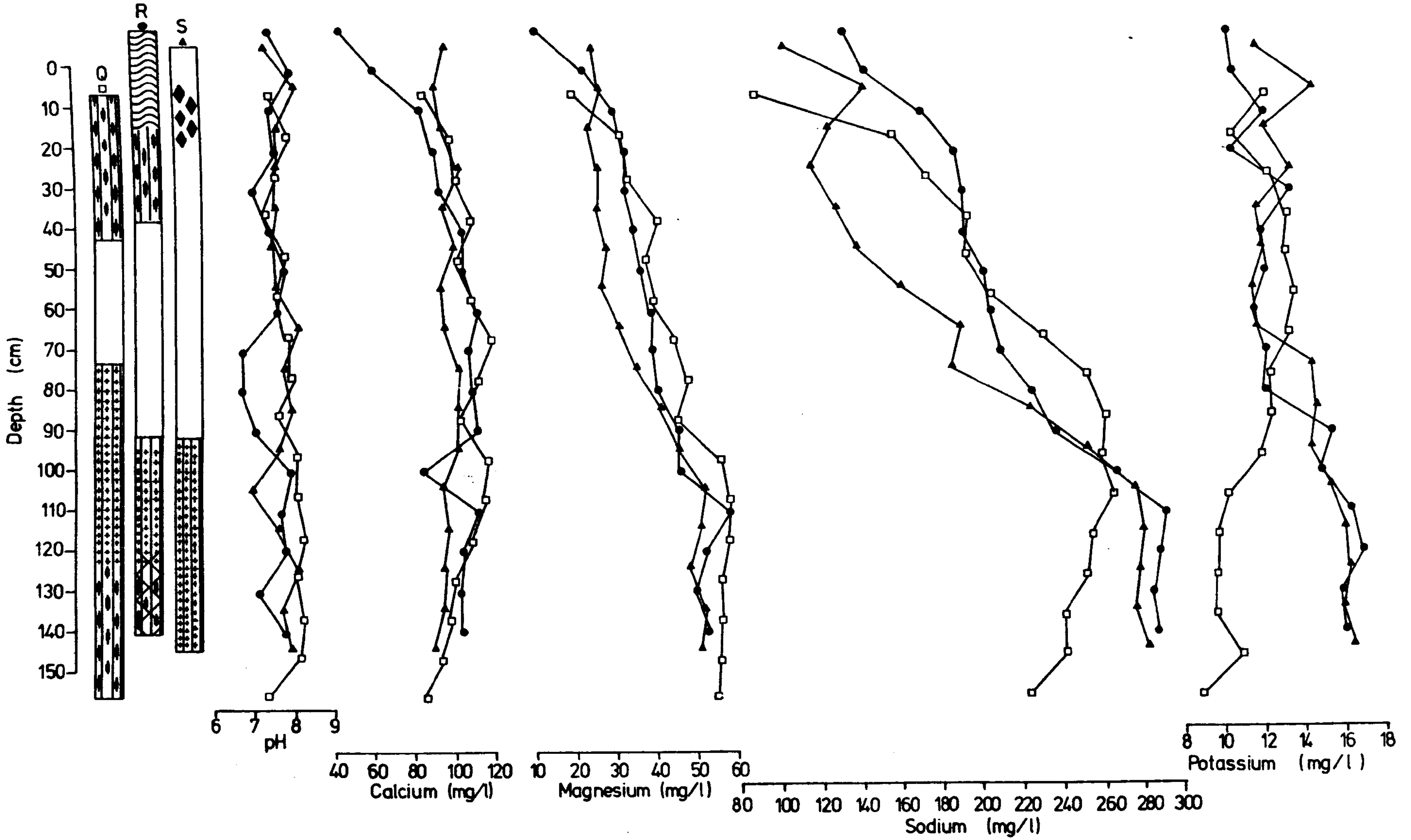


Fig. 5.18. Chemical analyses of peat waters from the upper 150 cm of peat in a *Phragmites-Typha angustifolia* community (Q) a *Betulo-Dryopteridetum cristatae* community (R) and a *Cladietum marisci* community (S). A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

Betulo-Dryopteridetum cristatae and *Cladietum marisci* communities the levels of potassium follow a quite similar trend to sodium and magnesium levels with depth below the surface. The potassium levels in *Phragmites/Juncus* peat below the *Phragmites/ Typha* community were consistently lower than those found at corresponding depths beneath the other two communities. This could possibly be due to better penetration of the roots and rhizomes of *Phragmites* and *Typha angustifolia* allowing uptake of potassium from the peat in these lower layers.

5.5.4. Investigations in Sedge Marshes

Surface water samples were collected on a transect across Sedge Marshes to Great Fen (Fig. 5.19). Levels of all the cations were higher in Great Fen than in Sedge Marshes. Levels of the cations were very variable in Sedge Marshes but increased markedly towards the open dykes at either side of the fen. Levels of all the cations were not noticeably different in the sample from the *Betulo-Dryopteridetum cristatae* community from those taken in the *Peucedano-Phragmitetum schoenetosum* communities.

The results of chemical analyses of peat waters from the surface 150 cm of peat in two areas of Sedge Marshes are shown in Fig. 5.20. One of these areas was a small *Betulo-Dryopteridetum cristatae* community developed over an overgrown dyke, while the other area was a *Peucedano-Phragmitetum schoenetosum* community (site. 8. SM). The levels of calcium,

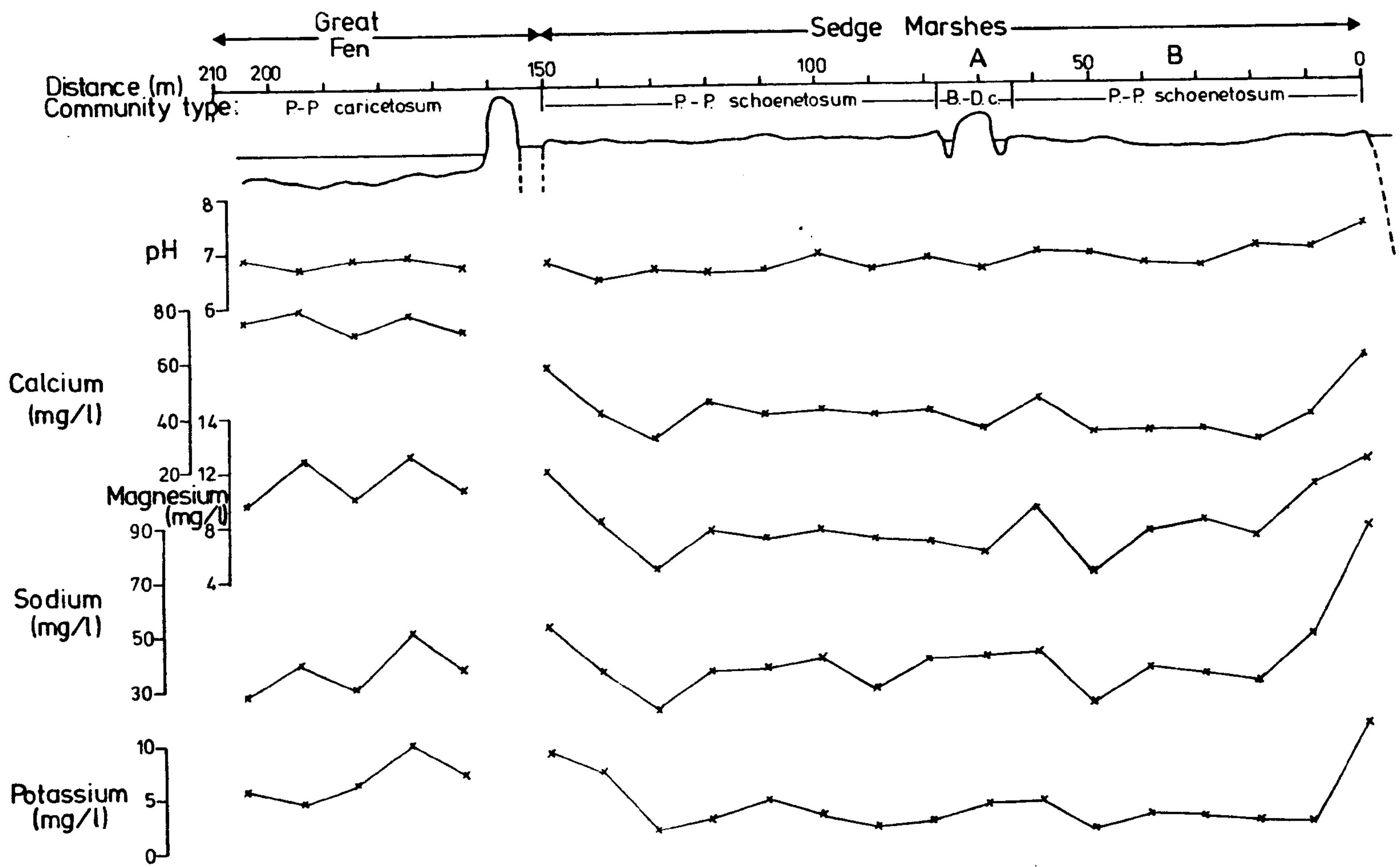


Fig. 5.19. Variation in pH and major cation levels in surface peat waters collected along a transect from Great Fen to Sedge Marshes.

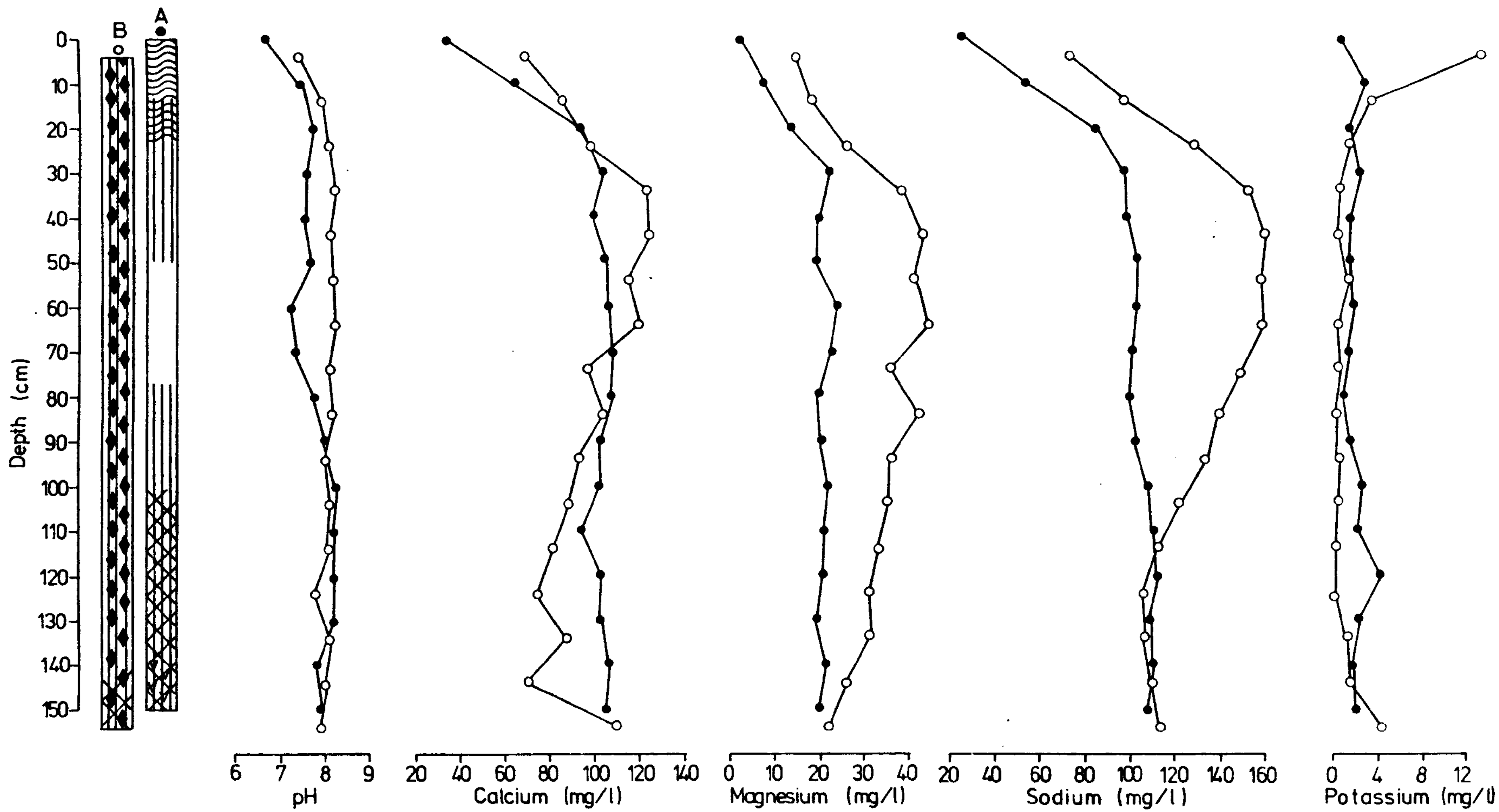


Fig. 5.20. Chemical analyses of peat waters from the upper 150 cm of peat in a *Peucedano-Phragmitetum schoenetosum* community (8. SM: B) and a *Betulo-Dryopteridetum cristatae* community (A).

magnesium and sodium decreased progressively in the upper 30 cm of peat in both communities. The levels of magnesium and sodium were generally higher in the peat waters from the more humified peat beneath the *P.-P. schoenetosum* community than those from beneath the *Betulo-Dryopteridetum cristatae* community. While the levels of all the cations were quite constant at depths greater than 30 cm beneath the *Betulo-Dryopteridetum cristatae* community the levels of calcium, magnesium and sodium were highest at 30-70 cm below the peat surface in the *P.-P. schoenetosum* and decreased below these horizons. Potassium levels were highest in the surface sample from the *P.-P. schoenetosum*.

5.5.5. Investigations in Fenside Marsh

The chemical stratification of the major cations in the peat waters in a *Betulo-Dryopteridetum cristatae* community (12. FBC), *Cladietum marisci* community (11. FBC) and *Cicuto-Phragmitetum* community (10. FBR) are shown in Fig. 5.21. The levels of pH, calcium, magnesium and sodium decrease progressively from 90 cm depth to the peat surface beneath the *Betulo-Dryopteridetum cristatae* community and are quite low in the *Sphagnum* peat layers. The levels of these three cations also decrease in the surface 30 cm in the two swamp communities, sodium decreasing gradually towards the surface from the lowest samples beneath the *Cicuto-Phragmitetum* community.

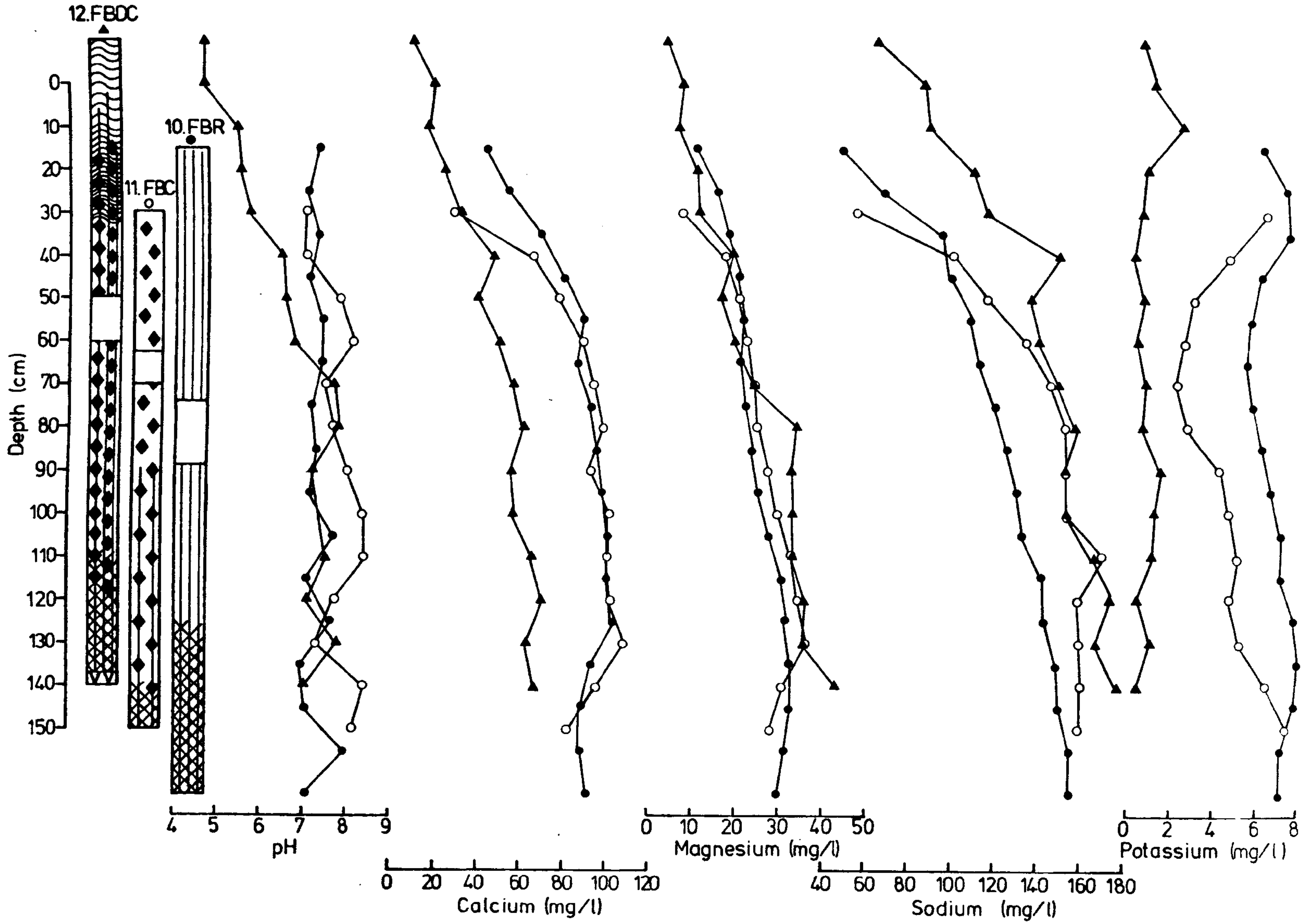


Fig. 5.21. Chemical analyses of peat waters from the upper 150 cm of peat in some study sites in Fenside Marsh. A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

The level of calcium was consistently lower in the samples from underneath the *Betulo-Dryopteridetum cristatae* community than in those from beneath the other two communities. Why this is so is not clear but it could be related to slightly more marginal location of the community. Levels of potassium were different in the water samples from beneath the three communities, being very low in the peat waters from beneath the *Betulo-Dryopteridetum cristatae* community.

5.5.6. Investigations in Main Reed Marsh

The changes in the shoot frequency and composition of the vegetation along a short transect from a *Cicuto-Phragmitetum* community to a *Betulo-Dryopteridetum cristatae* community (Site 13. MRM) in Main Reed Marsh are shown in Fig. 5.22. The vegetation of the open reed bed (0-8 m) is dominated by *Phragmites communis* with much *Typha angustifolia* and some swamp species (e.g. *Cicuta virosa, Sium latifolium* and *Carex pseudocyperus*). A narrow transitional zone (8-12 m) is present between this vegetation and the *Betulo-Dryopteridetum cristatae* (*B.-D. c.*) community. *Potentilla palustris* is very abundant in this transition zone where some *Sphagnum squarrosum* is present. There is little development of woody species in the *Betulo-Dryopteridetum cristatae* community where *Phragmites communis* is abundant growing through the continuous carpet of *Sphagnum squarrosum* and *S. subnitens*. *Peucedanum palustre* was more frequent in this community and the

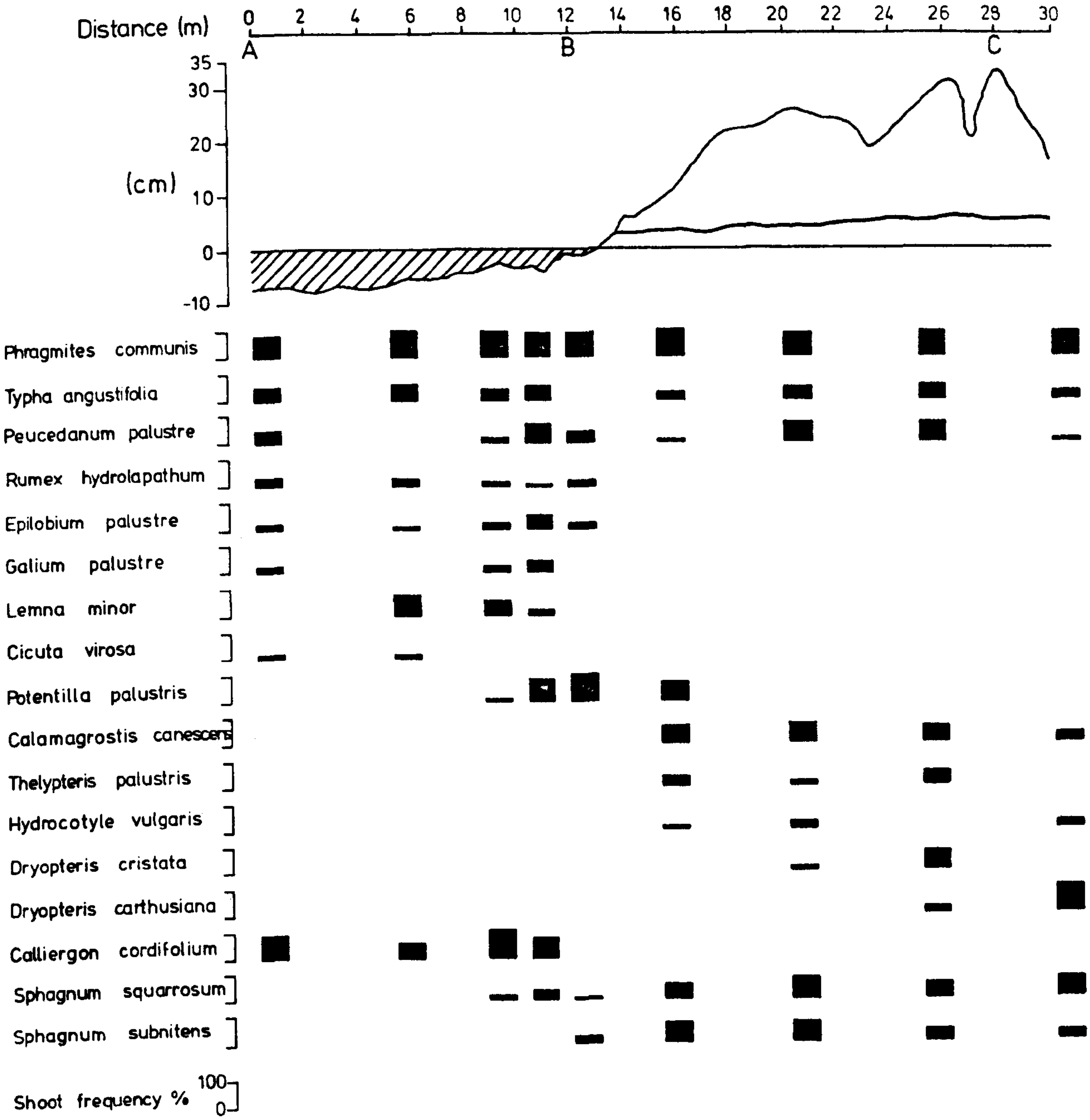


Fig. 5.22. Species composition and shoot frequency (%) along a short transect in Main Reed Marsh. The upper line indicates the height of *Sphagnum* hummocks above the peat surface. Additional species with distance along transect (m) and shoot frequency (%) in parentheses:

Agrostis stolonifera 0 (64); 11.5 (4); *Betula pubescens* 20 (16); *Cardamine pratensis* 8.5 (4); *Carex pseudocyperus* 0 (28); *Juncus subnodulosus* 25 (12); *Salix cinerea* 20 (4); *Sium latifolium* 5 (20); *Solanum dulcamara* 5 (28); *Stellaria palustris* 0 (48); 11.5 (4).

Aulacomnium palustre 15; *Calliergon cuspidatum* 8.5; *Calypogeia fissa* 30; *Campylium stellatum* 0; *Drepanocladus fluitans* 0, 8.5; *Eurhynchium praelongum* 25; *Pellia epiphylla* 15; *Plagiothecium denticulatum* 15; *Sphagnum fimbriatum* 20; *S. palustre* 25; *S. teres* 25.

transition zone than in the *Cicuto-Phragmitetum* community while several of the species were found solely in the *Betulo-Dryopteridetum cristatae* community (e.g. *Calamagrostis canescens*, *Hydrocotyle vulgaris*, *Dryopteris cristata*). The height of *Sphagnum* hummocks above the peat surface is also shown and is often between 20 and 30 cm.

Changes in the pH and major cation composition of the surface peat waters along this transect are shown in Fig. 5.23. The pH of the water samples was quite constant in the *Cicuto-Phragmitetum* community and decreased through the transition zone to much lower levels in the *Betulo-Dryopteridetum cristatae* community. Levels of calcium, magnesium and sodium followed a similar general trend to pH, but were much more variable in the transition zone and at the edge of the *Betulo-Dryopteridetum cristatae*. Levels of potassium were also quite constant in the *Cicuto-Phragmitetum* community where the water level was continuous above the peat surface at the time of sampling. The levels of potassium were both much higher and more variable in the samples from the *Betulo-Dryopteridetum cristatae*.

The decrease in acidity along the transect was demonstrated more clearly by changes in the peat pH (Fig. 5.24). The readings of peat pH were made directly in the field from sub-surface peat samples (5-10 cm deep) and it is obvious from these readings that the peat becomes more acidic across the transition zone from the *Cicuto-Phragmitetum* community to the *Betulo-Dryopteridetum* community. Levels of extractable calcium

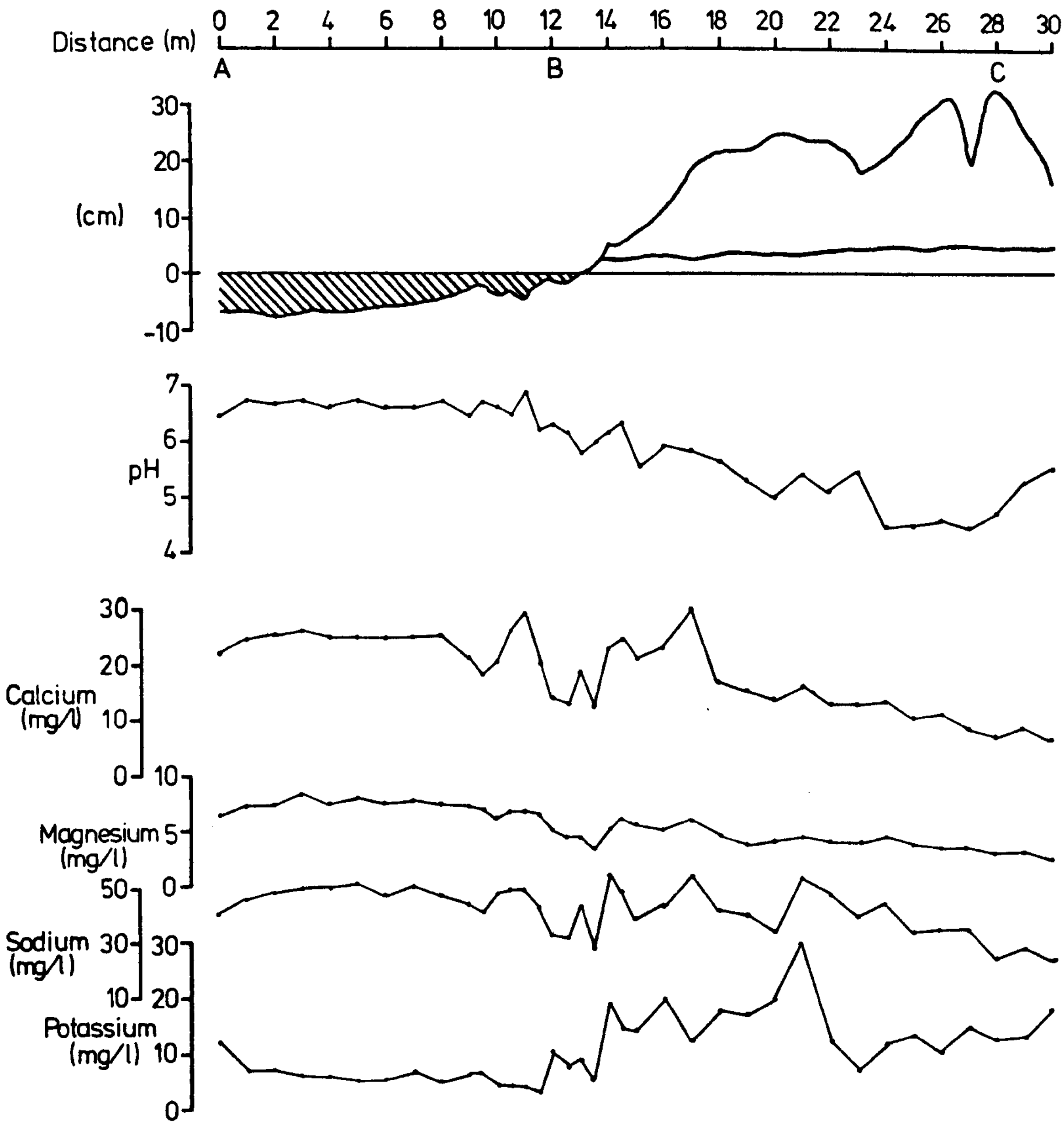


Fig. 5.23. Variation in pH and major cation levels in surface peat waters collected along the transect shown in Fig. 5.22.

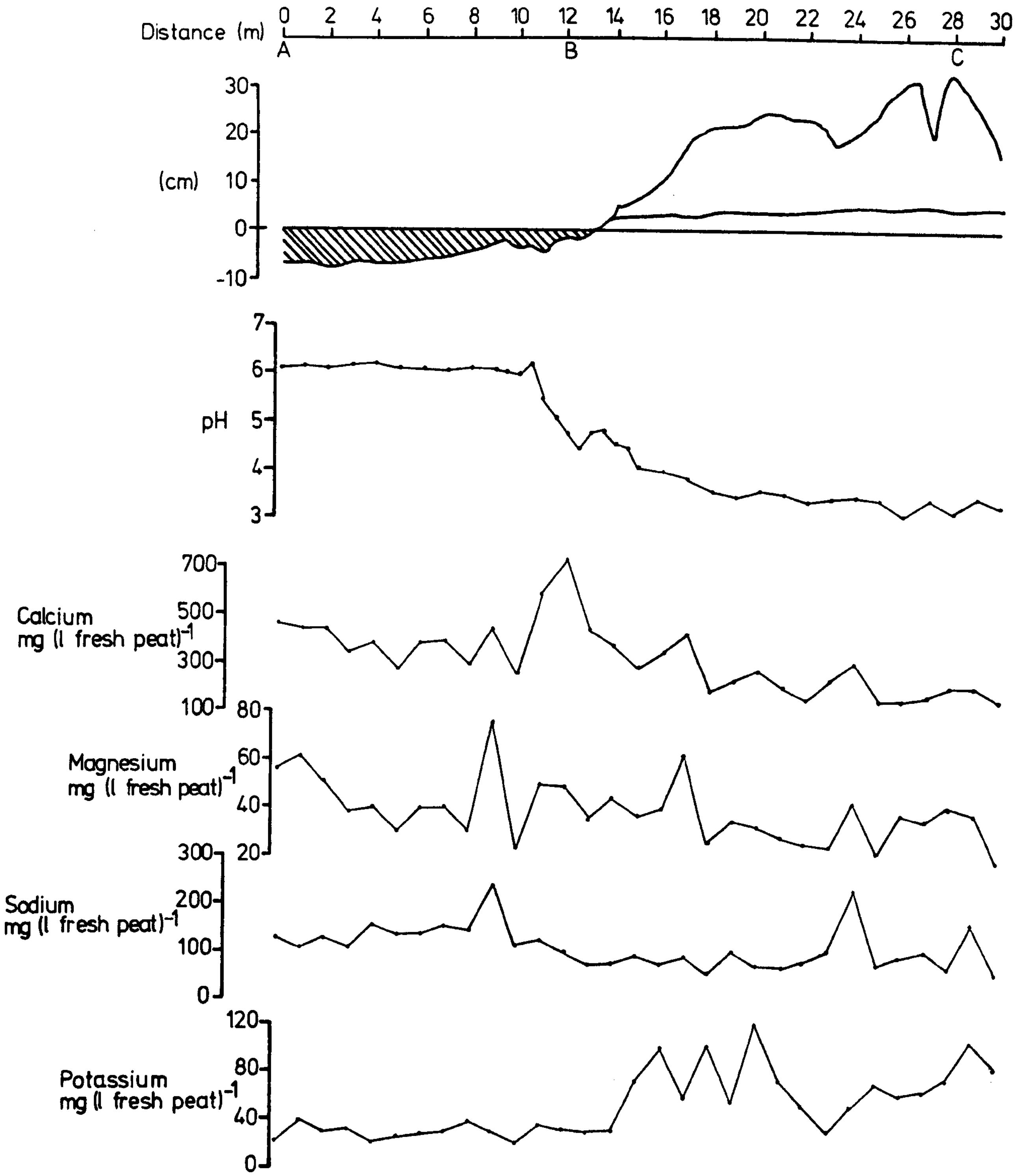


Fig. 5.24. Variation in pH and extractable major cations in peats collected along the transect shown in Fig. 5.22.

in the peat from 5-10 cm below the peat surface are lowest in the *Betulo-Dryopteridetum cristatae* community but are higher if more variable in the transition zone (8-12 m). The levels of extractable magnesium are very variable along the transect but tend to be lower in the *Betulo-Dryopteridetum cristatae* community and extractable sodium levels also tend to be lower in this area. The distribution of extractable potassium is very different from that of the other major cations. The levels are quite constant in the *Cicuto-Phragmitetum* community and the transition zone, but increase to much higher levels underneath the *Betulo-Dryopteridetum* community.

Vertical stratification of the peat waters

The results of chemical analyses of the peat waters sampled beneath the *Cicuto-Phragmitetum* community (A), the transition zone (B) and the *Betulo-Dryopteridetum cristatae* community (C) are shown in Fig. 5. 26. Levels of calcium, magnesium and sodium were lowest in the surface waters, while levels of potassium were higher in the surface waters in all three areas. The level of calcium was lower in the peat waters from below the *Betulo-Dryopteridetum cristatae* community than that from below the transition zone and *Cicuto-Phragmitetum* community, levels in all three sites increased with depth below the peat surface. The levels of magnesium and sodium were consistently much higher below the *Cicuto-Phragmitetum* community than below the other two areas. Levels of magnesium and sodium showed little variation with depth in the samples from below 20 cm.

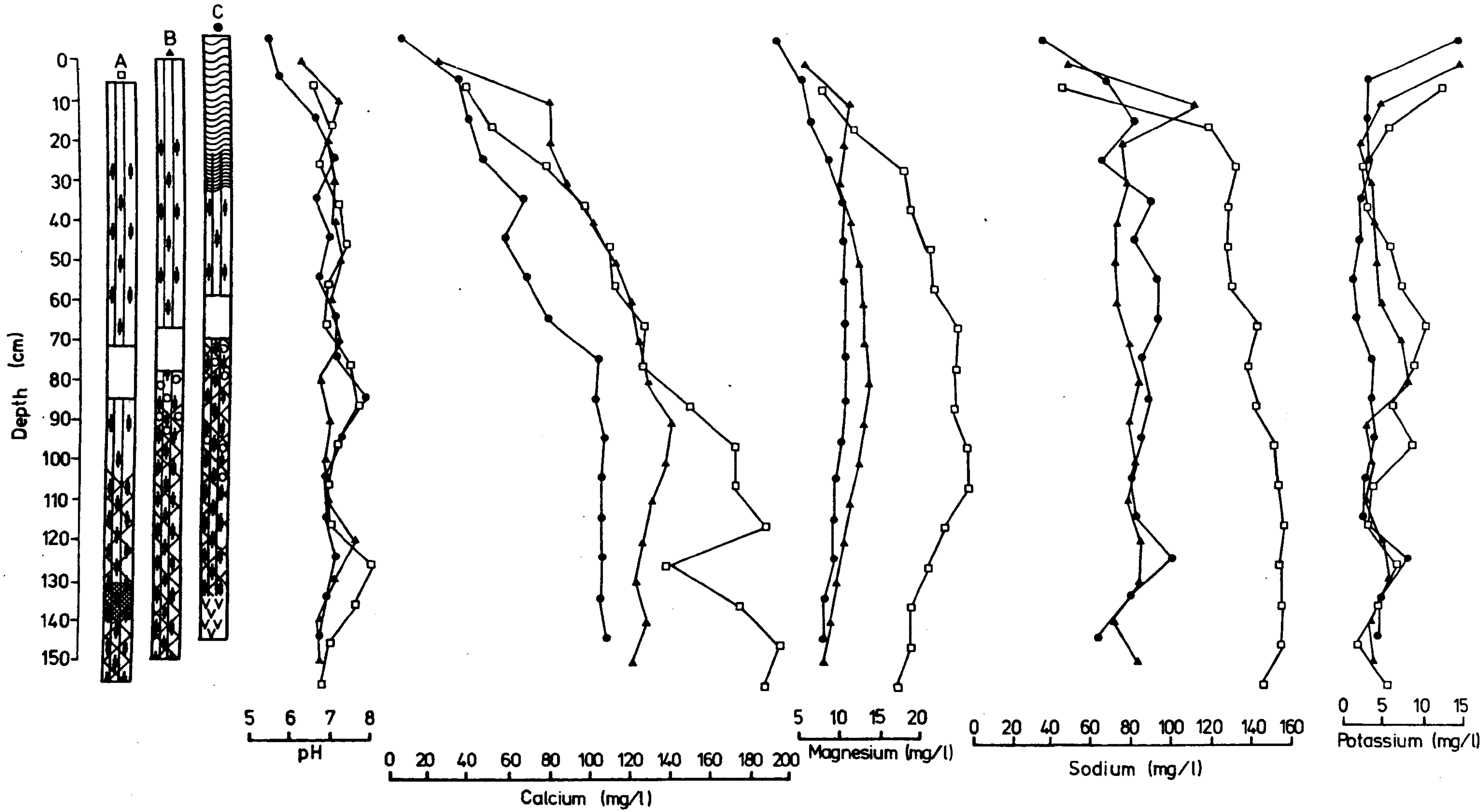


Fig. 5.25. Chemical analyses of peat waters from the upper 150 cm of peat in a *Cicuto-Phragmitetum* community (A), transition zone (B) and *Dryopteridetum cristatae* community (C). A key to the alluvial stratigraphy symbols is given in Fig. 3.2.

5.6. DISCUSSION

5.6.1. The chemistry of the surface peats and peat waters in relation to possible water sources

Examination of the levels of nitrogen and phosphorus along the transect leading away from Barton Broad (5.3.) indicates that potential effects of eutrophication by river water are limited to a narrow zone of fen within twenty metres of the broad margin. The vegetation of this area is a *Peucedano-Phragmitetum typicum Phalaris* var. community which contains nutrient demanding species such as *Epilobium hirsutum* and *Urtica dioica*. This community type is often found occupying a narrow band of fen around broad margins (Wheeler 1978). Elsewhere in the study area *Epliobium hirsutum* and *Urtica dioica* are only found alongside dyke edges, in mature alder carr communities on humified peat (4.5.14) or in areas where input of land drainage water occurs (e.g. the *Phragmites* sociation community in North Marsh, 2.4.). The limitation of evidence for eutrophication to such marginal areas is probably related to the assimilative capacity of peats for nitrogen and phosphorus (Sloey *et al.* 1978). Buttery, Williams and Lambert (1965) found a similar diminution in levels of available phosphorus with distance along a transect from floating *Glyceria maxima* swamp to *Phragmites-Phalaris arundinacea* fen 90 m from open water at Surlingham in the Yare valley. The levels of nitrogen, phosphorus and potassium reported from the Yare valley in available form (N 48-110 mg/l mud, P 9-110 mg/l mud and K 9-28 mg/l mud) and in the waters (NH_4-N 1.08-2.88 mg l^{-1}, NO_3-N 0.81-1.18 mg/l and P 0.167-0.297 mg/l) were much higher than those found within the study area corresponding with the more eutrophic character of the vegetation in the Yare valley fens.

The levels of calcium and magnesium in the dykes of the internal system (5.4) also decreased with distance away from land drainage inflow at the north-eastern corner of the study area. While there was generally some correlation between the levels of cations found in surface waters in the fens and those found in the surrounding dykes, levels of calcium and magnesium in particular were lower in areas of fen which are more isolated from the dykes (5.4). The transect of major cation levels across the *Peucedano-Phragmitetum schoenetosum* community in Sedge Marshes (Fig. 5.19) demonstrates that the levels of all the major cations were higher in areas close to the open dykes than in the more central areas of the fen suggesting little circulation of water over the fen. The distribution of high levels of iron found in this study highlights the importance of proximity to the land margins and the relative shallowness of the peat in such areas in determining high levels of iron in the peat waters. *Potentillo-Caricetum rostratae* communities were only found in such marginal areas where the peat was shallow (< 1 m deep) and levels of iron were high. The levels of the major cations in the surface water samples were very variable in these communities (Figs. 5.4-5.7). Levels of manganese were more variable and were not only high in marginal areas.

The dykes of the internal system had lower levels of potassium and sodium than those found in some dykes of the external system, reflecting the isolation of the internal system from the influence of river water. Levels of these cations were highest in some fens of the external system but it seems that these high levels are at least partly caused by the influence of the underlying alluvial deposits.

5.6.2. Chemical stratification of the peat waters

The influence of underlying alluvial deposits

A major factor influencing the levels of the major cations in the peat waters from several of the areas investigated appears to be the presence of clay deposits which were probably formed at the time of the Romano-British marine transgression (3.4). The narrow band of *Phragmites*/clay beneath the *Cicuto-Phragmitetum* community in Main Reed Marsh did not appear to have a particular influence on the levels of major cations (Fig. 5.25) except perhaps in the case of calcium. In other areas where clay deposits are present the influence is very pronounced but the levels of particular cations in the water samples from the clay horizons varied considerably (Table 5.2).

Table 5.2. The maximum levels of cations (mg/l) in water samples taken from horizons of clay deposits.

Site	Deposit Type	Ca	Mg	Na	K
3. GFS	*Phragmites*/Clay	180	34	176	7.8
4. LF	Pure blue-grey clay	272	59	408	0.8
5. NPF	*Phragmites*/clay	219	196	1420	91

The water samples from the *Phragmites*/clay horizons in Neatishead Poor's Fen (5. NPF) had by far the highest levels of magnesium and sodium of all the water samples from clay layers which were examined. The levels of sodium and magnesium were also much higher in the water samples from clay horizons in Little Fen (4. LF) than those from Great Fen (3. GFS). Lower levels of these two cations were therefore found to decrease with distance upstream along the former course of the River Ant, suggesting that the extent of the influence of brackish water decreased quite significantly with distance further up the river valley. The levels of sodium did not follow this pattern and were lower in the *Phragmites*/clay deposits of Great Fen and Neatishead Poor's Fen than in the pure blue-grey clay of Little Fen. The *Phragmites*/clay deposits were probably formed on the tidal flood-plain of the river during the marine transgression while the pure clay in Little Fen was probably formed along the old river channel. This pure clay would probably contain more material transported down the river, which could explain the relative richness of calcium in the water samples from this deposit.

Levels of potassium were also very different in water samples from the clay horizons of these three areas. Water samples from the two *Phragmites*/clays contained higher levels of potassium than those from the pure clay in Little Fen, perhaps partly due to the presence of much humified organic matter in the *Phragmites*/clays. The very high level of potassium (91 mg l^{-1}) found in a water sample from the *Phragmites*/clay in Neatishead Poor's Fen could relate to the greater influence of brackish water during the formation of this deposit.

High levels of sodium and magnesium were also found in the underlying *Phragmites/Juncus* peats (Fig. 5.18) in Irstead Poor's Fen (240-290 and 45-55 mg l^{-1} respectively) although no clay deposit was present in this area (Fig. 3.6). It is likely that these peat deposits were formed at the time of the marine transgression. Unfortunately water samples could not be obtained from beneath the *Peucedano-Phragmitetum schoenetosum* community in Moores Head Marsh (Site 7. MHM) where sodium and magnesium levels had been found to be very high (4.5.7). The samples were probably unobtainable due to the compact, humified nature of the peat.

High levels of sodium and magnesium determined in the peat waters from sampling tubes in earlier studies (4.5.7) in sites close to the present course of the River Ant have been related to recent flooding by brackish water (4.5.12).

Considerable levels of these cations found in deeper deposits in Neatishead Poor's Fen suggest that amounts found in the peat waters from the surface 50 cm (4.5.7) were probably a result of the combined effects of recent brackish water incursions and the influence of the underlying deposits. The high levels of calcium found in the peats and peat waters in Little Fen (4.5.7) were also probably due to the presence of the underlying calcium-rich clay.

Other factors influencing the chemical stratification of the peat waters

In many of the areas examined levels of calcium, magnesium and sodium increased with increasing depth below the surface. This was especially noticeable in areas such as Neatishead Poor's Fen, where the levels in the water samples from the greatest depths were particularly high, and is probably due to progressive dilution towards the surface by mixing with more dilute waters entering the sites during times of flooding and in direct precipitation. The surface peat layers are often less humified which will contribute to the lower levels of the cations in the surface horizons. Levels of these three cations did not always increase with increasing depth however.

In the profile constructed from analysis of peat water samples taken beneath the *Peucedano-Phragmitetum schoenetosum* community (8. SM) in Sedge Marshes (Fig. 5. 20). Levels of calcium, magnesium and sodium were lower in the basal 50 cm than above this depth. This study site is quite close to the land margin and the peat does not appear to have been dug (3.4). The lowest peat layers from which samples were taken were probably formed soon after the time of the Romano-British marine transgression, but the cation levels do not appear to have been strongly influenced by the estuarine conditions prevailing in the valley at this time. This area was probably more strongly influenced by water draining from the surrounding land which is underlain by Norwich Crag, an acidic substratum, which could explain the quite low levels of cations found in these deep horizons. The increase in levels of calcium, magnesium and sodium between 120 cm and 60 cm below the peat surface could have been caused by generally increasing water levels causing flooding by water from the river at a later date. The decrease in levels of these three cations in the surface 40 cm of peat which is also found in the upper peat layers in other sites of the internal system (e.g. Figs. 5.19, 5.21 and 5.25) perhaps indicates that oligotrophication of the internal system is taking place as it is now quite isolated from flooding by river water (4.4.1). The chemical profile from the northern part of Great Fen (Fig. 5.10) exhibits similar patterns to those described above in Sedge Marshes.

The relatively constant levels of the major cations beneath the *Betulo-Dryopteridetum cristatae* community developed over an overgrown dyke in Sedge Marshes (Fig. 5.20) and beneath the *Peucedano-Phragmitetum caricetosum* community in the central part of Great Fen (Fig. 5.10) could be due to the formation of these peats in quite recent peat cuttings. Other areas where peat cutting has apparently taken place quite recently (e.g. Main Reed Marsh) do not have such constant cation levels in the profiles, however.

An interesting feature of many of the profiles examined is the increase in potassium levels at the peat surface (Figs. 5.10, 5.11, 5.14, 5.20, 5.25). Recycling of potassium from the lower peat layers by deep rooted species is likely to maintain high levels at the surface and as many samples were collected in the autumn the potassium levels may be enhanced by leaching from freshly fallen litter. Damman (1978) found that most of the potassium in ombrotrophic bogs was in the surface peat layers.

Oligotrophication in surface *Sphagnum* peats

Generally levels of calcium and magnesium were lower in water samples taken from *Sphagnum* peat layers than from the underlying layers. This effect was particularly pronounced in the water samples from the *Betulo-Myricetum* community in Great Fen (Fig. 5.11), but could also be seen in areas with shallower *Sphagnum* peats, for instance in the *Betulo-Dryopteridetum* *cristatae* community in Irstead Poor's Fen. In the profile of cation levels beneath the *Betulo-Dryopteridetum cristatae* community in Fenside Marsh (Fig. 5.21) the levels of calcium were lower in the peat underlying the *Sphagnum* peat than in corresponding layers in the adjacent *Cladietum marisci* community which could have favoured the invasion of *Sphagnum* into this area. Calcium levels in the profiles of peat water chemistry from the *Betulo-Myricetum* community in Great Fen (Fig. 5.11) and the *Betulo-Dryopteridetum cristatae* community in Main Reed Marsh (Fig. 5.25) were lower below the *Sphagnum* peat layers than at greater depths. These decreased levels perhaps indicate that some oligotrophication had taken place before the invasion of *Sphagnum*. However, it is not known if these levels were the same at the time of formation of the peat deposits.

5.6.3. Surface oligotrophication of the fens

The peat and peat water chemistry transects from Great Fen to Barton Broad (Figs. 5.2., 5.3) demonstrate the oligotrophic nature of the peats beneath the *Betulo-Myricetum* and to a lesser extent those beneath the *Betulo-Dryopteridetum cristatae* community. Levels of pH, calcium and magnesium are low in such areas, but levels of sodium and potassium are not necessarily low (4.5.7). The short detailed transect of surface peat water chemistry across the *Peucedano-Phragmitetum caricetosum* community in Great Fen (Fig. 5.13) suggested that oligotrophication was taking place in more raised parts of the peat surface in the eastern part of this marsh. The occurrence of *Carex lasiocarpa* in the *Betulo-Dryopteridetum cristatae* community on this transect perhaps suggests that it has formed over a *Peucedano-Phragmitetum caricetosum* community.

The chemical analyses of peats and surface peat waters along transects which cross the boundaries of *Betulo-Dryopteridetum cristatae* communities with adjacent fen communities do not indicate that levels of pH, calcium or magnesium are necessarily low in the areas where *Sphagnum* appears to be expanding into the adjacent fen. In the transects from Main Reed Marsh pH values were lower (especially peat pH values) in the transition zone than in the adjacent *Cicuto-Phragmitetum* community. Some *Sphagnum squarrosum* was present here (Fig. 5.22) which may have been contributing to the acidity of the peat. In this transition zone calcium and magnesium levels were higher in the peat and surface peat water samples, than in those from the surrounding communities (5.9).

Clymo (1973) demonstrated that the growth of 'pioneer' *Sphagnum* species such as *Sphagnum squarrosum* and *S. subnitens* was not significantly reduced by 5 meq l^{-1} calcium concentrations in solution culture, but that high pH combined with high calcium concentrations were generally injurious to *Sphagnum* spp. It seems likely that *Sphagnum* species are colonising areas with quite high concentrations of the major cations probably in areas less susceptible to inundation.

5.7. CONCLUSIONS

1) The effects of eutrophication by river or land drainage water appear to be restricted to the margins of the study area.

2) Some correlations between the levels of cations in the dyke system and those found in the surface waters of the fens can be made.

3) In one area examined major cation levels were higher at dyke margins than in the central areas of the herbaceous fen community. There was evidence that this is the case in other areas.

4) The levels of the major cations in the upper peat layers are strongly influenced by the chemical composition of the underlying deposits in some areas, in particular by clay deposits.

5) There was some evidence that the internal system is becoming more oligotrophic than it was in the past.

6) Superficial oligotrophication occurs in *Sphagnum* communities. Evidence that oligotrophication may have occurred prior to *Sphagnum* invasion is contradictory. It appears that *Sphagnum* is invading areas with quite high levels of cations which are slightly more elevated and probably less frequently submerged by floodwater.

CHAPTER 6

THE EFFECTS OF MANAGEMENT ON THE VEGETATION OF THE STUDY AREA

6.1. INTRODUCTION

That man has been an important factor in influencing the distribution of the vegetation of the Catfield and Irstead Fens is indicated by the many straight boundaries between vegetation types (Plate 3). Whilst some of these boundaries relate to the distribution of peat cuttings (Figs. 2.1, 2.2), discrete boundaries are also present which delimit areas of vegetation still managed from areas that have been allowed to become derelict (e.g. the boundaries between the *Peucedano-Phragmitetum schoenetosum* and the *P.-P. myricetosum*) places.

The significance of management in determining the relative importance of various herbaceous fen dominants has been stressed (Godwin 1929; Lambert 1951) and possible effects of management on species density are discussed by Wheeler and Giller (1982a). Several management experiments have been established to examine the long term effects of the instigation of management regimes on the structure and composition of the vegetation. Also included here is some anecdotal and observational evidence of past and present management in the study area.

6.2. MATERIALS AND METHODS

6.2.1. Experimental design

As far as possible a large area of floristically and physiognomically uniform vegetation was selected within the community under examination. This was not always completely feasible due to the natural heterogeneity of vegetation. Each selected area was divided into several adjacent plots (depending on the number of management permutations to be examined) and the plots were marked out with large posts. To reduce trampling damage to a minimum paths between the plots were used wherever possible, except during management when crossing the plots is both necessary and part of the management practice. In each experiment a control plot was left untouched to allow future comparison with the managed plots.

6.2.2. Management

All mowing was carried out using a hand scythe. A Norfolk pattern 'Ajax' scythe stick (The Rake Factory, Sicklesmere, Suffolk) and 30" scythe blade (Tyzack & Co. Ltd., Sheffield) were obtained and assembled to personal specifications at The Smithy, East Ruston. All mown plant material was removed unless otherwise stated. Mowing machines were not used, to minimise disturbance and compaction of the peat. Shrubs and trees were removed using a billhook and in some cases glyphosate ('Round up', Monsanto Ltd) was painted onto the stumps to prevent regrowth.

6.2.3. Monitoring of management experiments

Metre square permanent quadrats were placed at equal intervals roughly in the centre of each plot. The shoot frequency (% occurrence of shoots in 25 (20 x 20 cm) sub-divisions of the quadrat) of the vegetation in each permanent quadrat was recorded annually in June. In some cases the number of species within 20 randomly placed half-metre square quadrats was recorded at the same time.

6.2.4. Measurements of light attenuation

Light intensity measurements were taken simultaneously at measured heights within the vegetation and above the vegetation using a matched pair of EEL Lightmeter Photometers. Light attenuation (as a percentage of incident light) was calculated from these two readings. As far as possible measurements were taken only in uniform, cloudy conditions between 15 July 1981 and 21 July 1981.

6.2.5. Problems of vegetation recording in herbaceous fen vegetation

The tall dense nature of the vegetation in the herbaceous fen communities of the Broadland flood plain mires makes the placing of quadrats at the base of the vegetation impossible without severe compression and damage to the vegetation in most cases. Rooted frequency estimates are therefore impractical as disturbance of the vegetation during recording must be minimised when examining the impact of management practices on the vegetation. Shoot frequency is more practical as the quadrat can be held in the vegetation at a height of roughly one metre and the recorder can then view the vegetation from above and count the occurrence of species in the quadrat divisions. Again this is not without problems. Species with long narrow leaves or shoots which tend to bend over can give disproportionately high values of shoot frequency compared with their actual cover or rooted frequency.

For instance, a single leaf of *Carex lasiocarpa* or stem of *Juncus subnodulosus* could give shoot frequency values of up to 25% or more. Subjective cover estimates were not considered to be particularly useful in most cases due both to their inherent subjective nature and the need for potentially more accurate recording in examining changes in abundance of many species.

It was decided to monitor the vegetation on a shoot frequency basis with a view to further quantifying changes in the vegetation using different methods, for instance cover estimates where they seemed to be of particular use.

Cropping and weighing of the vegetation was not used to monitor changes in the vegetation as the long term committment to such work would be greater than future practical constraints might allow. It was considered that such measurements at the beginning and end of each experiment might be useful in comparisons of the long term effect of management experiments and preliminary measurements of the amount of above-ground plant material were taken at the beginning of each experiment.

6.3. ANECDOTAL, OBSERVATIONAL AND CARTOLOGICAL EVIDENCE OF MANAGEMENT

The earliest aerial photographs of the whole study area obtained are from the nationwide wartime flights of the RAF. At this time the vegetation of the study area was much more open than at present. Management of the marshes of Broadland has decreased considerably since the turn of the century and has ceased in many areas. The maintenance of much herbaceous vegetation in the Catfield and Irstead Fens is due to the continuation of management, if on a smaller scale. Changes in the amount of open vegetation can be detected by comparison of the vegetation map (Plate 3) with the distribution of trees in 1946 (Fig. 6.1).

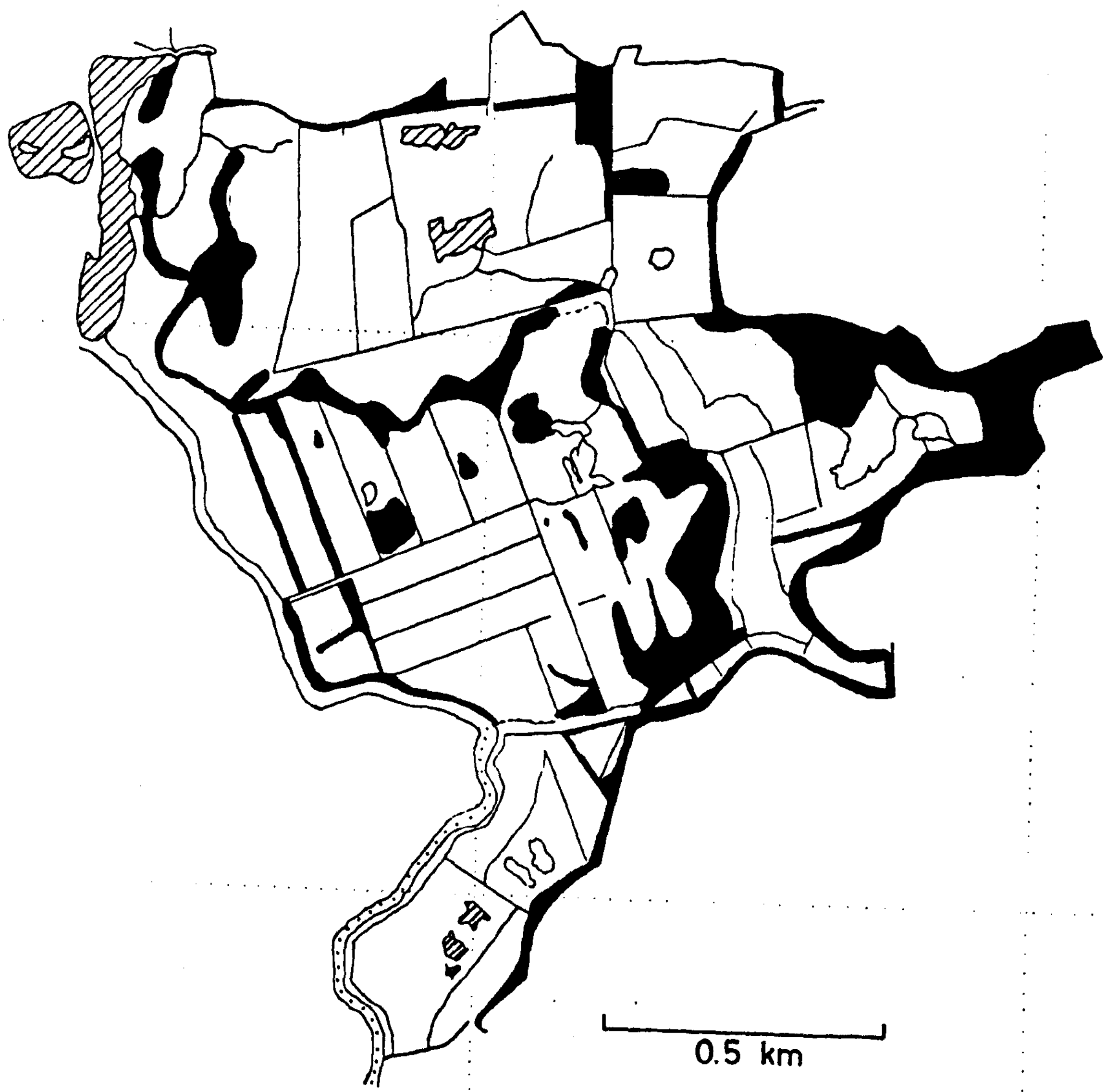


Fig. 6.1. Areas of swamp (▨) and woodland (■) as shown on an aerial photograph taken in 1946 (D.O.E.).

The extent of marginal vegetation along the edge of Barton Broad and in the two small broads in Fenside Marsh has decreased considerably since 1946 probably as a result of coypu activity (Lambert 1965; Boorman & Fuller 1981).

At present, much sedge (*Cladium mariscus*) and reed (*Phragmites*) is mown within the study area although harvesting of marsh hay or litter (mainly *Juncus subnodulosus*) has died out. Litter was mown in the summer, once or perhaps twice a year in more productive situations, but has not been harvested from the marshes of the study area for at least 25 years. The litter crop was processed by grinding, steaming and mixing with molasses before being made into winter cattle feed (B. Neave pers. comm.).

Mowing for sedge is usually on a cycle of three or more years and reed of one (single wale) or two years (double wale) (McDougall 1972). Sedge cutting in the study area during the past three years has been of three year old *Cladium* generally in marshes which are quite close to landing staithes (e.g. Moores Head Marsh, Sedge Marshes) but of older sedge (> 4 years old) in the more inaccessible areas (e.g. Irstead Poor's Fen). *Myrica gale* is a common species of the vegetation of the sedge beds of the *Peucedano-Phragmitetum schoenetosum* and in the three years left between successive mowings can reach a large size (0.5-0.75 m tall). In the cases where mowing is left for a longer period of time *Myrica* bushes are correspondingly larger and more difficult to mow through. This means that with decreasing frequency of mowing *Myrica* bushes are likely to reach a size at which the marshmen will tend to mow around the bushes rather than remove them. In the past before the introduction of 'piece-rate' payment for mowing, bushes were cut back individually below the peat surface with a knife and removed (J. Faircloth pers. comm.). Now these are simply left as stumps (≃ 10 cm above the peat surface) which regenerate.

In most marshes (e.g. Sedge Marshes) large areas, in some cases the whole compartment, were cut at the same time. In the central area of Great Fen mowing of the summer sedge crop was much more haphazard than in other marshes; small, different areas were cut in successive cases, the wettest areas being left uncut. Mowing of sedge occurred between April and November, In some cases *Cladium* failed to regenerate when cut underwater, presumably due to the lack of oxygen for respiration.

Reed is also harvested in many marshes within the study area, normally as a double wale crop. The reed crop has declined progressively in many areas of marsh, especially the reed beds of Neatishead Poor's Fen (P. Neave pers. comm.) The crop now contains much more 'gladden' or 'pokers' *(Typha angustifolia)* than was the case previously,reducing the economic value of the crop considerably. P. Neave (pers. comm.) suggests that these changes are due to the cessation of 'turfing out' (cutting of the surface 2-3 ft of peat) and that the reed fails as 'the bottom comes up'. It is certainly true that generally within the study area the reed grows much taller in wetter areas.

Reed and sedge cutting have both expanded as managment practices recently due to the rise in prices obtained for the crops.

Burning has also been observed in several areas of marsh in an attempt to remove shrub cover or 'clean-up' the marshes. Patches of *Salix cinerea, Myrica gale* and *Betula pubescens* subject to such burning have been examined in successive years and although the main trunks are often killed, regrowth usually takes place immediately from the bases of the plants which are presumably little damaged during such fires.

Another management practice which has now been abandoned is the pulling of *Sphagnum* which certainly occurred in the area of Great Fen which is now a *Betulo-Myricetum peucedanetosum Sphagnum* var. community (Site 14. BM). Up to 30 bags a week were taken away by cart in the past to be sold to florists as a packing material (P. Neave pers. comm.). This practice still occurs in some of the flood plain mires of the Netherlands (Gorter 1962).

The use of the large pool in central Great Fen for duck shooting has caused severe trampling damage to the vegetation since 1977 - a wide band of peat slurry now marks the normal route used when feeding the decoy birds.

6.4. MANAGEMENT EXPERIMENTS

The results of vegetation monitoring in the management experiments presented here can only be regarded as very preliminary and inconclusive as such experiments are necessarily long term. No statistical analysis has therefore been applied. It is hoped that these experiments will be continued for a further 10-15 years to provide more definite information on the effects of various management regimes on the structure and composition of the vegetation. Interpretation of the results is complicated by possible effects of variation in climatic conditions and water levels in different years on the vegetation.

6.4.1. Neatishead Poor's Fen Experiment

The *Phragmites-Typha angustifolia* community in which this management experiment was situated had poor, sparse reed growth and a dense carpet of *Agrostis stolonifera* covering the peat surface.

Objectives:

To investigate the possibility that poor reed growth may have been related to late mowing, after the emergence of colts on *Phragmites* and may also be related to the presence of the dense carpet of *Agrostis stolonifera.*

Treatments:

Four management regimes were instigated in 5 x 15 m plots: a control plot (1), a June mowing regime (2), a winter mowing regime (between January and March) (3) and winter mowing coupled with removal of the *Agrostis stolonifera* carpet (4).

Preliminary results (Table 5.1):

The shoot frequency of *Phragmites* and *Typha angustifolia* were both lower in the June mown plot in 1981 than in previous years while the shoot frequency results indicate no change in the amount of *Agrostis stolonifera* in any of the plots, visually the difference was very striking. Subjective estimates of cover of *Agrostis stolonifera* in June 1981 show that the cover in the June mown plot (1) was higher than that in the other plots. Removal of *Agrostis* in plot 4 was not completely successful but had reduced the cover considerably. The average height of *Phragmites* and *Typha angustifolia* in June 1981 was estimated to be approximately 1 m except in the control plot where it was roughly 1.4 m. Measurements of light attenuation at the base of the vegetation in each plot in August showed that light attenuation was less in all of the mown plots (< 48%) than in the control plot (85.7%) and was least in the June mown plot.

Table 6.1. Preliminary results of the management experiment in Neatishead Poor's Fen. Values are mean shoot frequency (%) in 3 permanent quadrats (1 m^2). Treatments: (1) = June mowing, (2) = Control, (3) = Winter mowing, (4) winter mowing + *Agrostis* removal.

	1979				1980				1981			
	1	2	3	4	1	2	3	4	1	2	3	4
Phragmites communis	93	100	100	99	100	100	100	100	84	100	100	100
Typha angustifolia	83	83	59	56	100	88	72	71	76	57	72	71
Agrostis stolonifera	100	100	100	100	100	100	100	100	100	100	100	100
Galium palustre	1	43	42	27	3	56	48	38	1	91	51	20
Lythrum salicaria	9	5	1	7	29	20	15	11	13	32	8	16
Epilobium palustre	8	3	4	1	8	3	13	29				
Peucedanum palustre	12	3			11	4	9	8		7		1
Rumex hydrolapthum	1		4	1	11		11	5	1	3	5	9
Stellaria palustris		1	1			5						
Lycopus europaeus	15	3										
Cardamine pratensis	1	4									4	
Atriplex hastata	27	20			4	5						
Oenanthe lachenalii			9	8								
O. fistulosa			1				9				7	1
Calystegia sepium			9	44			22	55			9	3
Solanium dulcamara			3					5				
Berula erecta			1									
Lemna minor												
Bryophytes[1]	11	3	4		2	3	2		4	83	37	32
Cover of *Agrostis stolonifera* (%)									95-100	80-90	80-90	20-30
Light attenuation (%) (at the base of each plot) (mean of 5 readings)									21	86	46.8	47.7

[1]*Drepanocladus fluitans, Campylium stellatum*

The effect of summer mowing compared with winter mowing already seems to be pronounced in relation to the shoot frequency and light attenuation of *Phragmites* and *Typha angustifolia.* It seems likely that this has led to the greater cover of *Agrostis stolonifera* in this plot in 1981. Light attenuation was also less in the two winter mown plots than in the control plot but this does not seem to have caused any marked changes in the vegetation. The fewer number of associated species recorded in 1981 compared with previous years could be related to the very high water levels in the spring of this year (4.2.2).

An exclosure was erected in Neatishead Poor's Fen in 1979 to examine the long term effects of the exclusion of coypus.

6.4.2. Little Fen Experiment

This management experiment is situated in a *Peucedano-Phragmitetum typicum* community in Little Fen, close to the study site 5. LF. Little Fen is now unmanaged but was mown for litter in the past (P. Neave pers. comm.).

Objectives:

To examine the effect of the timing of summer mowing and the effect of crop removal on the composition and species density of the vegetation.

Treatments:

Four plots (10 x 30 m): August mowing with crop removal (1), June mowing with crop removal (2), Control (3), August mowing and crop left (4).

Preliminary results (Table 5.2):

The shoot frequency of many species including *Phragmites* and *Juncus subnodulosus* was very reduced in the August mowing with crop left plot in 1981. The effect of litter accumulation in this plot has been very marked in the first three years of mowing, forming a very dense carpet across the peat surface. The shoot frequency of many forbs has also decreased over the three year period (e.g. *Galium palustre, Lycopus europaeus, Peucedanum palustre*). The shoot frequency of *Galium palustre* and *Epilobium palustre* increased in the two plots which were mown and the litter removed. Many seedlings of *Valeriana officinalis* were also noted in areas outside the permanent quadrats in these two plots in 1981. The species density was also higher (> 10 spp/ 0.25 m^2) in the two plots which were mown and the crop removed

Table 6.2. Preliminary results of the Little Fen management experiment. Treatments: (1) August mown + litter removal, (2) June mown + litter removal, (3) Control and (4) August mown + litter left. Values are mean shoot frequency (%) in 3 permanent quadrats (1 m^2).

	1979				1980				1981			
	1	2	3	4	1	2	3	4	1	2	3	4
Phragmites communis	89	96	100	97	79	91	92	91	96	97	100	69
Juncus subnodulosus	67	77	67	100	67	100	67	100	67	100	67	68
Thelypteris palustris	91	100	57	1	93	100	65	7	97	99	100	7
Peucedanum palustre	51	48	44	39	71	79	47	44	45	35	47	15
Lysimachia vulgaris	1	7	31	16	12	7	4	17	8	1	7	12
Galium palustre	7	24	65	76	23	27	23	24	30	33	36	12
Lythrum salicaria	12	5	9	5	13	9	28	13	19	16	21	7
Epilobium palustre	4	4	23	16	23	24	13	15	43	21	20	8
Potentilla palustris	1	3	9	25	1	3	19	30	5	7	8	27
Lycopus europaeus			11	27		5	15	9	5	8	10	5
Agrostis stolonifera		1		33	3	4	7	11	12		19	20
Rumex hydrolapathum		1	4	1	1	5	4	1		5	4	
Stellaria palustris			31	5		12	19	16	13	7	12	1
Valeriana officinalis	23				39	7			23			
Filipendula ulmaria	21			7	25			9	25			7
Cardamine pratensis				3	16		12	3			13	3
Scutellaria galericulata		1		5		4		1		3	1	
Typha angustifolia			3	9			3	15				3
T. latifolia	1			1	1							
Iris pseudacorus		1			1	3			1			
Carex acutiformis				4				9				3
Carex elata	5				4				7		1	
Calamagrostis canescens					13				3	16		
Ranunculus lingua			1				5			3		
Solanum dulcamara		7				3						
Epipactis palustris	11				13				12			
Ophioglossum vulgatum	11				7				13			
Lemna minor								24			1	1
Sium latifolium							1					
Bryophytes[1]	16	39	16	67	33	20	47	9	84	61	59	38
No. spp./0.25 m^2 mean	8.0	8.0	7.9	7.7	7.7	7.9	7.7	7.2	10.0	10.8	8.8	7.2
range	5-12	6-10	5-10	5-10	5-12	6-10	5-10	6-10	7-14	8-13	6-12	6-12

[1]*Calliergon cordifolium, C. cuspidatum, Mnium punctatum, Bryum pseudotriquetrum*

in 1981 than in the control plot or the plot which was mown and the crop left (< 9 spp/0.25 m^2).

It seems that the accumulation of a dense litter mat in the August mown plot where the litter is not removed is already having effects on the shoot frequency of many species and may also have reduced the species density. No marked differences between the June and August mown plots where the litter is removed are discernable as yet.

6.4.3. Great Fen (North) Experiment

Many parts of the *Peucedano-Phragmitetum caricetosum* community in this fen have become invaded with a dense growth of *Myrica gale, Salix cinerea* and *Betula pubescens*.

Objectives:

To examine the re-establishment of open herbaceous fen vegetation subsequent to the removal of scrub and reinstatement of a mowing regime.

Treatments:

Two plots (5 x 15 m):(1). Three yearly June mowing (2) Control. The plots are situated along a gradient from moderate bush growth (≃ 1.5 m in height) to dense bush growth (2-2.5 m in height). A permanent quadrat was located in the area of moderate bush growth (A) and dense bush growth (B) in each plot.

Preliminary results (Table 6.3).

As the experiment plot has only been cleared and mown once, little can be deduced of the long term effects of management. The results demonstrate the difference in the number of species which occurred beneath the shrub layer at each end of the plot. Although there was a high frequency of *Betula pubescens*, *Myrica gale* and *Salix cinerea* in the area of moderate bush growth many herbaceous species were found, persisting below the canopy while in the more mature, dense bush growth areas there were comparatively few herbaceous species. In this respect the experiment provides immediate results suggesting that a detailed examination of the flora in shrub invaded areas will indicate the immediate usefulness of management in terms of the rehabilitation of herbaceous fen.

Some species not recorded underneath the dense carr in the plot which was cleared were present a year after mowing. *Carex appropinquata* and *C. lasiocarpa* were recorded in 1980 and leaves of these species were overhanging the quadrat from plants rooting outside. *Galium palustre*, *Lycopus europaeus*, *Potentilla palustris* and *Agrostis stolonifera* were actually rooting within the quadrat. It is not clear by what method of regeneration these species had colonized the quadrat. *Cirsium palustre* was recorded under the dense carr in the control plot but this was a plant closely adjacent to the quadrat whose leaves were overhanging the recorded area. Shoot frequency of many herbaceous (e.g. *Carex appropinquata*, *Mentha aquatica*) plants

Table 6.3. Preliminary results of the management experiment in Great Fen (North). Treatments: (1) three-yearly mowing, (2) Control. (See text for explanation). Values are shoot frequency (%) in 1 m^2 permanent quadrats.

	1979				1980				1981			
	1A	2A	1B	2B	1A	2A	1B	2B	1A	2A	1B	2B
Betula pubescens	25											
Myrica gale	4	68	100	96		48	92	100		52	100	100
Salix cinerea	84	56			40	100			48	100		
S. repens		36	20			64	52			60	48	
Cladium mariscus	52	60		30	92	100		36	100	100		32
Phragmites communis	52	36	44	100	64	52	68	100	72	48	60	100
Juncus subnodulosus	100	100	12	60	96	100	36	80	100	100	40	92
Peucedanum palustre	44	56	48		52	72	40	60	48	88	64	56
Schoenus nigricans	24	20			20	24			20	36		
Carex elata	76	68	40		92	100	76	20	100	92	80	16
C. appropinquata	8	4			20	52	4		24	46	28	
C. lasiocarpa	52	100			84	100	4		100	100	16	
Molinia caerulea	16	36			10	40			24	36		
Galium palustre	92	16	16		100	20	20		100	48	64	
Hydrocotyle vulgaris	100	28			100	36			100	44		
Agrostis stolonifera	100	24			68	28	48		100	28	40	
Menyanthes trifoliata	100	100	48	8	96	100	44	12	100	100	52	8
Mentha aquatica	12	8			20	4			24	4		
Potentilla palustris	4	12				20	8			20	16	
Liparis loeselii	8				8				8			
Equisetum fluviatile	8		8	20	4		12	12	16		8	16
Lythrum salicaria		8			8	24	12	8	24	8	16	
Calamagrostis canescens				72				28				44
Solanum dulcamara				12			4	28				32
Cardamine pratensis				12	8				28			
Epilobium palustre						4						
Cirsium palustre								4				16
Lycopus europaeus							4				8	
Bryophytes[1]	28	36			24	32		56				

[1] *Calliergon giganteum, C. cuspidatum, Camplyium stellatum, Mnium pseudopunctatum, Bryum pseudotriquetrum*

within the permanent quadrat under less dense carr in the cleared plot was higher in 1980 than in 1979, although these plants had been cut back in 1979.

A further experiment designed to investigate the effect of annual summer mowing in the *Peucedano-Phragmitetum-caricetosum Menyanthes* var. *Molinia* sub. var. community of Great Fen North was established in 1980. *Cirsium dissectum, Molinia caerulea, Carex* spp., *Anagallis tenella* and *Samolus valerandi* were all flowering well in the mown area in 1981.

6.4.4. Fenside Marsh Experiment

This experiment is situated in a densely wooded *Betulo-Dryopteridetum cristatae* community at the southern edge of Fenside Outer Broad.

Objectives:

To investigate the effects of various methods of tree removal in the future development of the community. (In particular on the survival and performance of *Sphagnum* spp. and *Dryopteris cristata*).

Treatments:

Four plots (7 x 10 m). (1) trees removed and glyphosate applied to stumps, (2) trees removed, (3) control, (4) trees ring-barked.

Preliminary results (Table 6.4):

Methods of tree removal met with varying success. The application of glyphosate in plot 1 only killed 18% of the trees and in both plots where the trees were removed many new suckers had been produced from the base of the stumps. Re-application of glyphosate in plot 1 failed to kill many of the trees. Ringing of the trees in plot 4 was completely unsuccessful in killing the trees. In a few cases the main trunks of *Betula pubescens* had died but in all cases many more suckers had grown up from the base of the trunks. In 1980 the management of this plot was modified with greater success. A cut was made through the base of the live main trunks of the saplings and glyphosate painted onto the exposed wood. In 1981 few of the trees were still alive and the suckers at the base had also been killed.

No effect of the management on the frequency of *Sphagnum* was apparent in 1980. *Sphagnum* hummocks were often more bleached and desiccated on the surface between June and August in plots 1 and 2 than in the other plots but were not apparently different in the winter. *Dryopteris carthusiana* and *D. cristata* were not recorded in 1981 in plot 4 but were present elsewhere within the plot.

Table 6.4. Preliminary results of the management experiment in Fenside Marsh. Treatments: (1) = Clear felled and glyphosate applied, (2) = clear felled, (3) Control, (4) ring-barked. Values are mean shoot frequency (%) in three (1 m^2) permanent quadrats.

	1979				1980				1981			
	1	2	3	4	1	2	3	4	1	2	3	4
Betula pubescens	95	91	84	93	36	37	88	100	60	75	91	21
Salix cinerea	9	8	8	8	17	3	6	16	7	5	1	
Alnus glutinosa	11	5			4	1						
Myrica gale	4	8		4		1		10		4	7	8
Rubus fruticosus			3				4				3	
Quercus robur			3	3			5	10			5	1
Phragmites communis	53	23	83	44	56	61	37	56	79	71	61	33
Juncus subnodulosus	24	19	75	95	26	5	61	59	33	17	59	85
Cladium mariscus	13		25	33	7		33	33	12		33	21
Dryopteris carthusiana	11	28	33	19	8	35	45	25	16	49	47	
D. dilatata		12	8				3				13	
D. cristata		1	5	4			5	3		1	8	
Thelypteris palustris	7			7	13		8	8				
Eupatorium cannabinum	1											
Peucedanum palustre	7				4				8			
Calamagrostis canescens	11				13	4			23	11		1
Potentilla palustris		5										
Lythrum salicaria		1										
Carex elata				4								
Sphagnum spp.[1]	100	100	84	84	100	100	88	80	97	100	100	95
Polytrichum commune	4	19				16				19		

1
Sphagnum capillifolium, S. fimbriatum, S. magellanicum, S. palustre, S. recurvum, S. subnitens, S. squarrosum, S. teres.
Other bryophytes; *Aulacommium palustre, Calypogeia muellerana.*

6.4.5. Main Reed Marsh Experiment

The experiment was established across a transition zone between a *Betulo-Dryopteridetum cristatae* community and a *Cicuto-Phragmitetum* community (close to the transect described in 5.5.6).

Objectives:

To monitor any invasion of *Sphagnum* into the *Cicuto-Phragmitetum* community and to examine the effect of winter mowing on the rate of *Sphagnum* expansion and on the frequency of *Dryopteris cristata*.

Treatments:

Two plots (7 x 20 m): a control plot and a winter mown plot. In each plot two permanent quadrats were sited in the *Betulo-Dryopteridetum cristatae* community and two within the *Cicuto-Phragmitetum* community. A line of marker posts was placed to delimit the areas in which *Sphagnum* occurred in 1979.

Preliminary results (Table 6.5):

Unfortunately a misunderstanding with the local marsh-men led to the mowing of the *Cicuto-Phragmitetum* areas in both of the plots in the winter 1979-1980 and the destruction of the

Table 6.5. Preliminary results of the management experiment in Main Reed Marsh. (1) *Betulo-Dryopteridetum cristatae* community, (2) *Cicuto-Phragmitetum* community. Values are mean shoot frequency in 2 (1 m^2) permanent quadrats.

	1979				1980				1981			
	Mown		Control		Mown		Control		Mown		Control	
	1	2	1	2	1	2	1	2	1	2	1	2
Phragmites communis	100	100	90	100	100	100	66	100	92	100	50	100
Typha angustifolia	16	44	30	60	38	92	38	34	48	88	32	56
Potentilla palustris	16	44	18	4	32	4	10		44	28		8
Peucedanum palustre	100		100	40	100		100		100		96	
Epilobium palustre	6	36		14	2	60		44		12		4
Lysimachia vulgaris	6	32	18		2	12	4	18		12	4	76
Calamagrostis canescens	38		50		62		86		80		82	
Rumex hydrolapathum	6	4	14	40	6	20	8		8	4	4	16
Dryopteris carthusiana			2				4				6	
D. cristata	14		14		16		10		20		14	
Juncus subnodulosus			54				58				84	
Thelypteris palustris	6		40		36		20		52		36	
Lycopus europaeus	2	12		34	2	8	2	8		12		4
Galium palustre		32		26		20		8		84		36
Cicuta virosa	10	8		26	2	36		2				
Carex pseudocyperus	2	42		42		24				60		42
Sium latifolium		42		20		4		32		4		24
Cardamine pratensis		6		14		4				32		24
Agrostis stolonifera		6		32				8		12		68
Lemna minor		52		2						20		16
Stellaria palustris				2		2						
Myosotis caespitosa				2								
Salix cinerea				10	4		4	8	6	8	6	20
Utricularia vulgaris								2				
Sphagnum[1]	100		100		100		100		100		100	8
Brown mosses[2]		88		96		78		48		100		100

1 *Sphagnum fimbriatum, S. subnitens, S. squarrosum.*

2 *Calliergon cordifolium, C. cuspidatum, Campylium stellatum, Drepanocladus fluitans.*

permanent quadrats within this community. The quadrats were replaced in the following summer but could not be relocated in exactly the same position as before. The species composition within the replacement quadrats was very similar to that in the original quadrats.

The frequency of *Dryopteris cristata* increased more in the mown plot than in the control plot, the plants present also being of greater size in the mown plot. The area of *Sphagnum* delimited by marker plots had not change noticeably in 1981 from that in 1979. However, a few isolated plants of *Sphagnum squarrosum* were found within the *Cicuto-Phragmitetum* community of both plots in 1981, two of these occurred in the permanent quadrat of the control plot. The plants were in all cases submerged by shallow water (c. 5 cm deep) at the time of monitoring.

6.5. Measurements of light attenuation in herbaceous fen vegetation

Light attenuation within stands of *Cladium mariscus* dominated vegetation are shown in Fig. 6.2. The height at which no light attenuation occurred indicates the height of the vegetation in each case. Less than 40% of the incident light penetrated to within 40 cm of the peat surface in the unmanaged sedge bed in Irstead Poor's Fen, attenuation being greater than 99% at the peat surface. This species-poor *Cladium* dominated area contained only few associated species (e.g. *Juncus subnodulosus, Carex lasiocarpa, Myrica gale*) and had not been mown for at least six years.

In the managed sedge beds there was light penetration at the peat surface in the areas which had been mown in the previous year compared with areas which had been mown two or three

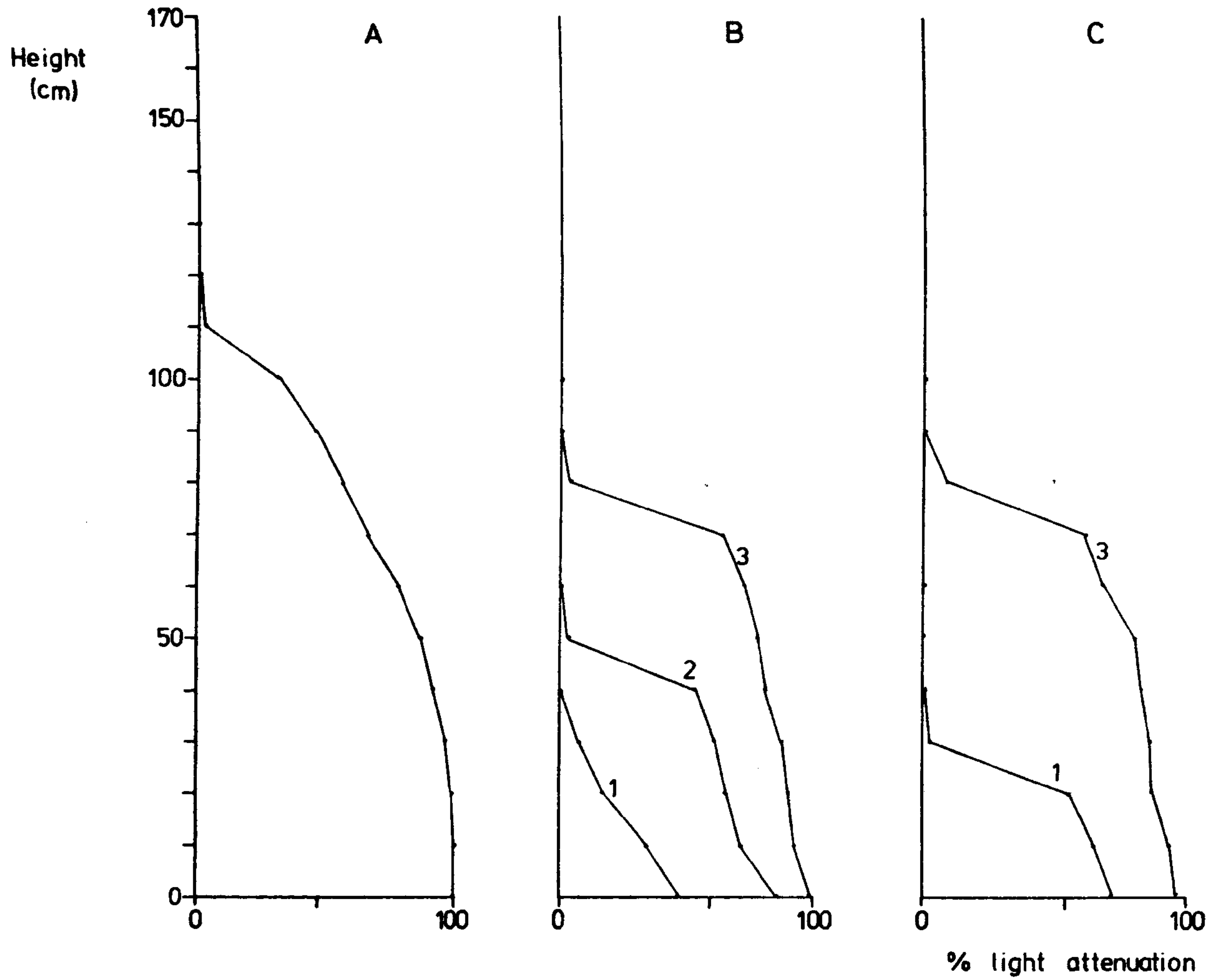


Fig. 6.2. Light attenuation in an unmanaged *Cladium* sociation community in Irstead Poor's Fen (A), a managed *Peucedano-Phragmitetum caricetosum* community in Central Great Fen (B) and a managed *P.-P. schoenetosum* community in Sedge Marshes (C). The numbers denote the number of years since mowing.

years before the measurements were taken. The greater attenuation found in Sedge Marshes compared with that in Great Fen in areas mown a year before is probably because Sedge Marshes was mown earlier in the year than Great Fen. Light attenuation was considerably greater in the area of Great Fen which was mown in 1979 and in those areas mown in 1978 (three years before the time of measurement) there was less than 96% of the incident radiation at the peat surface. There was little difference in the profiles of light attenuation in areas not mown for three years between the *Peucedano-Phragmitetum schoenetosum* community in Sedge Marshes and the *P.-P. caricetosum* community in Great Fen.

In the *Phragmites* beds in Irstead Poor's Fen light attenuation was greater beneath the managed reed than beneath the regularly managed reed (Fig. 6.3). The reduction of light at the peat surface in the managed reed bed was still quite high (76% of incident radiation) even though this area had been mown during the preceding winter. In most of the profiles of light attenuation described above the major part of the attenuation of light occurs in the upper 50 cm of the vegetation. In the profiles from the *Phragmites-Typha angustifolia* communities in Irstead Poor's Fen and Neatishead Poor's Fen the change in light attenuation is more gradual to similar levels (72% of incident radiation) at the base of the vegetation.

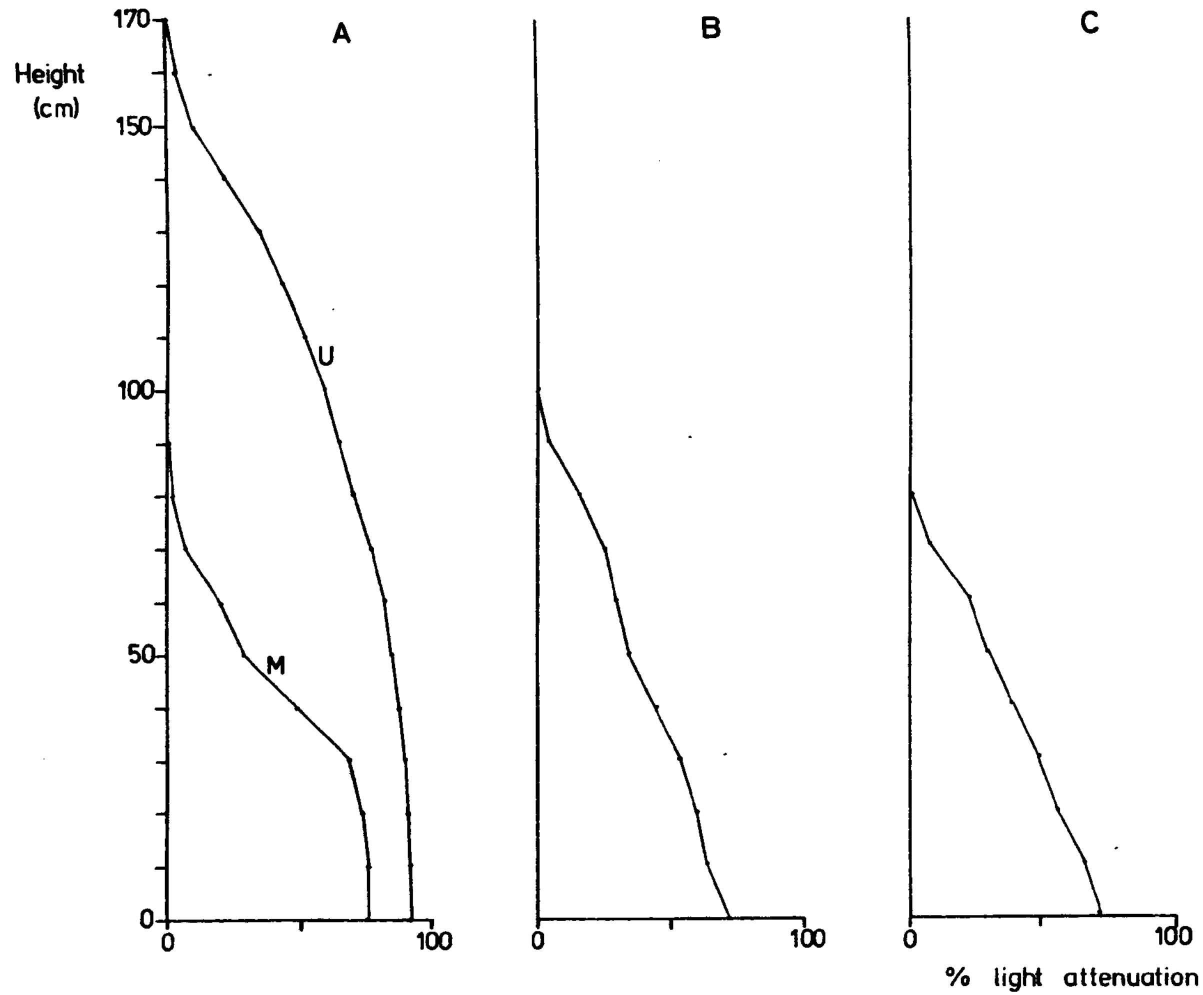


Fig. 6.3. Light attenuation in a *Phragmites-Sium latifolium* community in Irstead Poor's Fen (A), and *Phragmites-Typha angustifolia* community in Irstead Poor's Fen (B) and Neatishead Poor's Fen (C).

6.6. DISCUSSION

6.6.1. Management, light attenuation and possible effects on the vegetation

In the managed *Phragmites* bed in Irstead Poor's Fen light attenuation was quite severe in August after mowing in the previous winter while in *Cladium* dominated vegetation light attenuation was less a year after mowing. Reed beds are mown in the winter months when the dead *Phragmites* shoots contain only 10-20% of their summer mineral content (Haslam 1972) and before the emergence of new colts. Winter mowing of reed has little deleterious effect on the subsequent growth of *Phragmites*, indeed single wale cutting increases the shoot density and may give higher yields compared with double wale cutting (Haslam 1972). In particularly nutrient poor situations successive cropping may lead to a reduction in productivity due to nutrient depletion (Haslam 1972) as vigorous *Phragmites* growth is often associated with nutrient-rich conditions (Gorham & Pearsall 1956b). *Cladium* appears to be a slow growing species and has long lived, evergreen leaves (Conway 1936). Summer mowing has a marked effect on the biomass of *Cladium* in subsequent growing seasons with a corresponding increase in light penetration. Godwin (1941) found that the level of above-ground plant material of *Cladium* was restored to its former level in the fourth year after cutting. Three years after mowing, the levels of light attenuation at the base of the *Cladium* dominated stands was almost as great as that in the unmanaged sedge bed (6.5).

Wheeler and Giller (1982a) demonstrated that species density is negatively correlated with the amount of above ground plant material in the herbaceous fen vegetation of Broadland and that managed sedge beds had higher species density than unmanaged sedge beds. The high light attenuation found in unmanaged *Cladium* stands is probably a major limiting factor on the growth of associated species. The high light attenuation found in managed sedge beds three years after mowing is also likely to be deleterious to the growth of many associates and periodic mowing is probably essential for the survival of many species. Boryslawski (1978) demonstrated that *Scorpidium scorpioides*, a species only found in managed sedge beds in the study area, is markedly intolerant of shade. The large number of associate species found in the quite densely shrub invaded *Peucedano-Phragmitetum caricetosum* community in Great Fen (North) (6.4.3.) suggests that many of these species are quite tolerant of shading at least for several years. The low species density of unmanaged sedge beds is probably partly due to accumulation of persistent litter (Godwin & Tansley 1929). The plot in the Little Fen management experiment where the mowings were left in place was less species-rich than areas where the litter was removed in 1981 (6.4.2.). Often in unmanaged areas, for example Little Fen, the distribution of some species (e.g. *Ophioglossum vulgatum*, *Dactylorhiza pratermissa)* is restricted to the tops of tussocks of species such as *Carex elata* and *Carex appropinquata* where light penetration may be greater.

In *Phragmites* beds light attenuation was quite high in recently managed areas. Unmanaged reedbeds may have higher species density than managed reed beds (Wheeler & Giller 1982a) but this is probably not due to better light attenuation.

Mowing of sedge is likely to be important in the success of flowering and seed dispersal (especially by wind) of associated species. The importance of gaps for regeneration in the maintenance of vegetation with high species density has been stressed (Grubb 1977; Grime 1979). Mowing regimes may favour germination of many species in bare peat areas which can often be seen after cutting. Plants which have seeds in which germination is inhibited by darkness, such as *Cirsium palustre* and *Juncus subnodulosus* (Thompson 1977) or which germinate best in the light and under fluctuating temperatures for example, *Peucedanum palustre* (Harvey & Meredith 1981) may germinate well once the insulating effect of the vegetation is removed by cutting. Seedlings were not commonly found in managed or unmanaged areas except those of some members of the Umbelliferae (e.g. *Peucedanum palustre, Sium latifolium* and *Oenanthe fistulosa*). Most of the species found in the herbaceous fen of the study area are perennials and many plants, including several low growing forbs (e.g. *Anagallis tenella, Hydrocotyle vulgaris*) have the capacity for vegetative reproduction and this may well be the most important method of regeneration, especially in areas with continously high water levels.

The ability of many species commonly found in the study area to regenerate from submerged fragments of stem within a few days has been demonstrated recently (Hodgson & Pearce, In prep.). For instance, 1 cm stem fragments of *Galium palustre* produced roots in 6-8 days and *Oenathe fistulosa* leaf fragments produced new shoots and roots quite quickly. Such an ability to root quickly from small fragments of plant may be important in the regeneration and possibly in the spread of species in regularly managed areas when the extensive trampling involved in mowing is considered.

In the *Phragmites-Typha angustifolia* communities light attenuation was not particularly severe (Fig. 6.3) and yet few associates occur (2.4). In the area examined in Neatishead Poor's Fen the lack of associated species could be related to the dense carpet of *Agrostis stolonifera* preventing the occurrence of suitable gaps for regeneration. It is not clear what has led to the poor reed growth and the success of *Agrostis*. If the growth of reed was debilitated in some way, for example by late mowing, coypu activity or by a particularly severe drought, the growth of *Agrostis* may be favoured due to better light penetration. Once *Agrostis stolonifera* had established as a dense mat over the peat surface it may have a repressive effect on the growth of *Phragmites*. Dense litter carpets can reduce the number of buds produced in *Phragmites* (Haslam 1972). A summer mowing regime in this community has certainly reduced the shoot frequency of *Phragmites* and *Typha angustifolia* with a corresponding increase in the cover of *Agrostis stolonifera* (6.5.1) but this is probably due to the debilitating effect of summer mowing on reed.

6.6.2. Management and oligotrophication

Repeated mowing with its associated removal of nutrients in the crop may lead to progressive nutrient depletion in nutrient poor areas. There is some evidence that the fens of the internal system of the study have become more oligotrophic in the surface peat layers and this may have favoured the invasion of *Sphagnum* in some areas. *Sphagnum squarrosum* has been found in the *Cicuto-Phragmitetum* community in Main Reed Marsh in 1981 (6.5.5.).

Whether the presence of tree cover is necessary for the prolonged growth of *Sphagnum* once it has become established is being examined (6.5.4) and initial results suggest that *Sphagnum* spp. are able to withstand the desiccation during the summer months where the tree cover has been removed. *Dryopteris cristata*, a ubiquitous species of the *Betulo-Dryopteridetum cristatae* communities, appears to produce fertile shoots only in open conditions and is rarely found in the mature wooded *Betulo-Myricetum Sphagnum* var. communities. The shoot frequency of this species has increased in the area of the *Betulo-Dryopteridetum cristatae* community in Main Reed Marsh which has been mown in the winter. Although these results are only preliminary it seems likely that the maintenance of open *Sphagnum* communities by tree clearance and/or mowing may favour the growth and persistence of *Dryopteris cristata* in the *Sphagnum* communities.

6.6.3. Other management practices

There is little available information on the long term effects of burning or grazing in fen communities. Grazing tends to favour the invasion and growth of species such as *Holcus lanatus* and leads to a reduction in the abundance of some species (e.g. *Angelica sylvestris, Lysimachia vulgaris, Iris pseudacorus, Filipendula ulmaria*) (Baker 1937; Lambert 1948). All but some areas at the land margins of the study area are probably too wet to allow the use of grazing as a management practice.

Winter burning would probably have less direct effect on many species (especially if carried out when the water table is high) than summer burning. The effects of burning on nutrient release and possible indirect effects on the vegetation are unknown.

6.6.4. The invasion of carr.

As described earlier many areas of the study area where mowing has been neglected now support fen woodland communities where herbaceous fen was previously present (6.3). This is not true of all areas; for instance, some areas of fen which have not been managed for at least 30 years (P. Neave, pers. comm.) are still comparatively free of bushes (e.g. Little Fen, the western parts of Great Fen). This may well be related to the dense persistent litter produced by species such as *Cladium mariscus* (Godwin & Tansley 1929) and *Juncus subnodulosus* (Richards & Clapham 1941) as the accumulation of thick sedge mattresses may reduce the rate of bush invasion (Lambert 1951). Management may in some cases increase the ability of species to invade fen communities by removing such dense litter mats. The invasion of carr in areas which were cut for peat in the last century indicates that these areas have reached a successional state where tree growth may occur rapidly. The development of fen carr at Wicken Fen, Cambridgeshire subsequent to the abandonment of mowing has been documented by Godwin, Clowes and Huntley (1974).

6.8. CONCLUSIONS

Management strategies which may help to maintain the diversity of vegetation of the study area

1) Active management involvement is necessary to maintain a herbaceous plagio-climax.

2) The immediate usefulness of shrub clearance in the rehabilitation of herbaceous vegetation can be assessed by a detailed examination of the flora persisting beneath the shrub canopy.

3) Management should be continued as at present in the species-rich sedge bed communities, the *Peucedano-Phragmitetum caricetosum* and the *P.-P. schoenetosum*.

4) Actively managed litter fen is very rare in Broadland. Re-instatement of annual summer mowing in sites with much *Juncus subnodulosus* (e.g. Little Fen) would add to the community diversity of the study area.

5) Control of tree growth in the *Betulo-Dryopteridetum cristatae* communities may be beneficial in maintaining a suitable habitat for the growth of *Dryopteris cristata*.

6) In the long term, peat cutting is essential to rejuvenate vegetation types characteristic of early hydroseral stages.

CHAPTER 7

GENERAL DISCUSSION

7.1. GRADIENTS OF CHEMICAL VARIATION

Within the Catfield and Irstead Fens there appear to be three main gradients of chemical variation: increasing base-saturation, increasing eutrophication and increasing salinity.

The majority of the marshes are rich-fen as they are inundated - at least periodically - by base-rich ground water. Developed within them are poor-fen communities, characterised by the presence of *Sphagnum*, which are not normally flooded by base-rich water.

In areas of rich-fen there are further gradients dependent on the quality of the water source. Eutrophic areas are found only at the land or river margins and within the remainder of the study area the degree of nutrient impoverishment is related to the degree of spatial or vertical isolation from sources of floodwater.

A further gradient is imposed by proximity to sources of brackish water, both from underlying deposits (5.6.2) and/or present day brackish water incursions (4.5.14). Obviously these gradients may be superimposed upon each other, for example, slightly oligotrophic areas may more readily give rise to poor-fen and saline, eutrophic fens may occur.

Within this scheme, two major lines of successional development can be recognized in the absence of management; the development of rich-fen carr communities and poor-fen carr communities. Associated with these successional trends is nutrient enrichment in rich-fen carr communities and progressive nutrient depletion and acidification in poor-fen carr communities.

A major factor determining the chemical and successional gradients is the differing hydrological status in fen communities, whether by variation of the quality of water within the site (due to spatial or vertical isolation) or by the effects of low summer water levels which may directly alter the course of succession. In turn the hydrological conditions prevailing in any area depends on the seral state of that area and human interference by peat removal or water level management.

Located within this complex of variation of the study area are the plant communities, the presence of which will depend on the past and present management involvement. In this discussion attention will be paid to the factors and processes which determine the present day pattern of vegetation in the Catfield and Irstead Fens, within this general scheme, and to the likely possibilities for future succession.

7.2. GENERAL RELATIONSHIPS TO ENVIRONMENTAL GRADIENTS

7.2.1. Chemical gradients

The surrounding upland of the study areas is naturally rather acidic and nutrient poor (2.6., D.S.A. McDougall pers. comm.). In some reflooded marshes at the land margins, where there is little input of agricultural drainage water the *Potentillo-Caricetum rostratae* communities occur. In Middle Marsh such a community adjoins a *Cirsio-Molinietum nardetosum* community with *Nardus stricta* and *Sieglingia decumbens*, and several *Potentillo-Caricetum* communities contain much *Sphagnum*, overall suggesting that these communities are developed in moderately oligotrophic areas. In contrast, where agricultural run-off enters the study area or close to the River Ant, the adjacent marshes support a eutrophic vegetation containing nutrient demanding species such as *Epilobium hirsutum*.

The effects of eutrophic water on the vegetation of the study area appear to be restricted to the very marginal fens described above, and most of the fens of the study area appear to be rather unproductive (Wheeler & Giller 1982a). Some communities, for instance the *Peucedano-Phragmitetum schoenetosum* appear to have low levels of essential nutrients in extractable form which may be due to depletion as a result of prolonged management as well as isolation from eutrophic water.

Exceptions to this general rule are some *Osmundo-Alnetum* and *Salix* carr communities. Examples of these community-types examined (4.5., 5.3.2) had comparatively high levels of extractable nitrogen and phosphorus, perhaps partly due to inundation with water from the River Ant and the influence of underlying deposits. These rich-fen carr communities have low summer water levels and the main cause of the high nutrient levels is likely to be rapid mineralisation of tree litter (perhaps coupled with nitrogen fixation input from *Alnus glutinosa*). Such communities are the only areas where *Phalaris arundinacea* and *Urtica dioica* occur away from the dyke margins in the study area and probably represent 'seral eutrophication' (cf. Green 1972). Similar successional invasion of fen carr by *Urtica dioica* and *Sambucus nigra* has been described from Wicken Fen, Cambridgeshire (Godwin, Clowes & Huntley 1974).

The distribution of some communities does not appear to be affected by the freshwater-saline gradient. *Peucedano-Phragmitetum schoenetosum, P.-P. myricetosum* and *Phragmites-Typha angustifolia* communities are found both in areas of low and high salinity in the study area (*P.-P. schoenetosum* communities are common in the saline fens of the Thurne valley (Wheeler & Giller 1982c)). *Peucedano-Phragmitetum cicutetosum, P.-P. typicum* and *Cladietum marisci* communities are found in areas of low to moderate salinity and the development of *Betulo-Dryopteridetum cristatae* communities has taken place in both such conditions (4.5., 5.5.3). Some species, for example, *Scirpus tabernaemontani* are only found in areas of moderate or high salinity in the study area. There are, however, some community-types which are only found in areas of relatively low salinity - the *Peucedano-Phragmitetum caricetosum* and the *Potentillo-Caricetum rostratae* (4.5., 5.4) - which appear to be isolated from brackish water and are not found in areas with underlying clay deposits.

7.2.2. Hydrological gradients

Variations in the relative height of the water level between different parts of the study area are considerably influenced by the presence of peat cuttings. In those areas apparently not cut for peat, the water levels fall well below the peat surface in the summer months. The extent to which the water levels fall is dependent on isolation from the dyke system (Godwin & Bharuca 1932), the water retention capacity of the peat (Boelter 1974) and the relative height of the peat surface. Community types almost completely restricted to uncut peat surfaces are the *Peucedano-Phragmitetum schoenetosum* and *P.-P. myricetosum* and also the *Osmundo-Alnetum*. In *Osmundo-Alnetum* communities the water level is well below the peat surface except during times of severe flooding in the winter.

In marshes which were cut for peat recently the surface peats are unconsolidated and subsidence of the peat surface can take place when water levels are low. The relative height of the water level in areas where the peat is unconsolidated are mainly dependent on the successional status of the plant communities and the method of colonisation of the peat cuttings. There appear to be two methods of colonisation, by establishment of emergent vegetation or by the invasion of semi-floating rhizome rafts. Swamp communities such as the *Cladietum marisci* and the *Scirpo-Phragmitetum* have high water levels throughout the year. The *Peucedano-Phragmitetum caricetosum* communities have widely differing water levels which are reflected in their species composition (7.3.1). In *Cicuto-Phragmitetum* and *Peucedano-Phragmitetum cicutetosum* communities, water levels below the peat surface are not found to any marked extent, while the water level fell below the surface in the *Peucedano-Phragmitetum typicum* community examined. The water levels of the two *Phragmites-Typha angustifolia* communities examined exhibited different characteristics. In one where colonisation of a peat cutting had taken place by the formation of a floating raft of vegetation, water levels were maintained at the peat surface in the summer months, while in the other, the water level fell below the peat surface.

The poor-fen communities appear to be able to maintain relatively constant water levels at or slightly below the peat surface. The hydrological isolation of these *Sphagnum* dominated areas is mediated both by the water retention capacity of *Sphagnum* peats and their occurrence over semi-floating vegetation rafts in some situations (4.4.3).

The rate of successional development, which has led to the variety of water level characteristics between different areas, has obviously been very fast as many areas were cut for peat in the last century. Gunn (1890) estimated the rate of peat growth in the Catfield diggings to be 1 ft in 20 years ($\approx$ 150 cm/100 yrs) which is well above any rates cited by Walker (1970). In these peat cuttings the surface 'peats' are composed mainly of a loose peat slurry within a matrix of living rhizomes and some compaction of the deposits will undoubtedly occur in the future. While the distribution of vegetation types has been discussed here in relation to chemical and hydrological gradients, it is obvious that the gradients are, at least to some extent, determined by processes of management and succession (i.e. processes are important in determining factors).

7.2.3. Vegetation development in relation to past environmental gradients and management

It is possible that the environmental conditions which prevailed at the time of initiation of the communities may well be more important in determining the present distribution of vegetation-types than present day conditions. This may especially be the case if a particular mowing regime had been imposed to maintain the dominance of a certain species.

Early colonisation of peat cuttings by *Cladium* apparently occurred only in areas isolated from clay deposits and the present river course. While the nutrient levels prevailing in areas when *Cladium* became established can only be speculated upon, it is likely that areas further from the river and closer to the rather acidic upland would have been more oligotrophic and less saline than areas close to the river courses. The development of fen carr immediately above the clay deposits in Moores Head Marsh suggests that management has been important in maintaining the open character of herbaceous *Cladium* communities in areas not cut for peat.

Management regimes may well have been instigated to harvest species, which had already become established (i.e. the distribution of dominant species may well have been determined by past environmental gradients and management imposed as a response to their distribution).

If management is neglected or changed, species may lose the dominance they had previously maintained. The invasion of carr is an obvious example, but the comparatively recent establishment of *Cladium* and *Juncus subnodulosus* over *Phragmites* peat in some areas (3.5)) may have resulted from such a change. A crop not now harvested in the broads is 'schoof-stuff' - summer mown mixed fen vegetation - management for which may have led to the development of *Juncus subnodulosus* dominated 'litter fen'. The recent invasion of *Cladium* may well be related to the neglect of mowing in reedbeds (cf. Lambert 1951).

Once a particular vegetation has become established it may be able to persist in environmental conditions which are sub-optimal or unsuitable for development of that type of vegetation. Appropriate management can also prolong the length of time for which seral stages of vegetation may persist.

An example of species growing in conditions which may well be unsuitable for their establishment is found in the *Sphagnum* dominated, poor-fen communities. In these areas the dominant species of the herbaceous fen community which has become invaded by *Sphagnum* often persist, growing through the *Sphagnum* carpet. Such a phenomenon can be interpreted as 'Biological Inertia' (Gorham 1957; Summerfield 1972). The species persisting may root at depths below the *Sphagnum* carpet where cation levels are higher (5.6.2) or may in some cases simply be persisting in conditions not particularly suitable for their growth or establishment. This is probably not the case for all species more characteristic of the herbaceous rich-fen communities which are found in *Sphagnum* communities, as some species (e.g. *Peucedanum palustre*) appear to regenerate and thrive in such areas.

7.3. SOME VEGETATION-TYPES OF PARTICULAR INTEREST

7.3.1. Species-rich sedge beds

The highly species-rich *Peucedano-Phragmitetum caricetosum* is restricted to areas in which there is good evidence that peat cutting has taken place. Two sub-varieties of the *Menyanthes* variant of this community type occur in the Catfield and Irstead Fens in separate fen compartments in which the water levels differ. The difference in species composition of these two sub-varietal forms is probably a reflection of the relative height of summer water levels (4.4.2). The *Molinia* sub-var. which contains much *Molinia caerulea* and few aquatic or swamp species is found in Great Fen (North), where water levels below the peat surface were recorded in the summer months. In the *Ranunculus lingua* sub-var. of central Great Fen below surface water levels were not observed and many aquatic and swamp species are present.

The *Peucedano-Phragmitetum caricetosum* and *P.-P. schoenetosum* communities of the study area are physiognomically similar, managed sedge bed communities. Of these communities, those belonging to the *Peucedano-Phragmitetum caricetosum* are by far the most floristically diverse which is probably related to the differences in hydrology between the communities (4.4.2). The low summer water levels found in the *Peucedano-Phragmitetum schoenetosum* communities are likely to be the main reason for the absence of many small, shallow-rooted forbs from such areas because of desiccation stress. In the *Peucedano-Phragmitetum caricetosum* communities water levels rarely fall much below the peat surface and desiccation stress will be considerably reduced. The assemblage of species characteristic of soligenous fens (4.4.5), and the abundance and variety of bryophytes, found in *Peucedano-Phragmitetum caricetosum* communities may also be related to the constantly high water levels. The dense bryophyte carpets may themselves contribute to the diversity of vascular plants as some species (e.g. *Drosera anglica, Utricularia intermedia*) are usually found growing on bryophyte mats (cf. Clapham 1940).

A further factor contributing to the great diversity of the *Peucedano-Phragmitetum caricetosum* is the marked variation in height of the peat surface (Fig. 5.12) when compared with areas of the *P.-P. schoenetosum* (Fig. 5.19). The topographical variation is probably a result of a complex pattern of peat cutting depths coupled with the presence of small tussocks of some species (e.g. *Carex appropinquata*). Elevation of the peat surface appears to have led to the presence of more oligotrophic areas within the *P.-P. caricetosum* of central Great Fen (5.5.1). Such a mosaic of wetter and drier areas, perhaps associated with differences in nutrient status, will provide a wide variety of niches for associate species (cf. *limes divergens* of van Leeuwen (1966)).

7.3.2. Reed Beds

Some attention has been paid in earlier discussions (4.4.5., 6.6.1) to the cause of poor growth of *Phragmites* and *Typha angustifolia* in the *Phragmites-Typha angustifolia* communities which is often associated with the development of dense carpets of *Agrostis stolonifera*. These communities are present in areas which formerly supported good reed growth. Effects of saline water or reducing conditions within the peat do not appear to have caused the depauperate growth of reed. It seems likely that some catastrophic effect of a severe drought (cf. van der Valk & Davis 1980), late mowing or perhaps coypu grazing, - or a combination of such factors - has led to the debilitation of *Phragmites* and *Typha* and the corresponding rampant expansion of *Agrostis stolonifera*. Coypu can cause severe damage to *Phragmites* and *Typha angustifolia* as they excavate and eat the rhizomes in winter when other food is scarce (Gosling 1974). There has been much evidence of coypu activity in these communities in the past three years.

More floristically diverse reed beds are the *Cicuto-Phragmitetum* and *Peucedano-Phragmitetum cicutetosum*. In such communities, growth of reed is usually quite vigorous. *Agrostis stolonifera* is normally present but in small amounts, although a few areas contain it in abundance. The *P.-P. cicutetosum* is probably a successional development from the *Cicuto-Phragmitetum*; it contains most species found in the *Cicuto-Phragmitetum* with additional species characteristic of the *Peucedano-Phragmitetum* association (e.g. *Carex elata, Lysimachia vulgaris*). There is evidence (both photographic and hearsay - J. Faircloth pers. comm.) that some examples of the *Cicuto-Phragmitetum* and *Peucedano-Phragmitetum cicutetosum* in the internal system supported better reed growth some 15-20 years ago. At this time reed beds were wetter and were harvested using boats on the marshes. The decrease in height and vigour of *Phragmites* may, in such cases, be related to the accrual of peat causing lower water levels in relation to the peat surface. Nutrient depletion may be associated with a higher peat surface due to lack of water circulation over the reed beds during the growing season. There is also evidence that the internal system has become generally more oligotrophic in recent years (5.6.2.) which may be partly due to hydrological isolation from flooding by river water.

7.3.3. The development of poor-fen communities

Sphagnum is not a new addition to the flora of the study area, as records from the Ant valley are given in Nicholson (1909) and Pallis (1911a), and *Sphagnum* has been harvested in the past (6.3). *Sphagnum* species have only been recorded from parts of the marshes where there is evidence of peat cutting or reflooding following earlier drainage (e.g. North Marsh). The absence of *Sphagnum* in areas which were not cut for peat is probably due to the low water levels found in such areas during the summer months (4.4.2). The communities in which *Sphagnum* is found, the *Betulo-Dryopteridetum cristatae* and *Betulo-Myricetum Sphagnum* variant, have developed as part of the primary hydrosere of peat cutting colonisation (3.5).

Sphagnum appears to be able to establish in areas which have quite high cation levels but which are more isolated from inundation by floodwater (5.6.3). The comparative isolation of areas invaded by *Sphagnum* from floodwater appears to be mediated by either a naturally elevated peat surface or the formation of semi-floating rafts of vegetation. Pallis (1911a) describes the distribution of *Sphagnum* around reed stools 'above the general level of the ground waters'. Once *Sphagnum* has become established its presence can lead to acidification (Clymo 1964). The occurrence of *Sphagnum magellanicum* and *S. capillifolium* which are less tolerant of high pH conditions than the 'pioneer' *Sphagnum* species (e.g. *Sphagnum squarrosum*, *S. subnitens*) (Clymo 1973) is probably due to the prior acidification of the environment by such species, coupled with isolation from inundation once the communities have become established. Mr D.S.A. McDougall of Catfield Hall rather aptly describes these *Sphagnum* communities as 'boils' swelling up within the marshes.

In most areas where *Sphagnum* occurs there is a dense growth of *Betula pubescens* which appears to have become established subsequent to *Sphagnum* invasion. *Dryopteris cristata* is ubiquitous in young open examples of the *Betulo-Dryopteridetum cristatae*, but appears to be intolerant of shading and is often absent from *Sphagnum* communities with a mature tree canopy (the *Betulo-Myricetum* communities). It has been suggested that *Dryopteris cristata* is becoming increasingly rare due to hybridisation with *D. carthusiana* (to give *D.* x *uliginosa*) but close examination of these species within the study area does not support this suggestion. The *Betulo-Myricetum* communities are often adjacent to *Betulo-Dryopteridetum cristatae* communities and are probably a further seral stage of development.

7.4. FUTURE SUCCESSION AND MANAGEMENT FOR THE CONSERVATION OF COMMUNITIES

7.4.1. The fate of herbaceous plant communities

At the present there appears to be little active colonisation of open water in the study area; in fact open water is now found in areas which were formerly reedswamp (6.3). The reasons for this regression of swamp are not completely clear but are probably related to reed 'die-back' which has occurred in many parts of Broadland and to grazing by coypu (Lambert 1965; Boorman & Fuller 1981).

Swamp communities are often short lived (Lambert 1951, Walker 1970) although some areas of swamp are still present in nineteenth century peat cuttings in the study area. With progressive peat accrual, which appears to have happened at a very fast rate in many parts of these peat cuttings, the swamp communities will become drier. If left unmanaged swamp communities are likely to become invaded by species such as *Salix cinerea* and quickly become fen carr (probably semi-swamp carr), while if managed, fen communities are likely to be formed. The nature of the fen vegetation which may form over present-day swamp communities depends on the present dominant species, as long as appropriate management is instigated. It is likely that an early fen phase would be the *Peucedano-Phragmitetum cicutetosum* which may, in areas dominated by, and managed for, *Cladium mariscus*, give rise to *Peucedano-Phragmitetum caricetosum* communities - *if* the environmental conditions are suitable.

Management of present-day *Peucedano-Phragmitetum caricetosum* communities seems destined, under continued management to produce a less diverse *Peucedano-Phragmitetum schoenetosum*. The two sub-varieties of the *Peucedano-Phragmitetum caricetosum* which are found in the study area may well represent different successional stages.With continued accretion of peat the *Ranunculus lingua* sub. var. may well give rise to a *Molinia* sub. var. in turn being succeeded by a *Peucedano-Phragmitetum schoenetosum* community.

In some compartments with reed dominated vegetation small patches of *Cladium mariscus* are found, for example, in the *Phragmites-Typha angustifolia* communities of Neatishead Poor's Fen. When mowing for reed in the winter, the marshmen mow around the *Cladium* patches and have been observed to mow out the sedge in the summer. It is possible that continuation of such management will allow the *Cladium* patches to expand gradually, perhaps eventually giving rise to *Cladium* dominated communities.

Within the period of this research (i.e. since 1978) bush growth has appeared to become more prominent in many parts of the study area. This may well be a result of seedling establishment during the dry summer of 1976 (4.4.5.) but it indicates that many of the areas where peat has been cut have reached - or soon will - a stage where colonisation by trees and shrubs can occur. Once established, species such as *Myrica gale* and *Salix cinerea* can withstand severe flooding and active removal is probably the only long term solution for maintaining herbaceous vegetation in areas which become invaded by shrubs.

Another successional change which appears to have happened recently in areas of peat cutting is the development of poor fen vegetation with much *Sphagnum*. The formation of such areas appears to happen irrespective of management but is dependent on isolation from regular flooding (4.4.2., 5.6.3). Again many areas of past peat cutting appear to have reached a favourable stage for the formation of poor-fen communities and it is probable that such communities will continue to expand. *Sphagnum* does not appear to be able to establish in areas which have not been cut for peat and where the water level falls far below the peat surface, although some of these areas, for example those which support *Peucedano-Phragmitetum schoenetosum* communities, appear to be nutrient poor (4.5.4.). In these communities carr development may take the form of *Betulo-Myricetum typical* var. communities (i.e. without *Sphagnum*).

In the long term much of the study area appears destined to the seral development of fen carr communities, rich-fen carr and poor-fen carr, in the absence of mowing. The only way the present character and composition of the fen communities of the study area can be maintained is by re-initiation of the hydrosere in new peat cuttings.

7.4.2. Possible climax vegetation

The future development of the *Sphagnum* communities is uncertain. Walker (1970) suggests that, once established, *Sphagnum* will maintain its dominance. Deposits of *Sphagnum* peat, similar in species composition to those found within the study area, were reported from the Barnby Broad areas, the Waveney valley and the areas of Buckenham and Hassingham Broads in the Yare valley by Lambert and Jennings (1960). These *Sphagnum* peats were formed prior to the Romano-British marine transgression and were found to be intercalated with hypnoid moss peats. The lack of *Sphagnum* dominance here may have been related to generally rising water levels which allowed the concurrent development of brushwood peat in many other areas of the Broadland river valleys.

In some parts of the study area the development of mature birch carr in *Sphagnum* communities appears to have led to compression and lowering of the peat surface which has caused flooding, death of the trees and the virtual elimination of *Sphagnum*. (Good examples of this development can also be seen in the marshes around Heigham Sound in the Thurne valley). In other areas, presumably where the peat has become more consolidated, mature birch carr appears able to persist. Tucker and Fitter (1981) suggest that *Betula pubescens* will be replaced from an acidic birchwood with *Sphagnum* (referable to the *Betulo-Myricetum*) by *Quercus robur*. Many *Betulo-Myricetum* communities in the study area exhibit some degeneration of birch, but there is no evidence of invasion by other trees, birch maintaining its dominance.

It has been suggested that the low rainfall of East Anglia would check the growth of *Sphagnum* and that the climax vegetation would be deciduous (oak) woodland (Pallis 1911a ; Godwin and Turner 1933). Such oak woodland has only been described from very marginal areas of the Broadland flood-plain mires, or on drained peat, where it has probably not developed as part of the hydrosere. The *Sphagnum* communities investigated here appear to be able to maintain high water levels in the peats during times of generally low water, (4.4.2) and raised bog development in the East Anglian Fenland has been described by Godwin & Clifford (1938).

If the *Sphagnum* dominated communities are able to expand and cover larger areas, the capacity to retain high water levels is likely to be increased, and further growth away from the level of floodwater may be possible. At present such communities are only found in areas where the peat has been cut, but possibly, with the increased water holding capacity of a large mass of *Sphagnum* peat , *Sphagnum* may spread over areas which are normally of low water level in the summer months. It is unlikely, however, that such expansion of *Sphagnum* could encroach into areas particularly close to the River Ant where susceptibility to inundation would be greater and a 'steady-state' situation may be attained. If such a bog development happened (and there does not appear to be any particular evidence to suggest it should not) it is not clear whether the present abundance of *Betula pubescens* in poor-fen communities might be reflected in the potential climax vegetation. Kulczynski (1949) describes the development of wooded raised bogs in the continental climate of Poland.

Whatever the natural climax vegetation of the Broadland flood-plain mires may be, the possibility that present-day poor-fen communities are the precursors of a climax ombrotrophic mire cannot be excluded.

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Appendix 1

Location of Species Lists in Table 2.2.

List No.	Community Type	Compartment Name	Grid Reference
1.	*Peucedano-Phragmitetum typicum*	Great Fen	TG 36482126
2.	"	"	TG 36502115
3.	"	"	TG 36612102
4.	"	"	TG 36502095
5.	"	Little Fen	TG 36872087
6.	"	North Marsh	TG 37382128
7.	"	Little Fen	TG 37012092
8.	"	Irstead Holmes	TG 37182104
9.	"	Neatishead Poor's Fen	TG 37002039
10.	*Phalaris* var.	Moores Head Marsh	TG 36402108
11.	"	Marginal Area	TG 37402040
12.	"	Moores Head Marsh	TG 36362122
13.	*myricetosum* subassociation	Irstead Holmes	TG 37082083
14.	"	Moores Head Marsh	TG 36402108
15.	"	Rose Fen	TG 37552075
16.	*cicutetosum* subassociation	Great Fen	TG 36602094
17.	"	Hubbard's Piece	TG 37182128
19.	"	" "	TG 37192124
18.	"	Irstead Holmes (North)	TG 36832074
20.	*schoenetosum* subassociation	Sedge Marshes	TG 36802110
21.	"	" "	TG 36782130
22.	"	Neatishead Poor's Fen	TG 37172047
23.	"	Moores Head Marsh	TG 36562070
24.	Transitional *cicutetosum/caricetosum*	Great Fen	TG 36602125
25.	"	"	TG 36622123

Appendix 1 (Continued)

26.	*caricetosum* subassociation	Great Fen	TG 36632114
27.	"	Great Fen (North)	TG 36562135
28.	*Potentillo-Caricetum rostratae*	Fenside Marsh	TG 37032151
29.	"	" "	TG 37062150
30.	"	" "	TG 37022152
31.	"	North Marsh	TG 37292145
32.	"	" "	TG 37282148
33.	"	" "	TG 37402133
34.	"	Middle Marsh	TG 37302119
35.	"	" "	TG 37312113
36.	"	Sharp Street Fens	TG 37182006
37.	"	"	TG 37132002
38.	*Cicuto-Phragmitetum*	Fenside Marsh	TG 36902122
39.	"	" "	TG 36932121
40.	"	Main Reed Marsh	TG 36922106
41.	"	" " "	TG 37112109
42.	"	Mill Dyke Marsh	TG 37402085
43.	*Scirpo-Phragmitetum*	Fenside Marsh	TG 36872112
44.	"	Mill Dyke Marsh	TG 37312095
45.	"	Sharp Street Fens	TG 37102008
46.	"	" " "	TG 37021991
47.	"	North Irstead Marshes	TG 36792072
48.	*Cladietum marisci*	Fenside Marshes	TG 36892128
49.	"	Neatishead Poor's Fen (North)	TG 36552075
50.	"	Irstead Poor's Fen	TG 37182056
51.	*Phragmites* sociation	North Marsh	TG 37462147
52.	"	Irstead Poor's Fen	TG 37312048
53.	*Phragmites-Sium latifolium* community	" " "	TG 37342055
54.	"	Irstead Holmes	TG 37182088
55.	*Phragmites-Typha angustifolia* community	Neatishead Poor's Fen	TG 36812055
56.	"	" " "	TG 36832049
57.	"	" " "	TG 36782060
58.	"	Irstead Poor's Fen	TG 37202068

59.	*Phragmites-Agrostis stolonifera* community	Neatishead Poor's Fen	TG 36972063
60.	"	" " "	TG 37062057
61.	*Phragmites-Potentilla palustris* community	Fenside Marsh	TG 37132123
62.	"	Catfield Broad Marshes	TG 37622085
63.	"	" " "	TG 37542070
64.	*Phragmites-Thelypteris palustris* community	Neatishead Poor's Fen	TG 37042060
65.	*Cladium-Thelypteris palustris* community	Fenside Marsh	TG 36972130
66.	*Cladium-Carex elata* community	Fenside Marsh	TG 36812133

Location of Species Lists in Table 2.3

List No.	Community Type	Compartment Name	Grid Reference
1.	*Myricetum gale*	Fenside Marsh	TG 36852138
2.	" "	Irstead Holmes	TG 37042084
3.	*Betulo-Dryopteridetum cristatae*	Fenside Marsh	TG 36962134
4.	"	North Marsh	TG 37302149
5.	"	Mill Dyke Marsh	TG 37252097
6.	"	Irstead Poor's Fen	TG 37202060
7.	"	Neatishead Poor's Fen	TG 37092064
8.	"	Main Reed Marsh	TG 36912113
9.	"	Fenside Marsh	TG 36852130
10.	*Betulo-Myricetosum peucedanetosum*	Great Fen	TG 36542128
11.	*Sphagnum* var.	Great Fen	TG 36532123
12.	"	North Marsh	TG 37262130
13.	"	North Irstead Fens	TG 36972080
14.	Typical var.	Irstead Holmes	TG 37122086
15.	"	Irstead Poor's Fen	TG 37282051

Location of Species Lists in Table 2.3 (Continued)

16.	*Salix* carr	Great Fen (North)	TG 36552139
17.	"	Great Fen (South)	TG 36442093
18.	"	Little Fen	TG 36882084
19.	"	Church Marshes	TG 36772052
20.	*Osmundo-Alnetum glutinosae*	Moores Head Marsh	TG 36352135
21.	*lycopetosum*	Moores Head Marsh	TG 36372123
22.	"	Great Fen	TG 36442125
23.	"	The Heronry	TG 32602100
24.	*Sphagnum* var.	North Marsh	TG 37272127
25.	Marginal Woodland	Sedge Marshes	TG 36702136
26.	" "	Fenside Marsh	TG 36852140
27.	" "	Catfield Broad Marshes	TG 37792077

APPENDIX 2

1. METHODS FOR PREPARATION OF PEAT EXTRACTS AND DIGESTS

a). Peat extractions

Three separate peat extractions were carried out on portions of each peat sample. The amount of peat to be extracted was measured using small beakers of measured volume (≈38 ml). The beaker was filled completely, care being taken to minimise compression of the peat. The peat sub-sample was transferred to a 250 ml bottle to which 100 or 200 ml of the relevant extractant was added (see table below). The bottles were then shaken for 1 hour on an 'end-over-end' shaker and the extract was filtered and stored at 5^{o}C until further analysis was complete.

Extractant	Volume used (ml)	Reference	Subsequent Analyses
2 M Potassium chloride	100	Black (1965)	NH_4-N, (NO_2+NO_3)-N
0.5 M Ammonium acetate pH 7.0	200	Allen (1974)	Ca, Mg, Na, K, Fe, Mn.
0.5 M Sodium bicarbonate pH 8.5	100	Allen (1974)	PO_4-P.

b). Peat digestion

A measured volume remaining from the peat samples used for the above extractions was dried at 50°C to constant weight and the weight recorded to determine the water content of the peat. The sample was then ground finely using a Cassella mill and mixed thoroughly. Two 100 mg sub-samples were taken from each sample and digested using a sulphuric acid-hydrogen peroxide digestion mixture (Allen 1974). The tubes were warmed gently until the initial effervescence had subsided and then heated to 340°C (Grant BTS test tube heater) until the digest had cleared (8-10 hours). Heating was continued for a further 30 minutes to ensure complete digestion. After the tubes had cooled the digest was diluted to 50 ml and stored at 5°C until further analysis was complete.

2. METHODS FOR CHEMICAL ANALYSIS OF WATERS, EXTRACTS AND DIGESTS

a). pH

pH was measured electrometrically using a Pye Model 79 pH meter. The glass electrode was inserted directly into a sub-sample of the fresh peat or water sample.

b). Conductivity

Electrical conductance of water samples was measured using an EIL conductivity measuring bridge type MC 1 MK V with automatic temperature compensation to 25°C. If the pH of the water sample was below 4.5 the approximate contribution of H^+ to the conductivity was subtracted from the measured conductivity using values quoted by Golterman *et al.* (1978).

c). Nitrogen

i). Semi-micro Kjeldahl distillation method (Black 1965)

10-50 ml of sample, depending on the concentration of nitrogen present, was steam distilled with magnesium oxide to measure ammonium-N and a further aliquot was steam distilled with magnesium oxide and Devarda's alloy to measure (ammonium + nitrite + nitrate)-N. The first 25 ml of distillate was collected in 5 ml of boric acid-indicator solution and titrated with 0.01 M sulphuric acid.

ii). Automated phenol/nitroprusside method

Reagent solutions:

EDTA, Citrate; 2 g disodium ethylenediaminetetra-acetic acid with 1 g trisodium citrate in 1 litre of water. pH adjusted to 12.2 by addition of 10 M sodium hydroxide.

Phenol/nitroprusside; 20 ml 80% w/w phenol solution with 160 mg sodium nitroprusside in 800 ml of water.

Hypochlorite; 50 ml sodium hypochlorite solution (12% w/v available chlorine) with 50 ml 10 M sodium hydroxide and 100 ml of water.

Method:

This method employed a Pye-Unicam AC 1 automatic chemistry unit, SP 550 spectrophotometer and Hewlett-Packard 975 programmeable calculator. The automatic chemistry unit was set to inject 80 μl of sample into a reaction tube and to add 1 ml EDTA reagent, 1 ml phenol/nitroprusside reagent and 0.2 ml hypochlorite reagent. Reaction tubes were maintained at 45°C in a water bath for 20 minutes and the solution was passed automatically through the flow-through cuvette of the spectrophotometer, which was also maintained at 45°C. The absorbance (1 cm light path) of the blue colour formed was measured at a wavelength of 625 nm. From this the calculator computed the nitrogen concentration in the sample in $\mu g\ ml^{-1}$ having been first calibrated using the optical density of blank digests and ammonium standards (ammonium chloride in 4% v/v sulphuric acid).

d). Phosphorus

i). Soluble reactive phosphorus in water samples

A molybdenum blue method using antimony as a colour enhancing agent and asorbic acid as the reductant (Stainton, Capel and Armstrong 1977) was used to measure SRP. The absorbance (1 cm light path) was measured at 885 nm using a Pye-Unicam SP 550 spectrophotometer.

ii). Phosphate-P in peat extracts and digests

A very similar method to that used for SRP in waters was used to determine PO_4^{-P} in peat extracts and digests. This method allows for a wide range of molarity of digestion or extraction reagents in the sample, standards being prepared with added extractant or digestion mixture and absorbance measured at 882 nm (John 1970). The background absorbance due to the dark natural colouration of the extracts produced with the bicarbonate extractant was found to be negligible except in a few cases where a slight depression of absorbance occurred. To overcome this interference the background absorbance was subtracted from the measured absorbance of the phospho-molybdate complex. Activated charcoal was found to decolourize the extracts (Allen 1974) but gave higher variability of the results and was therefore not used.

e). Calcium and Magnesium

Ca^{2+} and Mg^{2+} in waters, peat extracts and peat digests were measured by atomic absorption flame spectrophotometry. The samples were first diluted to fall within a range of 0-4 mg l^{-1} using a solution of lanthanum chloride calculated to give a final concentration of 800 mg l^{-1} La^{3+}. The absorption was measured at 422.7 nm for Ca^{2+} and 285.2 nm for Mg^{2+} on a Pye-Unicam SP 190 atomic absorption spectrophotometer calibrated with mixed standards which were also diluted with lanthanum chloride.

f). Iron and Manganese

Concentrations of iron and manganese in waters, peat extracts and peat digests were measured as in (e) above. If necessary the samples were diluted with deionised water to fall within a range of 0-2 mg l^{-1}. The wavelengths used for detection were 248.3 nm for iron and 279.5 nm for manganese.

g). Sodium and Potassium

Na^+ and K^+ were measured simultaneously by flame emission spectrophotometry using an EEL 227 integrating flame photometer. The standards and samples were diluted with lithium chloride to give a final concentration of 100 mg l^{-1} Li^+ as this instrument integrates the amount of light emitted by Na^+ and K^+ against that emitted by the standard concentration of Li^+. The instrument was calibrated over the range of 0-20 mg l^{-1} Na^+ and 0-2 mg l^{-1} K^+.

h). Bicarbonate (as titratable alkalinity)

The amount of HCO_3^- in water samples was determined within 24 hours of collection by titration with 0.01 M H_2SO_4 to an end point between pH 4.2 and 5.4 using methyl orange (0.05% w/v) as the end point indicator. The accuracy of the titrations was checked using a pH meter to determine the end point.

i). Sulphate

The concentration of sulphate in water samples was measured using a turbidimetric method involving precipitation of barium sulphate in an acid solution (Golterman *et al.* 1978). The absorbance was measured with a white light source using an EEL Nephelometer Head and Unigalvo type 20 galvanometer.

j). Chloride

Chloride in water samples was titrated with mercuric nitrate using a diphenylcarbazone-bromophenol blue indicator solution (Golterman *et al.* 1978) to determine the end point.

k). Sulphide

S^{2-} was precipitated as CdS in the field by collecting the sample in a bottle containing 1 ml of 2% $CdCl_2$ solution. When the preciptate had settled the supernatant was decanted and the precipitate dissolved in an acid-iodine solution. The excess iodine was titrated with sodium thiosulphate using a starch indicator to determine the end point (Golterman *et al.* 1978).

l). Percentage ash content

The ash percentage of peat samples was measured by igniting an accurately determined weight of peat (0.5-1 g dry wt.) in porcelain crucibles at 500°C for 3 hours in a muffle furnace. The crucibles were cooled in a desiccator, reweighed and the percentage ash content calculated from the weights of the sample before and after ignition.

m). Redox potential

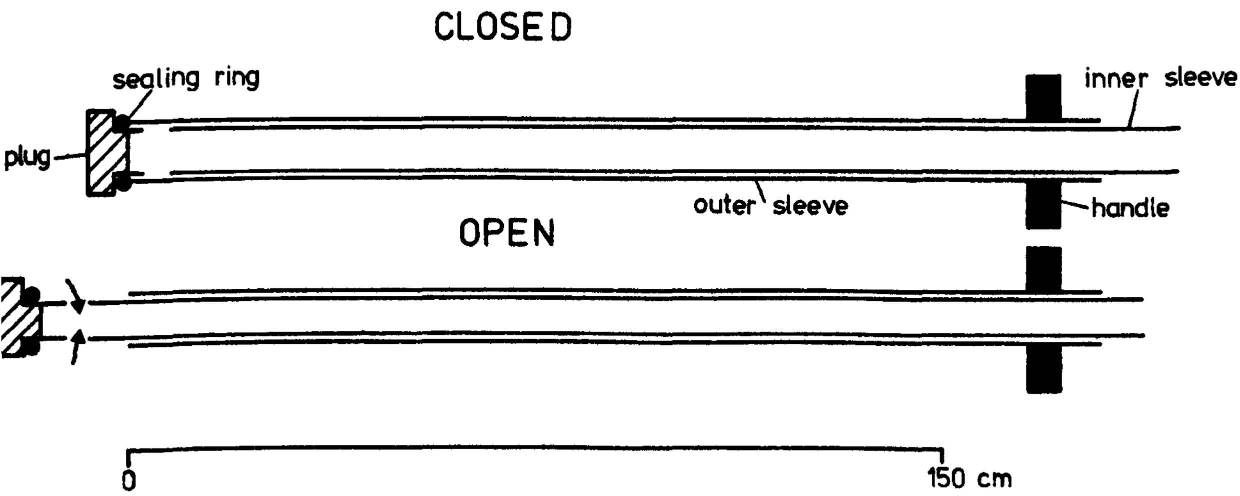
Measurements of redox potential were made in the field using a platinum electrode directly inserted into the peat and a saturated calomel reference electrode. Readings were taken when the redox potential had stablised (sometimes over 5 min after insertion). All readings were corrected to pH 7 (E_7) using a correction factor of -59 mV/pH (Bohn 1963).

3. TEMPERATURE MEASUREMENT

A linear-response transistor (type 2N3M04) was embedded in a copper cone which was connected to a calibrated 175 cm length of metal tubing. Temperature readings were made with the sensor-transistor connected to an Intersil 7106 analog to digital converter. Accuracy was estimated at ± 0.1°C.

4. SAMPLER FOR EXAMINATION OF VERTICAL STRATIFICATION OF PEAT WATERS.

The sampler was constructed from two, closely fitting lengths of ABS pipe:



5. METHODS FOR DATA PROCESSING

One-way analysis of variance was performed on data sets of each chemical variable, at each time of analysis using the SPSS MK. 6 package sub-program ONEWAY. Duncan's New Multiple range test (with unequal numbers of replicates (Kramer 1956)) was used to separate the sites at the $P < 0.05$ level of significance. Graphs of fluctuations in concentration of chemical variables (Figs. 4.10-4.19) were plotted using program ALL GRAPHS by F. Sutton, U.C.P.E., Sheffield University. Cluster analyses were computed with the CLUSTAN 1C package using Ward's method (Ward 1963) of hierarchical fusion.

Appendix 3. Some Additional Chemical Results

1. REPLICATE REDOX PROFILES - (MARCH 1981).

Site	1. GFN			2. GFC			3. GFS			8. SM		
	E_7 (mV)			E_7 (mV)			E_7 (mV)			E_7 (mV)		
Depth	a	b	c	a	b	c	a	b	c	a	b	c
0	187	210	198	55	-40	35	27	65	43	320	281	340
10	180	-26	165	27	-15	16	-23	-43	-36	47	68	36
20	367	-46	85	-33	-35	-34	-24	-25	-37	77	46	39
30	-53	-45	-68	-54	-73	-33	- 3	-23	-24	48	56	49
40	-46	-28	-73	-65	-45	-73	-25	-28	-50	36	50	53
50	-34	-13	-43	-57	-64	-45	-28	-24	-45	45	33	27

As the redox profiles were fairly consistent a single profile (a) was used to represent each site.

2. Fluctuations in iron concentration (mg/1) in the peat waters from September 1979 to September 1980. Values are means of 5 analyses except in sites 1 a). and 2 a). which are means of 2 analsyses.

Site	1.9.79	26.10.79	6.1.80	26.3.80	1.5.80	6.7.80	13.9.80
	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.
1. GFN	0.41 (0.10)	0.25 (0.05)	0.11 (0.03)	0.15 (0.09)	0.10 (0.03)	0.10 (0.01)	0.08 (0.03)
1a) GFNP	0.15 (0.05)	0.05 (0.05)	0.05 (0.01)	0.06 (0.02)	0.06 (0.04)	-	-
2. GFC	0.08 (0.01)	-	0.06 (0.01)	0.06 (0.01)	-	0.03 (0.01)	0.04 (0.01)
2a) GFCL	0.16 (0.01)	-	0.05 (0.01)	0.05 (0.01)	-	0.08 (0.01)	0.04 (0.01)
3. GFS	0.11 (0.01)	0.04 (0.04)	0.12 (0.02)	0.09 (0.03)	0.04 (0.01)	0.08 (0.02)	-
4. LF	0.13 (0.01)	0.14 (0.03)	0.13 (0.05)	0.08 (0.01)	0.07 (0.01)	0.10 (0.02)	0.10 (0.01)
5. NPF	0.12 (0.05)	0.14 (0.07)	0.28 (0.27)	0.12 (0.03)	0.10 (0.01)	0.19 (0.02)	0.12 (0.05)
6. IPF	0.11 (0.01)	-	0.06 (0.01)	0.04 (0.01)	-	0.18 (0.08)	-
7. MHM	1.86 (0.62)	1.78 (0.40)	0.94 (0.23)	1.48 (0.83)	0.53 (0.07)	1.50 (0.54)	1.19 (0.87)
8. SM	1.39 (0.32)	1.24 (0.43)	1.15 (0.28)	1.33 (0.59)	1.56 (0.90)	0.78 (0.47)	0.70 (0.19)
9. OA	0.37 (0.06)	0.25 (0.07)	0.05 (0.01)	0.12 (0.02)	0.06 (0.02)	-	0.10 (0.02)
10. FBR	0.06 (0.01)	0.17 (0.06)	0.06 (0.16)	0.05 (0.01)	0.04 (0.10)	0.05 (0.01)	0.05 (0.01)
11. FBC	0.06 (0.01)	-	0.07 (0.01)	0.05 (0.01)	-	-	0.04 (0.01)
12 FBDC	0.85 (0.24)	0.41 (0.12)	0.39 (0.07)	0.39 (0.10)	0.38 (0.11)	0.34 (0.08)	0.50 (0.14)
13 MRM	1.55 (0.20)	2.16 (0.11)	-	1.08 (0.11)	1.37 (0.13)	1.08 (0.17)	0.84 (0.11)
14 BM	0.67 (0.17)	0.67 (0.23)	0.57 (0.19)	0.42 (0.16)	0.43 (0.15)	0.42 (0.12)	0.38 (0.12)

3. Fluctuations in manganese concentration (mg/1) in the peat waters from September 1979 to September 1980. Values are means of 5 replicate analyses except in Sites 1 a). and 2 a) which are means of 2 analyses.

Site	1.9.79	26.10.79	6.1.80	26.3.80	1.5.80	6.7.80	13.9.80
	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.	x ± S.E.
1. GFN	0.55 (0.16)	0.01 (0.39)	0.35 (0.06)	0.39 (0.31)	0.47 (0.11)	0.44 (0.14)	0.31 (0.15)
1a) GFNP	0.33 (0.17)	0.21 (0.21)	0.03 (0.03)	0.18 (0.15)	0.26 (0.17)	0.72 (0.13)	-
2. GFC	0.05 (0.05)	-	0.12 (0.08)	0.21 (0.07)	0.13 (0.05)	0.16 (0.11)	0.16 (0.06)
2a) GFCL	0.24 (0.02)	-	-	0.16 (0.05)	-	-	0.05 (0.04)
3. GFS	0.11 (0.04)	0.08 (0.04)	0.32 (0.06)	0.14 (0.04)	0.05 (0.03)	0.03 (0.01)	0.10 (0.03)
4. LF	0.18 (0.01)	0.33 (0.05)	0.51 (0.05)	0.13 (0.03)	0.09 (0.02)	0.15 (0.03)	0.09 (0.02)
5. NPF	-	0.25 (0.01)	0.31 (0.01)	0.15 (0.03)	0.08 (0.01)	0.04 (0.02)	0.16 (0.05)
6. IPF	0.27 (0.04)	0.11 (0.05)	0.02 (0.01)	0.12 (0.05)	-	0.05 (0.03)	0.05 (0.04)
7. MHM	1.69 (0.31)	1.10 (0.30)	0.30 (0.05)	0.63 (0.18)	0.38 (0.14)	0.90 (0.33)	1.01 (0.13)
8. SM	0.49 (0.32)	0.64 (0.26)	0.76 (0.29)	0.72 (0.26)	0.66 (0.24)	0.25 (0.23)	0.50 (0.17)
9. OA	0.68 (0.23)	0.44 (0.15)	0.06 (0.06)	0.15 (0.03)	0.03 (0.01)	0.11 (0.09)	0.64 (0.15)
10. FBR	0.45 (0.29)	0.44 (0.21)	0.15 (0.03)	-	0.03 (0.01)	-	-
11. FBC	0.16 (0.04)	0.25 (0.18)	0.07 (0.20)	-	-	-	0.06 (0.06)
12. FBDC	0.18 (0.03)	0.07 (0.03)	0.07 (0.02)	0.09 (0.01)	0.07 (0.01)	0.07 (0.03)	0.11 (0.02)
13. MRM	0.18 (0.01)	0.23 (0.01)	-	0.15 (0.04)	0.13 (0.01)	0.13 (0.03)	0.25 (0.04)
14. BM	0.14 (0.02)	0.04 (0.01)	0.15 (0.06)	0.09 (0.04)	0.06 (0.03)	0.06 (0.01)	0.06 (0.01)

TABLES 2.2.

4.3.

FIGS. 3.3.

3.5.

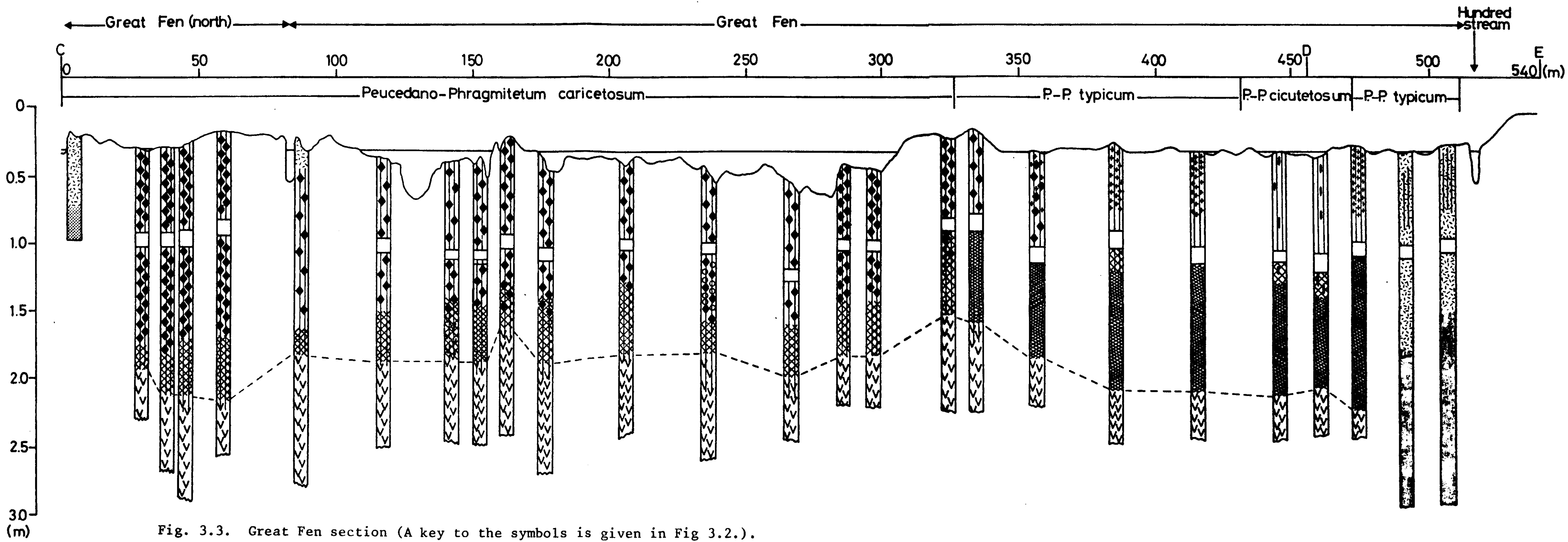


Fig. 3.3. Great Fen section (A key to the symbols is given in Fig 3.2.).

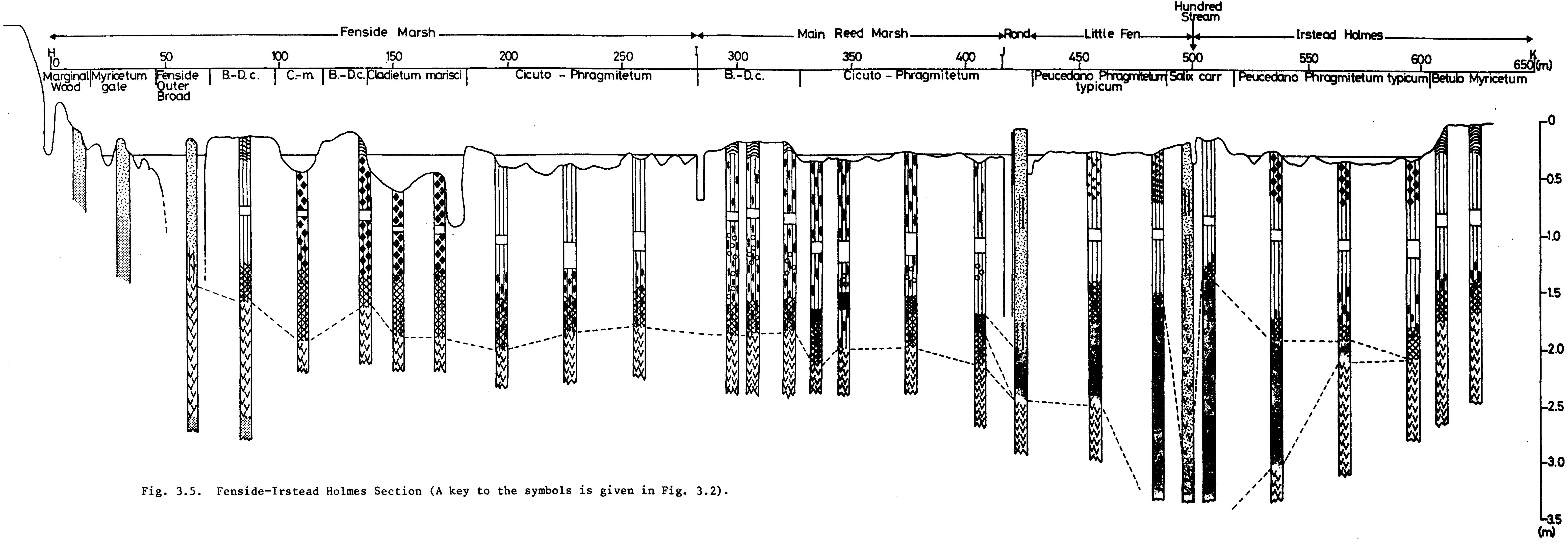


Fig. 3.5. Fenside-Irstead Holmes Section (A key to the symbols is given in Fig. 3.2).

Table 4.3. Some chemical characteristics of the peat from the study sites. The values refer to the mean ($\bar{x}$) and standard error (S.E.) of 5 replicate peat extractions. All concentrations are expressed in (mg/l peat). See Table 4.1. for a description of the study sites and Appendix 2 for details of the extractants used.

Site	Main macrofossils in peat	Humification (von Post scale)	pH $\bar{x}$ ± S.E.	Dry weight (g/l peat) $\bar{x}$ ± S.E.	NH_4-N $\bar{x}$ ± S.E.	(NO_2+NO_3-N) $\bar{x}$ ± S.E.	(NH_4+NO_2+NO_3)-N $\bar{x}$ ± S.E.	PO_4-P $\bar{x}$ ± S.E.	Ca $\bar{x}$ ± S.E.	Mg $\bar{x}$ ± S.E.	Na x ± S.E.	K x ± S.E.	Fe x ± S.E.	Mn x ± S.E.
1 GFN	*Cladium*	5	6.3 (0.07)	67 (5.2)	0.08 (0.08)	0.93 (0.07)	1.01 (0.11)	0.92 (0.04)	678 (48)	46 (3.0)	115 (8.2)	20.1 (4.2)	0.29 (0.12)	4.12 (1.14)
2 GFC	*Cladium*	3	6.5 (0.02)	59 (3.5)	0.39 (0.12)	1.17 (0.03)	1.56 (0.27)	0.90 (0.05)	910 (74)	87 (4.8)	124 (24.7)	20.6 (4.6)	-	1.63 (0.48)
3 GFS	*Phragmites/Typha*	2	6.5 (0.04)	61 (1.5)	0.39 (0.02)	1.55 (0.30)	1.94 (0.30)	0.76 (0.07)	723 (20)	62 (1.5)	140 (4.3)	3.9 (2.9)	0.09 (0.09)	0.38 (0.05)
4 LF	*Juncus/Phragmites*	5	6.4 (0.07)	72 (2.4)	0.35 (0.14)	1.24 (0.26)	1.59 (0.22)	1.57 (0.21)	869 (36)	76 (3.4)	179 (7.9)	20.9 (4.8)	-	0.61 (0.14)
5 NPF	*Phragmites/Typha*	2	6.7 (0.04)	58 (5.0)	0.85 (0.33)	0.16 (0.10)	1.01 (0.32)	0.92 (0.18)	499 (21)	128 (2.8)	357 (9.3)	12.0 (2.2)	-	0.22 (0.04)
6 IPF	*Phragmites/Typha*	2	6.5 (0.04)	60 (6.1)	0.62 (0.20)	0.43 (0.22)	1.05 (0.31)	0.38 (0.06)	531 (57)	71 (6.7)	189 (14.5)	26.8 (10.8)	-	0.20 (0.04)
7 MHM	*Cladium*	7	6.5 (0.02)	79 (5.4)	0.08 (0.05)	0.23 (0.11)	0.31 (0.14)	0.79 (0.04)	774 (23)	146 (3.4)	331 (16.2)	29.8 (5.3)	0.04 (0.04)	5.43 (0.78)
8 SM	*Cladium*	7	6.1 (0.02)	61 (2.2)	0.19 (0.09)	-	0.19 (0.09)	0.26 (0.02)	805 (41)	88 (4.5)	116 (8.1)	9.1 (2.5)	0.03 (0.03)	5.99 (0.63)
9 OA	Brushwood	9	6.5 (0.06)	109 (5.5)	0.27 (0.08)	2.10 (0.26)	2.37 (0.60)	1.44 (0.10)	1840 (80)	129 (6.9)	179 (12.9)	7.9 (1.7)	-	0.99 (0.48)
10 FBR	*Phragmites*	2	6.4 (0.04)	63 (2.6)	1.20 (0.39)	0.16 (0.10)	1.36 (0.47)	1.33 (0.21)	495 (49)	74 (6.1)	105 (2.8)	22.7 (6.4)	-	3.76 (0.60)
11 FBC	*Cladium*	2	6.4 (0.03)	65 (3.9)	0.39 (0.30)	0.35 (0.16)	0.62 (0.45)	1.23 (0.12)	792 (39)	89 (4.1)	116 (9.0)	23.8 (9.0)	-	5.96 (0.72)
12 FBDC	*Sphagnum/Cladium*	4	4.7 (0.24)	62 (7.8)	0.66 (0.14)	0.35 (0.17)	0.89 (0.27)	0.63 (0.13)	305 (56)	58 (10.1)	102 (8.3)	13.7 (4.2)	0.10 (0.10)	0.29 (0.05)
13 MRM	*Sphagnum/Phragmites*	2	4.2 (0.04)	53 (3.9)	0.54 (0.16)	-	0.54 (0.16)	0.73 (0.31)	174 (32)	16.3 (0.5	61 (2.2)	28.6 (4.5)	0.70 (0.10)	0.35 (0.04)
14 BM	*Sphagnum*/brushwood	8	3.7 (0.03)	103 (2.9)	-	1.16 (0.12)	1.16 (0.12)	0.55 (0.11)	412 (30)	53 (3.4)	154 (33.9)	34.5 (5.5)	-	0.46 (0.16)