The Scottish Borders Fens:

Controls on Vegetation Development and Composition

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Summary

1. The Scottish Borders fens represent an important group of British fen sites. Despite their small size many of these fens support various rare plant communities and nationally and locally rare plant species as well as a wide range of species characteristic of wetland habitats. This study has demonstrated the importance of management history, site chemical conditions and site size and morphology in the vegetation development of the Scottish Borders fens.

2. Sixty-eight sites were included in a general survey. The vegetation at these sites was systematically recorded. Site features (vegetation rafts, springs, drains), surrounding land-use, gross peat stratigraphy and measurements of pH and electrical conductivity of the fen water were also recorded. A subset of contrasting sites was selected for detailed investigations into site chemical conditions and peat fertility, peat stratigraphy and the development of vegetation rafts.

3. The quadrat data were analysed using a range of multivariate classification procedures. One classification was selected as the basis for the description of Scottish Borders fen plant communities. Twenty-four plant communities and variants are described representing rich-fen, poor-fen, bog, tall herb fen, fen meadow and swamp habitat types. The Scottish Borders fen plant communities were compared to existing comprehensive classifications of British fen vegetation.

4. The impact of marl and peat extraction at each site was investigated using documentary, visual and stratigraphic evidence for disturbance at each site. The status of each site was determined (cutover, partly cutover, un-disturbed) and this was related to the development of the present vegetation. Most of the Scottish Borders fens have been cut for peat or marl to some extent. However at some sites the peat stratigraphic sequences represent un-modified peat development since the late glacial. The efficiency of drains, strength of springs and basin morphology are important factors determining the development of vegetation over former peat and marl cuttings.

5. Site chemical conditions show much variation. The intensity of the surrounding land-use is positively correlated with peat fertility at the edges and water inflows of sites. The main axes of floristic variation correspond to the variation in base-richness of the fen water and fertility. There was no simple relationship between chemical variables and the occurrence of different plant communities.

6. The vegetation has developed as a quaking raft over fluid peat at many sites. Two *Sphagnum* dominated plant communities are confined to vegetation rafts. Their occurrence is determined by the inundation of the vegetation surface with base-rich water, the depth of the fluid peat beneath the raft and the degree of isolation of the vegetation surface from telluric water input. Where the vegetation has developed as a raft over the entire site the thickest rafts are found in the central areas. The mechanisms of central raft thickening are thought to be influenced by differential fluctuation of the water table relative to the vegetation surface across sites.

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Chapter 1: General Introduction

Mires can be defined as freshwater peatlands and related habitats that are permanently waterlogged but not deeply inundated (Gore 1983). Mires have been divided into two basic categories (Du Rietz 1949): minerotrophic mires (fens), and ombrotrophic mires (bogs). Fens are widespread throughout Britain. The vegetation of fens has been described synoptically from a range of sites (McVean & Ratcliffe 1962, Spence 1964, Birse 1980, Wheeler 1980 a,b,c,). They support a rich assemblage of species. A total of 653 plant species have been recorded from British fens (Wheeler 1993). Many of these species are particularly characteristic of wetland habitats, but fens also support more widespread species, many of which are in decline in other, perhaps 'preferred', habitats (Wheeler 1993). This underlines the importance of fen ecosystems for the maintenance of botanical diversity. However their position in the landscape, often within intensively farmed catchments, has frequently led to the destruction of fens through drainage and impoverishment of species-rich vegetation by nutrient enrichment (Wheeler 1983, Verhoeven *et al.* 1988). Many areas of conservationally-important fen vegetation have been subject to past disturbance, particularly drainage and peat cutting (Giller & Wheeler 1986, Wheeler & Shaw 1995a). Other areas have traditionally been mown to produce reeds and marsh hay and many sites are grazed. Therefore much of the present vegetation of lowland fens is semi-natural and does not represent an unmodified successional sequence from initiation to the present. The composition of fen vegetation is often subject to spontaneous change, especially in sites which have developed hydroserally (through the terrestralization of open water (Tansley 1939, Walker 1970)). Natural processes of succession in fens often lead to the development of fen woodland (carr) from herbaceous vegetation although on solid peat it is often difficult to know whether tree encroachment represents true autogenic succession or just colonisation. Tree encroachment is sometimes perceived as being undesirable by conservationists. Past management in the form of mowing or grazing has been effective in preventing the development of scrub in fens (Shaw & Wheeler 1991) but recent abandonment of these practices may lead to its rapid expansion (e.g. Fuller 1986).

A range of factors is thought to be important in controlling the development of fen vegetation and the occurrence of fen species. These include the chemistry of mire waters (Du Rietz 1949, Sjors 1950, Verhoeven *et al.* 1983, Malmer 1986), water flow (Kulczynski 1949), successional phase (Segal 1966, Walker 1970, Van Wirdum 1991), geographical location (Perring & Walters 1962, Wheeler 1993), past peat excavation (Lambert *et al.* 1960, Giller & Wheeler 1986) and present land management (Shaw & Wheeler 1991). An understanding of the processes and controls on the development of fen vegetation is necessary for the successful conservation management of fen sites and the restoration of fen vegetation.

The Central Scottish Borders are located approximately 30 miles south of Edinburgh (figure 1.1) at the eastern extremity of the Southern Uplands. The area is bounded in the north and north-east by the Moorfoot and Lammermuir Hills and in the south by the Cheviots. The rivers Tweed and Teviot flow eastwards through the area. The land surrounding the sites is gently undulating, mostly pastoral farmland.

The corrugated hills of the Central Scottish Borders contain a large concentration of small basin fen sites supporting a wide range of vegetation types. Many sites show clear vegetation zonation and support nationally and locally uncommon species. Distinctive vegetation types found in the Scottish Borders fens include:

- Fen vegetation dominated by a mixture of fine-leaved sedges *Carex diandra*[*], *Carex rostrata*, *Carex lepidocarpa* and *Carex lasiocarpa* with a ground cover of *Amblystegious* mosses is particularly characteristic of the Scottish Borders fens and often very species-rich. Within this rich-fen vegetation, hummocks of base-tolerant *Sphagnum* species are sometimes found (*Sphagnum contortum, S. teres, S. warnstorfii*).
- Poor-fen vegetation types characterised by abundant populations of *Sphagnum* species; typically *Sphagnum recurvum, S. palustre, S. fimbriatum* and *S squarrosum* occur widely and dominate extensive areas at some sites.
- Bog vegetation characterised by the species *Eriophorum vaginatum, Sphagnum papillosum* and *Sphagnum magellanicum* has occasionally developed within these systems.

These potentially nationally important fen sites of the Scottish Borders are concentrated in a small geographical area. The sites vary in size but most are small (<5 ha). They support a wide range of different vegetation types, many of which have developed as rafts over flooded former peat and marl workings.

[*] Species nomenclature follows Clapham *et al.* (1981) for phanerogams, Smith (1978) for mosses and Watson (1981) for liverworts.

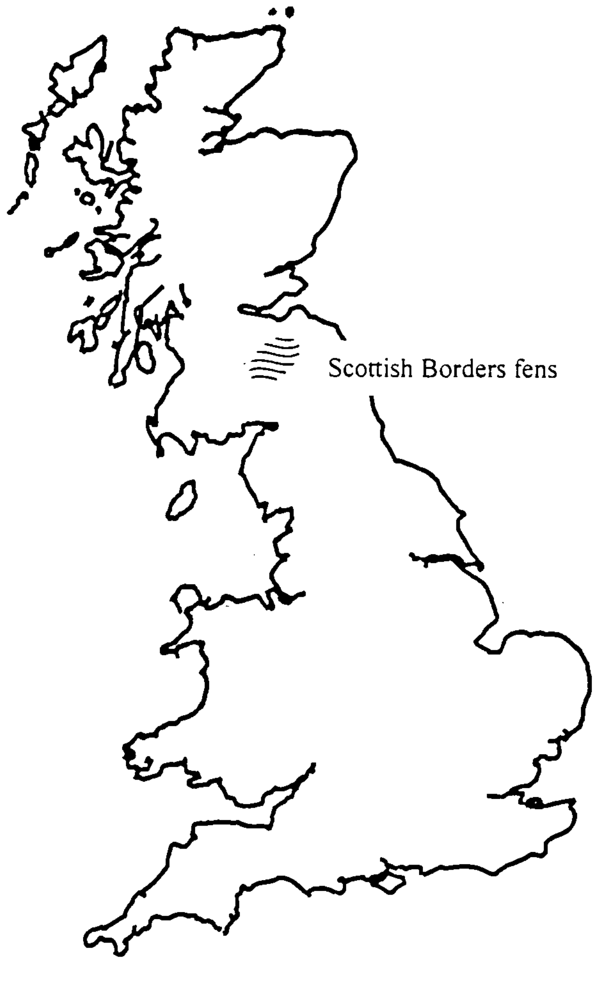


Figure 1.1. Location of the Scottish Borders fens within the United Kingdom.

1.1 Topographical context

1.1.1. THE SCOTTISH BORDERS FENS

The Scottish Borders fens are topogenous mires, developed in small basins. The fens are small, mostly less than 5 ha, and numerous - almost 100 occur in an area of about 300km^2. They are often found aggregated in "complexes" although a few occur as isolated systems. They can be classified as percolating fens (Succow & Lange 1984, Wheeler & Shaw 1995b), essentially topogenous fens with a subsurface flow of water usually derived from marginal springs and flushes. Upwelling springs, or "well-eyes" are commonly found around the mire margins (Murder Moss, Blackpool Moss, Ashkirk Loch, Wester Branxholm Loch, Boghall Moss, Whitmuirhall Loch etc.). The force of the upwelling water is thought to exploit structurally weak areas in the peat, allowing the establishment of a column of water and preventing the deposition of peat (Tight 1987). They appear as deep, sheer-sided pools, rarely colonised by plants, often with gas bubbles rising to the surface. Other features of the Scottish Borders fens include, peripheral "lagg" areas, floating rafts of vegetation ("schwingmoor").

The Scottish Borders fens represent an important series of basin fens in Britain. No similar concentration of this mire type is known elsewhere in Britain. The fens support a wide range of rich-fen plant communities with associated soligenous flushes and localised development of *Sphagnum*-rich poor-fen and ombrogenous bog vegetation. The flora of some sites includes rare northern continental elements including *Corallorhiza trifida*, *Juncus alpino-articulatus*, *Hierochloë odorata* and *Calamagrostis stricta*. The nationally rare bryophytes *Calliergon giganteum*, *Cinclidium stygium*, *Homalothecium nitens*, *Rhizomnium pseudopunctatum*, *Sphagnum contortum*, *Sphagnum fuscum*, *Sphagnum imbricatum*, *Sphagnum teres* and *Sphagnum warnstorfii* are present and locally abundant in some of the Scottish Borders fens. The nationally scarce sedge *Carex diandra* is widespread and abundant.

1.1.2 STUDY AREA

The study area was chosen as the area which contained the greatest concentration of fens in the Scottish Borders (NT 400300-550100) (figure 1.2). This is an area between Selkirk and Hawick measuring 15x20 km (300km^2). It contains almost 100 sites (of which 68 are included in this study), including the Whitlaw Mosses National Nature Reserve in the north-east and Wester Branxholm Loch in the south-west. The fens occur at altitudes between 150-300 metres O.D.

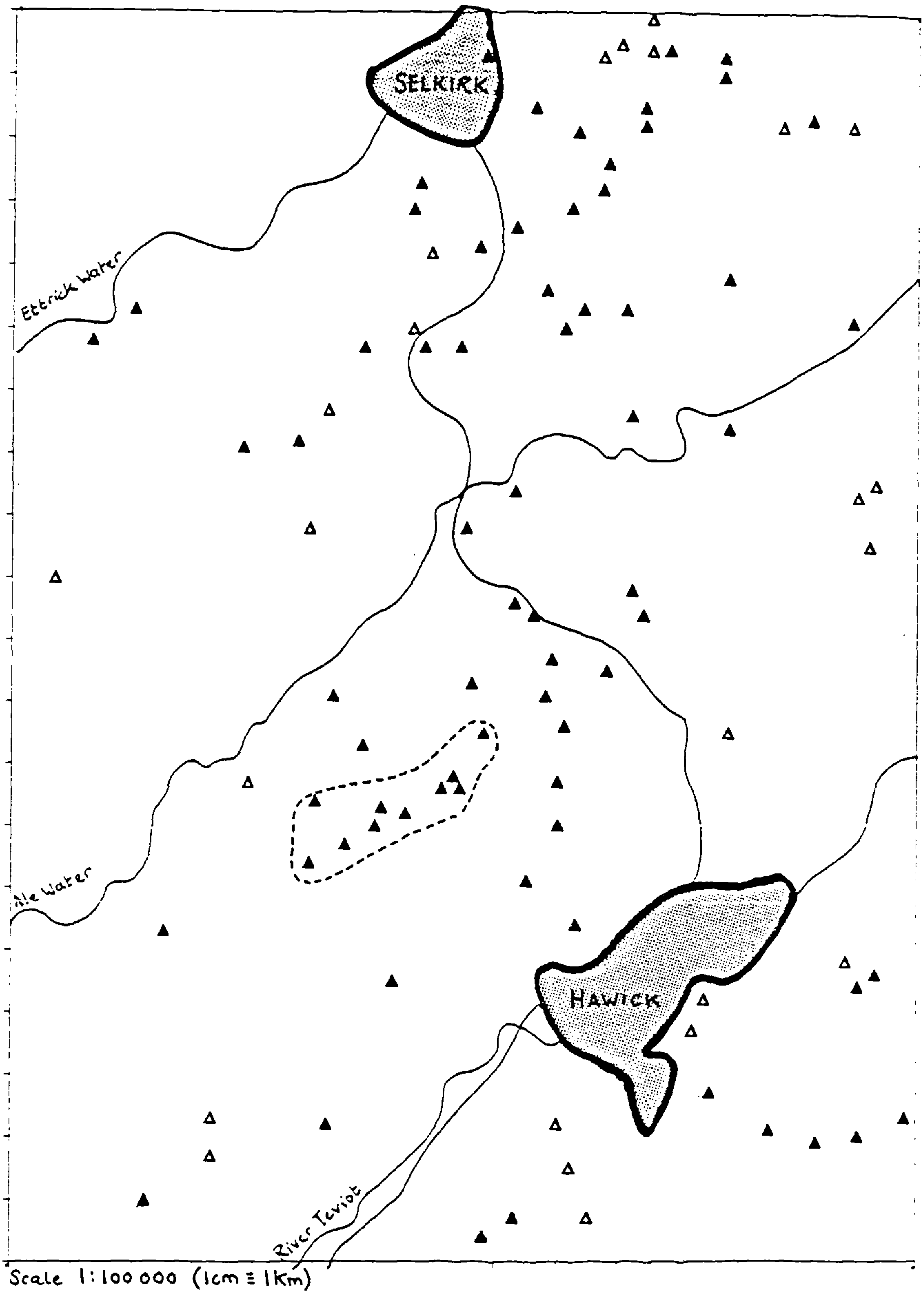


Figure 1.2. Locations of the Scottish Borders fen sites within the study area.

▲ Sites included in the general survey (see table 1.1)
△ Sites excluded from the general survey (see table 1.2)
--- Boundary of the former Wilton Common.

1.1.3 GEOLOGY

The bed rocks of the area are the Silurian greywackes (Silurian Birkhill shales and Gala group of the Llandovery series). These lower Palaeozoic rocks are tightly folded and almost vertically oriented. The effect of erosion on the alternating bands of hard and soft rock gives rise to a micro-relief of closely spaced ridges and hollows (corrugations). The bedrock is covered by till or stony drift and solifluction deposits. The till is a fine textured brown-grey matrix with lumps of shale (Ragg 1960). The main directions of iceflow over the area in the Devensian were northeast and east, approximately following the valley of the river Tweed from a dispersal centre in the middle of the Southern Uplands. This area carried glaciers during the Loch Lomond readvance (stadial of the Late Devensian Late-glacial, equivalent to Godwin's zone III (Godwin 1975)) (Sissons 1967, 1974). There are no major differences in the solid or quaternary geology within the study area but the soils around the Drinkstone Hill area and Selkirk Common area are different from those in the rest of the study area. They have less capability for agriculture (grade 5: suited only to rough grazing and improved grassland) than those in the valley areas (grade 4: land capable of producing a narrow range of crops and grassland with short arable breaks) (Macaulay Institute 1982).

1.1.4 CLIMATE

Maps from the Macaulay Institute (1970a, 1970b) categorise the area's climate as:

- Cool (825-1100 Accumulated Day Degrees Celsius above 5.6°C);
- Moist (25-50mm Potential Water Deficit);
- Exposed (4.4-6.2m/s wind speed);
- Rather severe winters (110-230 Day Degrees Celsius. Accumulated frost).

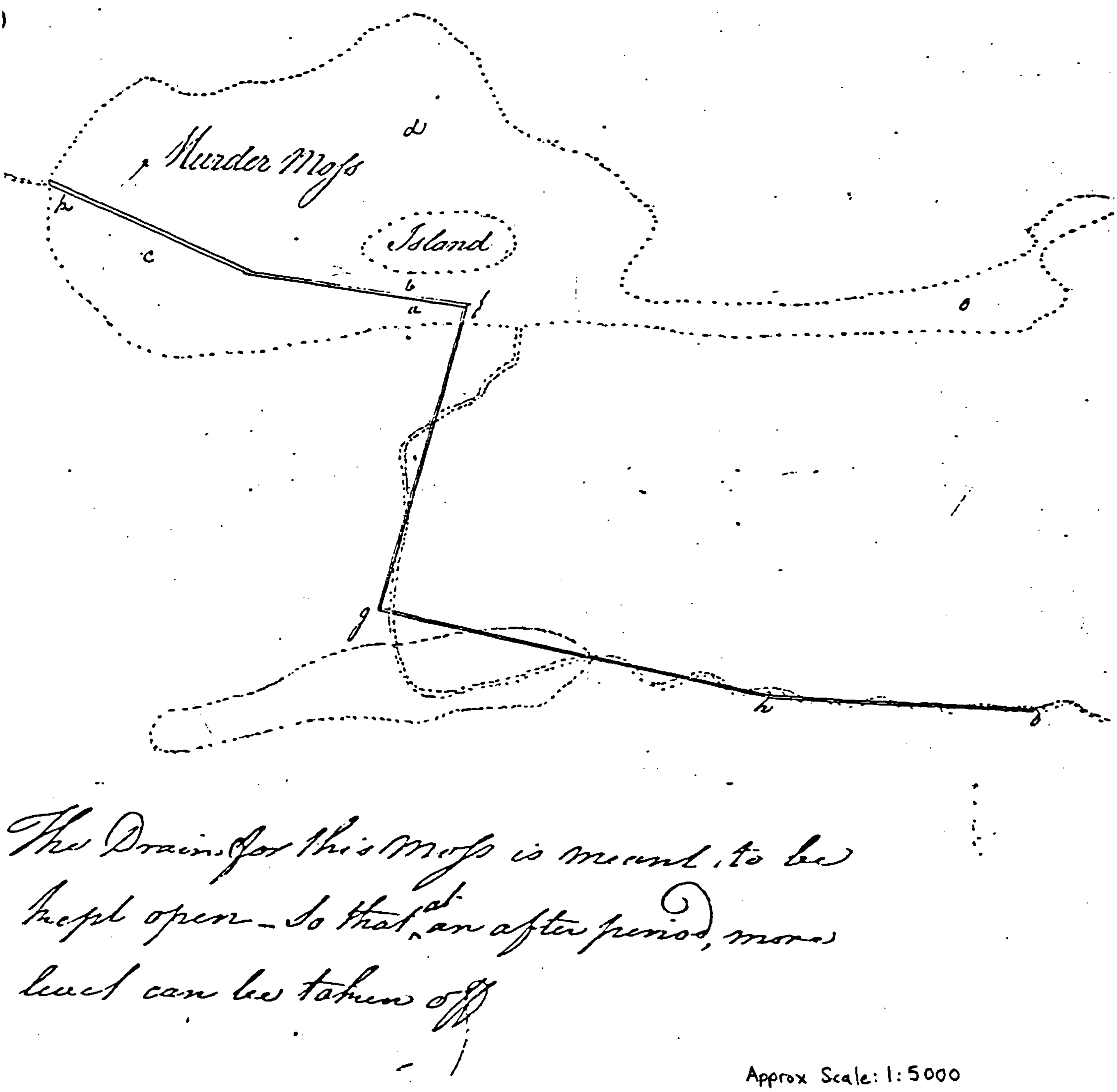
Average annual rainfall data for the period 1941-1970 recorded from 2 stations in the study area were 1012mm (Roberton), and 792mm (Hawick). Total annual rainfall recorded in 1991 was 1009mm (Roberton), 798mm (Hawick) and 814mm (Selkirk). These figures are considerably higher than the total annual rainfall recorded by the rain gauge at Beanrig Moss. Total annual rainfall at Beanrig Moss during 1991 was 577mm and the mean annual rainfall (for the period 1983-1990) was 598mm.

Snow tends to lie for about 20-30 days and the growing season is about 195 days.

1.2 Historical Context

Most of the fen sites in the Scottish Borders were used by local inhabitants during the 18th and 19th centuries as a source of peat for fuel (Dodgshon 1978, Robson 1985). Many were also drained and dug for marl, a calcareous deposit which served as a low-grade lime to improve farmland. The history of some of these sites is unusually well documented due to the survival of various sources many of which are conserved in estate records and national archives. Material available includes maps, accounts, comments on the quality and quantity of peat, the location of "common" mosses and descriptions of the practice of peat and marl extraction and quantities removed. Evidence for the management history of the Scottish Borders fens has been obtained from the following sources:

1. Site survey reports (some with plans). In these reports the peat and marl content of the site was assessed and the cost and benefits of drainage and peat and marl extraction were estimated (e.g. Todshawhill Moss, Blackpool Moss, Murder Moss, Branxholm Easter Loch, Kingside Loch, Over Whitlaw Moss, Whitmuirhall Loch and Huntley Moss). Figure 1.3 shows a plan of Murder Moss from a survey undertaken in 1785 to assess the peat and marl content of the site and estimate the cost of drainage.
2. Accounts kept by large Estates. Detailed accounts were kept by large estates describing commercial operations to drain sites and to extract and sell the peat and marl deposits to their tenants and other farmers and householders (e.g. Groundistone Moss, Whitmuirhall Loch, Huntley Moss, Greenhead (Pot Loch) and Todshawhill Moss);
3. Tenancy agreements. These included statements about the tenants' rights to obtain peat and marl from mosses within the estate (e.g. Harden and Mabonlaw Mosses, Blackpool and Murder Moss);
4. Records of legal proceedings. Legal records document the division of common land into private ownership and the assessment of commoners (fewers) rights to obtain peat from sites for domestic use and the allocation of suitable sites for this purpose. Figure 1.4 shows a plan of the division of Wilton Common (Hawick) between neighbouring farms which took place in 1764. This plan shows the fens (mosses) and the sites with their spread ground which were allocated to the parishioners of Wilton as "common mosses" (Long Moss, Todshaw Moss and Threephead Moss). The area this represents is marked on the sketch map of the study area in figure 1.2;
5. Correspondence concerning disputes between parties with shared interests in sites and the rights of different parties to marl (e.g. Blackpool Moss, Murder Moss and Curdyhaugh Moss).



Approx Scale: 1:5000

Figure 1.3. Surveyors sketch map of Murder Moss and Curdyhaugh Moss c. 1785 showing the location of peat borings and proposed drains.
(The associated surveyors report states that the quantity of peat which would need to be removed to make the drain on Murder Moss from f-k was calculated as 5331 cubic yards;at boring (a) there were 6 feet of peat over 4.5 feet of marl over clay; at boring (b) there were 7.5 feet of peat over 6 feet of marl over clay. No boreswere made at (c) or (d) because they were flooded and no marl was found at (e) (Robson 1985))

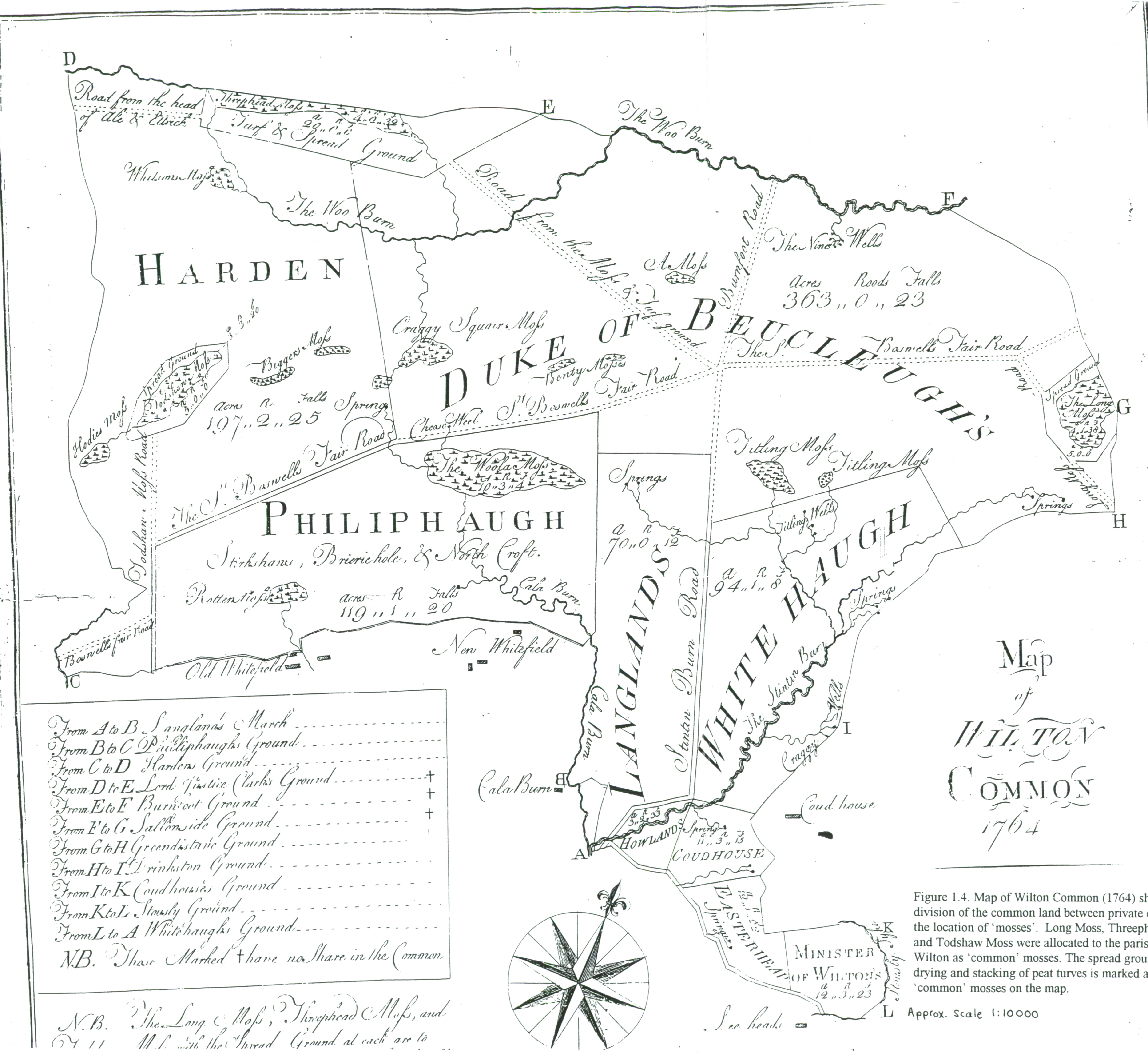


Figure 1.4. Map of Wilton Common (1764) showing the division of the common land between private estates and the location of 'mosses'. Long Moss, Threephead Moss and Todshaw Moss were allocated to the parishioners of Wilton as 'common' mosses. The spread ground for the drying and stacking of peat turves is marked around the 'common' mosses on the map.

Approx. Scale 1:10000

Many drainage operations were well documented and refer both to general acquisition of peats and to specific operations at certain named sites. Stone-lined drains and conduits still lead from many of the sites (e.g. Ashkirk Loch, Blackpool Moss, Borthwickshiels Loch, Dunhog Moss, Easter Branxholm Loch, Groundistone Moss, Hall Moss, Kippilaw Moss, Mabonlaw Moss, Muirfield Moss, Murder Moss, St Leonards Moss, Synton Courses Loch, Synton Loch, Whitmuirhall Loch).

The available documentary material has been researched by Robson (1985) and the following is a summary of the main general points from his manuscript.

Peat and marl extraction occurred on a large scale in the parishes of Wilton, Ashkirk, Lilliesleaf, Ancrum, Selkirk and Bowden, which contained abundant peat-filled hollows. Much of the surviving documentary material refers to this area.

The Scottish Borders fens provided fuel for lowland farm and village communities. Records document the removal of peat and use of sites for livestock grazing from the early 16th century although the main period of large-scale peat and marl extraction occurred between 1750 and 1830. The fens had many uses including:

- cutting peat for fuel;
- cutting grass and reeds for fuel;
- wood and brush cutting;
- summer grazing of sheep and lambs;
- winter grazing when the ground was frozen;
- cattle grazing of the margins;
- cutting of hay for cattle fodder.

Certain sites within each parish were designated "common" mosses where the parishioners could obtain peats. Other sites were shared between tenants of farmsteads and householders (fewers) from particular villages. This was the case at Blackpool and Murder Mosses which were shared between Nether Whitlaw Farm, Clarilawmuir farm, Holydean farm and the fewers of Midlem (a nearby village). Some large estates drained sites and then sold the peat and/or marl to householders from settlements nearby and at a discounted rate to tenants. The peat and marl extraction was carried out by the purchaser, tenant, householder or parishioner and his workers. Fens were surrounded by designated "spread" ground, an area adjacent to the site for the drying and stacking of peat turves. Once all the useful material had been removed from a site another source was found. The fen peat was often 6-7 m deep. Exploiting such a depth required the removal of a large quantity of water. Peat cutting could take place around the edges of a site without major drainage, though sooner or later it became necessary to work further into the moss and this meant getting rid of more water. Draining the moss became a lengthy, expensive but inevitable necessity, particularly if the intention was to reach the marl which lay below the peat. The presence of marl and the depth and quality of the peat was 'proved' by excavation or boring with rods. Shallow surface drains could lower the water level enough to provide extra grazing for stock and to make the site accessible so that the vegetation could be cut. (A very dry summer or hard frost could have the same effect). Deeper drains were required for the removal of peat and subsequently marl. Draining was often very expensive. Shallow surface cut drains were followed by deeper ones and then sometimes by subterranean culverts. Drains were cleared and maintained by the parties with rights to the peat, the householders, tenants, parishioners usually at the start of the main peat-cutting season (which normally began in May). Some large estates employed workers to maintain the drains, and carry out general duties associated with the extraction of peat and marl.

The methods of draining the site, cutting the peat and removing the marl were common to all areas so the practice at one site would be similar to that at all others. These methods are described in detail in Robson (1985).

1.3 Revegetation of peat and marl workings

In the past fen sites have been an important source of peat for domestic fuel throughout Britain, and have been drained and dug on a large scale. The Norfolk Broads are extensive flooded peat cuttings (Lambert *et al.* 1960) and similar sites exist in the Netherlands (Segal 1966, Van Wirdum 1991). Regular peat cutting in these lowland areas generally ceased with the onset of industrialisation when improved transport and the development of towns meant that the rural communities contracted and other fuel sources, mainly coal, became more widely available (Wells 1988). Many former peat-cuttings have re-vegetated since abandonment. Some factors determining the type of vegetation colonising flooded former peat cutting in bogs were identified by White (1930). She found that the depth of cutting determined the type of colonising vegetation so aquatic communities would colonise the deepest cuttings, followed by fen communities, followed by poor-fen communities dominated by *Sphagnum* species. The subsequent succession then followed this sequence until the vegetation became indistinguishable from that present on the original bog surface. Its rate was influenced by the area of the peat cutting and was most rapid in the smallest areas. In the Scottish Borders fens some former peat and marl workings reflooded on abandonment and these have re-vegetated hydroserally. In others the drains have remained intact and a vegetation layer of fen meadow or small sedge fen has developed on solid material over the base of the peat / marl working. At yet other sites the drains were initially effective but then later became blocked leading to the gradual re-flooding of the peat-cutting. This resulted in either rooted vegetation with standing water or, perhaps, floating rafts where the layer of vegetation became detached from the solid peat and floated to the surface. The latter process has been described from some Dutch sites (H. Piek (1972), cited by Bakker (1979)).

Some of the most scarce and valued plant communities in British fens occur in former peat cuttings which have re-vegetated hydroserally (Wheeler 1993). However many of them represent a transient phase in the terrestralization sequence and may be lost as the infilling process continues, despite continued vegetation management (Giller & Wheeler 1986). Therefore the only way of ensuring the perpetuation of these plant communities may be through the re-excavation of peat pits (Wheeler 1993).

In contrast to peat-cuttings, the re-vegetation of marl pits has not been much investigated, although the development of vegetation in an actively depositing marl bed in the U.S.A. has been described by Seichab (1984).

1.4 Rationale

The concentration of a large number of fens, many with a well documented management history, of the same mire type, within the same geological and climatic region but supporting a wide range of fen plant communities presented an unparalleled opportunity to investigate the influence of management history and environmental conditions on vegetation development.

The aims of this study were to investigate the role of site chemical conditions, surrounding land-use, the past extraction of peat and marl and site size and morphology in the development of the present vegetation of the Scottish Borders fens, and to evaluate the national and regional conservation importance of the Scottish Borders fen sites included in this study.

The project was organised into two phases of investigation:

1. A general survey to broadly identify the fen resource of the Central Scottish Borders;
2. Ecological studies into aspects of vegetation development at a small number of contrasting sites.

1.4.1 PHASE 1: GENERAL SURVEY

This involved the compilation of an inventory of sites within the study area. Base-line vegetation, chemical (pH and electrical conductivity measurements) and peat stratigraphic data were recorded from all accessible sites within the study area. Features of sites and the surrounding land use were recorded and a sketch map of the vegetation at each site was produced. These data were then analysed with respect to known or measurable site variables which may influence the development of the present vegetation (site history, site management, site modification, base-line chemical status, size, isolation and catchment land-use). The sites included in the general survey are listed in table 1.1. Sites excluded from the general survey are listed in table 1.2.
The main features of each site included in this study are summarised in Appendix 1.

1.4.2 PHASE 2: DETAILED INVESTIGATIONS

This involved the selection of a small number of sites which represented the range of site and vegetation types found in the general survey to examine in detail the development of the present vegetation in relation to chemical conditions, catchment land use and site history. Particular emphasis was made on the revegetation of peat cuttings and vegetation raft formation.
The investigations which took place at each site are presented in table 1.1.
Plans of sites selected for more detailed studies showing the location of transects and sample points are presented in Appendix 2.

1.5 Organisation of thesis

This thesis is organised into the following sections:

- Description of vegetation types and peat stratigraphy of the Scottish Borders fens (Chapters 2,3).
- Investigation of factors (water chemistry, peat fertility, intensity of surrounding land use, site morphology and site management) which may affect vegetation development (Chapters 4,5,6).
- Implications for habitat conservation and fen vegetation management (Chapter 7).

In chapter 2 the present vegetation of the Scottish Borders fens is systematically described and classified using multivariate procedures. This classification is compared with existing comprehensive mire vegetation classification schemes (e.g. Wheeler 1980 a,b,c and Rodwell 1991, 1994).

The role of site management histories, in particular peat and marl extraction, in the development of the present vegetation is examined in chapter 3 and the status of each site (cutover, part cutover, un-modified) is determined on the basis of documentary, visual and stratigraphic evidence. Factors affecting the re-vegetation of peat cuttings are discussed.

The relationship of water chemical conditions and peat fertility to catchment land-use and occurrence of plant communities is investigated in chapter 4.

Many of the Borders fens support quaking rafts of vegetation. In chapter 5 the processes of formation and development of vegetation rafts are investigated.

The Scottish Borders fens are a potentially nationally important group of sites. In chapter 6 the relation of species richness to biogeographical variables (shape, area and isolation) is examined and the conservation importance of each of the Scottish Borders fens sites included in this study is evaluated on the basis of species-richness, rarity and biodiversity.

Table 1.1. List of names and grid references of sites included in the general survey (site description and recording of vegetation, gross stratigraphy and pH and electrical conductivity) and indication of their inclusion in detailed investigations of peat stratigraphy, fen water chemistry, peat fertility, and the chemistry and stratigraphy of vegetation rafts.

		Selected Sites			*Vegetation Rafts*	
Site name	*National Grid Reference*	*Peat Stratigraphy*	*Water Chemistry*	*Peat Fertility*	*Water Chemistry*	*Stratigraphy*
Adderstonelee Moss SSSI	NT 533 119					
Ashkirk Loch SSSI	NT 476 193	✓	✓	✓		
Beanrig Moss NNR	NT 517 293	✓	✓	✓	✓	
Beeswood Moss	NT 447 232					
Berry Moss	NT 491 250					
Bitchlaw Moss	NT 525 121					
Blackcraig Moss	NT 502 208					
Blackpool Moss NNR	NT 517 290	✓				
Blind Moss SSSI	NT 458 183	✓			✓	
Boghall Moss	NT 491 186					
Borthwickshiels Loch	NT 425 153					
Branxholm Easter Loch SSSI	NT 433 117					
Branxholm Wester Loch SSSI	NT 422 110					
Brown Moor Heights pSSSI	NT 458 247	✓				✓
Buckstruther Moss SSSI	NT 540 120					
Clerklands Moss	NT 494 253					
Curdyhaugh Moss	NT 504 282					
Dry Moss	NT 483 266					
Dunhog Moss SSSI	NT 474 247					
Fluther Moss	NT 548 123					
Greenside Moss	NT 518 258	✓				✓
Groundistone Moss	NT 498 195	✓			✓	
Haining Moss	NT 467 273					
Hall Moss	NT 489 197					
Harden Moss	NT 449 164					
Hare Moss	NT 468 247					
Hartwoodburn Moss	NT 466 269					
Highchesters Moss	NT 463 145					
Hummelknowes Moss SSSI	NT 515 127					
Huntley Moss	NT 413 248					
Hutlerburn Loch	NT 420 253					
Kippilaw Moss	NT 493 154	✓	✓	✓		✓
Ladywoodedge Moss	NT 488 256					
Lilliesleaf Moss	NT 539 251					
Lionfield Moss	NT 485 161					
Little Moss	NT 540 144					
Long Moss SSSI	NT 478 185	✓	✓		✓	
Mabonlaw Moss	NT 455 167					
Muirfield Moss	NT 504 204	✓	✓	✓		
Murder Moss NNR	NT 504 285	✓	✓	✓		
Nether Whitlaw Moss SSSI	NT 508 294	✓	✓		✓	✓
Newhouse Moss	NT 518 234					
Pickmaw Moss	NT 493 281					
Riddellshiel Moss	NT 501 253					
Rotten Moss	NT 460 170					
Sea Croft Moss	NT 478 104					
Selkirk Hill Moss	NT 486 285					
Selkirk Pot Loch	NT 478 283					

Table 1.1 cont.

Site name	National Grid Reference	Selected Sites: Peat Stratigraphy	Selected Sites: Water Chemistry	Selected Sites: Peat Fertility	Vegetation Rafts: Water Chemistry	Vegetation Rafts: Stratigraphy
Selkirk Race Course Moss SSSI	NT 498 276					
Shielswood Loch	NT 453 191					
St. Leonards Moss	NT 483 107	✓	✓	✓		
Stoneyford Moss	NT 486 204					
Stouslie Pool	NT 490 170					
Synton Loch	NT 483 206					
Tandlaw Moss	NT 490 177					
Tathyhole Moss	NT 475 218					
Threephead Moss	NT 450 175					
Tocher Lodge Moss	NT 438 231					
Todshawhill Moss	NT 452 122					
Whitehaughmoor Moss W	NT 471 176					
Whitehaughmoor Moss E	NT 474 176	✓	✓	✓	✓	✓
Whitehaughmoor Moss M	NT 472 176					
Whitmuihall Loch SSSI	NT 497 272	✓	✓	✓		
Whitmuir Moss	NT 492 269					
Woolaw Loch	NT 461 173					
Woolaw Moss	NT 465 172					

Table 1.2. List of site names and grid references of sites excluded from the general survey.

Site Name	*N.G.R.*	*Reason for exclusion*
Branxholm Easter Loch	NT 433 117	Open Water
Essenside Loch	NT 449 218	Open Water
Ewens loch	NT 512 137	Landfill site
Green Diamonds	NT 466 250	Open Water
Lindean Reservoir	NT 505 294	Open Water
Nig Knowes Moss	NT 490 122	Access denied
Whithope Moss	NT 433 123	Access denied
Greenhead	NT 497 293	Access denied
Lindean Mast	NT 500 295	Access denied
Prieston Cooksmoss	NT 532 283	Treated with weedkiller
Prieston Templehall	NT 527 282	Treated with weedkiller
Eastfield	NT 539 282	Access denied
Catshawhill 1	NT 540 223	Access denied
Catshawhill 2	NT 543 225	Access denied
Marlside Hill	NT 542 215	Access denied
Big Wood	NT 477 263	Access denied
Braw Moss	NT 469 262	Access denied
Over Whitlaw	NT 505 299	Access denied
Loch Syke	NT 452 237	Forestry Plantation
Groundistone Covert	NT 488 191	Access denied
Acreknowe Reservoir	NT 495 107	Open Water
Williestruther Loch	NT 492 115	Open Water
Weavers Moss	NT 439 177	Forestry Plantation
Mosshills Loch	NT 514 142	Access denied
Akermoor Loch	NT 207 210	Open Water
Cavers Knowes Moss	NT 538 148	Access denied
Headshaw Loch	NT 460 235	Open Water
Alton Pond	NT 518 185	Open Water

Chapter 2: Plant communities of the Scottish Borders fens.

2.1 Introduction

In lowland agricultural landscapes wetlands provide one of the main semi-natural habitats, and form repositories for a wide range of plant species including those plant species which are particularly characteristic of fens and bogs (Wheeler 1988, 1993). Wetlands support a wide range of plant communities (Wheeler 1980a,b,c, Rodwell 1991, 1994). Many rare species occur within wetland plant communities, including many bryophytes which are well represented in these habitats (Wheeler 1988, 1993). Some of these rare species are specially adapted to the wetland environment, but many other species are simply tolerant of the water regime and the wetland habitat is a refuge for rare species e.g. *Listera ovata*, which would thrive on dry soils but which either cannot compete in certain (e.g. unmanaged) dryland communities or where their dryland habitat has been destroyed (e.g. ploughed up old pasture) (Wheeler 1993). Therefore the potential niche of many species typical of wetland plant communities is considerably broader than their realised niche. The actual habitat requirements of many wetland species is however unknown and comparative screening programmes have not included typical 'wetland' species.

The physical characteristics of a site have often been used to characterise mire vegetation through the classification of wetland type (Kulczynski 1949). The environmental conditions present at a site are often important in determining the occurrence of certain species and plant communities. Generally the mire habitat is very variable and subject to a wide range of different environmental conditions (Wheeler 1993). This variation is manifested in the vegetation and it is often difficult to divide some groups of mire vegetation into distinct floristic units (Wheeler 1980a,b,c, O'Connell 1981). Mire vegetation in the U.K. and Northern Europe has broadly been categorised into rich-fen, poor-fen and bog (Du Rietz 1949, 1954, Sjors 1950). Within these categories several mire plant communities have been described and classifications produced for Britain (e.g. McVean & Ratcliffe 1962, Spence 1964, Daniels 1978, Wheeler 1980a,b,c, O'Connell 1981, Rodwell 1991, 1994).

The most recent classification of British mire vegetation has been the National Vegetation Classification (Rodwell 1991, 1994) which was designed to standardise the description of U.K. vegetation. This is based on analyses of the data from most of the existing U.K. classifications combined with new data recorded using standardised sampling procedures.

The Scottish Borders fens support many nationally scarce plant species and wetland plant communities which represent rich-fen, poor-fen and bog habitat types. The vegetation of many of the Scottish Borders fens has not been systematically described.

The aims of this part of the study were to:

1. Describe the full range of wetland plant communities represented in the Scottish Borders fens;
2. Compare a range of multivariate classification procedures used to classify the vegetation data recorded in the general survey of the Scottish Borders fens. Assess the performance of different procedures and select one classification as a basis for the description of the plant communities of the Scottish Borders fens;
3. Relate the classification of the Scottish Borders fens vegetation data to other schemes, in particular the National Vegetation Classification;
4. Relate the vegetation composition of the Scottish Borders fens to particular features of these fen systems.

2.2 Methods

2.2.1 SAMPLING STRATEGY

The aim of the survey was to sample the vegetation of all the wetland habitat types (rich-fen, poor-fen and bog) occurring in the basin area at each site.

The methods were designed to be compatible with other studies that have been conducted on fens in the U.K (Wheeler 1975, Wheeler & Shaw 1987) and with the National Vegetation Classification approach (Rodwell 1991, 1994).

Each site was sampled by selecting visually-uniform vegetation units (stands) and recording the following data from a representative $4m^2$ quadrat (samples).

Vegetation was described and recorded. Abundance of species was scored using the Domin scale. Species occurring within the stand but outside the quadrat within an area of approximately $100m^2$ were also noted.

The pH and electrical conductivity of the interstitial fen water were recorded in the field.

2.2.2 CLASSIFICATION STRATEGY

There are several existing schemes for the classification of fen vegetation in Britain and in NW Europe based on comprehensive description of vegetation types (Kulczynski 1949, Wheeler, 1975 & 1980a,b,c, Schaminée et al. 1995). The National Vegetation Classification (Rodwell 1991,

1994) has been produced by the re-analysis of data from U.K. classifications combined with new data from smaller scale surveys.

The quadrat data were classified using multivariate analyses: Ward's analysis (Ward 1963), a polythetic, agglomerative technique and TWINSPAN (Hill 1979), a polythetic, divisive technique. Both binary (presence/absence) data and quantitative data for the $4m^2$ and $100m^2$ data sets were analysed and the differences between the classifications were assessed. Prior to the analyses, data for species with less than three occurrences in the entire data set were removed to reduce 'noise' in the data.

A National Vegetation Classification (N.V.C.) community was assigned to each quadrat using the computer programme MATCH (Malloch 1988).

2.3 Results

2.3.1 PRESENTATION OF THE PLANT COMMUNITY DESCRIPTIONS AND VEGETATION TABLES

The vegetation units are described following the N.V.C. approach using as the basic unit the community. This may contain variants. Each community is assigned to the broad habitat categories of rich-fen, poor-fen, bog, and species-poor fen and swamp. The frequency of species within each group was calculated and scored on a five point scale as follows:

Frequency Score	*Frequency*
I	0-20%
II	21-40%
III	41-60%
IV	61-80%
V	81-100%

In the plant community descriptions constant species (frequency V or IV) are listed and associated species (frequency III) and differential species (with a frequency less than III but which are largely confined to that community) are indicated [in square brackets].

The vegetation tables (tables 2.8-2.24) contain the frequency scores of species with a frequency greater than 5% within the community. Constant species have a frequency of V and IV. Differential species have a frequency 25% higher than that found in any other community, or are confined to one community.

2.3.2 VEGETATION CLASSIFICATIONS

Overall 313 quadrats were recorded from 68 sites. 183 species were present in the data set used in the analyses. The numbers of species recorded are presented in table 2.1. These are categorised into species characteristic of rich-fen, poor-fen and bog habitats (see Appendix 3, Wheeler 1996). Rare-fen species are those which have a national frequency less than 5% (Wheeler 1988, 1996).

Table 2.1. Numbers of species recorded in the Scottish Borders fens.

	Total species	Rare fen species	Bog species	Poor-fen species	Rich-fen species
Total species	209	39	25	60	90
Vascular species	150	29	16	40	74
Bryophytes	52	10	8	19	16
Liverworts	7	0	1	1	0

The number of clusters / end-groups yielded by each classification procedure are presented in table 2.2. The TWINSPAN classification procedure is based on dividing one large group made up of all the samples into smaller groups of similar samples. The TWINSPAN analysis was set to split the data into groups at 5 levels, potentially yielding 32 endgroups. However, if the samples are unevenly split at any point the subsequent division may fail because there are too few samples, as was the case in these analyses. Groups of samples which are very distinctly different from other samples are often split from the mass of data early on in the classification procedure.
The Ward's analysis is based on grouping the individual samples into successively larger clusters based on the similarity of samples. There are therefore potentially as many clusters as samples using this technique! At each step samples and clusters are grouped together which lead to the smallest increase in the similarity coefficient between clusters. The difference between the similarity coefficients at each step in the procedure indicates how similar the clusters at one step are to the next. The final clusters, or end-groups, are identified as those beyond the point of the first marked difference in the similarity coefficient in the clustering procedure.

Table 2.2. Numbers of communities yielded by different classification procedures of the Scottish Borders fens vegetation data.

Classification procedure	*Number of clusters / end-groups (plant communities)*
Twinspan (binary)	18
Twinspan (quantitative)	17
Wards (binary)	19
Wards (quantitative)	18

There were some broad similarities between the outcomes of the different techniques, but generally the classifications produced strikingly different results, especially between quantitative and binary analyses.

Generally all the classification procedures grouped the samples into groups which could be interpreted as rich-fen, poor-fen, bog and species-poor swamp and fen. Samples representing some distinctive vegetation types (e.g. *Sphagnum recurvum* dominated poor-fen, *Sphagnum papillosum* dominated bog, and species-rich short sedge fen with *Carex dioica*, *Carex hostiana* and *Ctenidium molluscum*) were grouped together by all the classification procedures.

The quantitative analyses grouped samples primarily on the basis of dominance so that samples containing a dominant species tended to be grouped together, often disregarding more subtle variations in species composition, especially when the vegetation was very species-rich. The qualitative classifications grouped the samples more successfully on the basis of composition, although very species-poor vegetation which is often *characterised* by the dominant species tended to be split into a few large indistinct groups.

2.3.2.1 TWINSPAN

In the TWINSPAN classification procedures samples from some distinctive vegetation types were split from the majority of samples early on in the classification leaving just a few unwieldy groups containing a large number of samples that were broadly similar but which represented different types of vegetation. Further division of these groups simply resulted in a few samples being split, apparently arbitrarily, from the main group which remained very large. Therefore the TWINSPAN classifications were on the whole less satisfactory than those produced by the Wards method and were disregarded.

2.3.2.2 Quantitative Ward's Analysis

The quantitative Ward's analysis (figure 2.1 and table 2.3) yielded a classification which was based on a combination of species dominance and composition with variants based upon the prominence of a particular species. This method did not detect some of the more subtle floristic differences within plant communities so that potentially important variants (for example, quadrats representative of small scale mosaics, and transitional plant communities) were often subsumed into larger clusters. The characteristic rich-fen vegetation type containing abundant base-tolerant *Sphagnum* species was not separated from the other rich-fen communities in this classification. The species-poor swamp and fen samples were grouped into 9 communities although one of these was very ill-defined and contained stands from vegetation which could not easily be fitted into the other groups. This was usually because these quadrats were dominated by species which did not

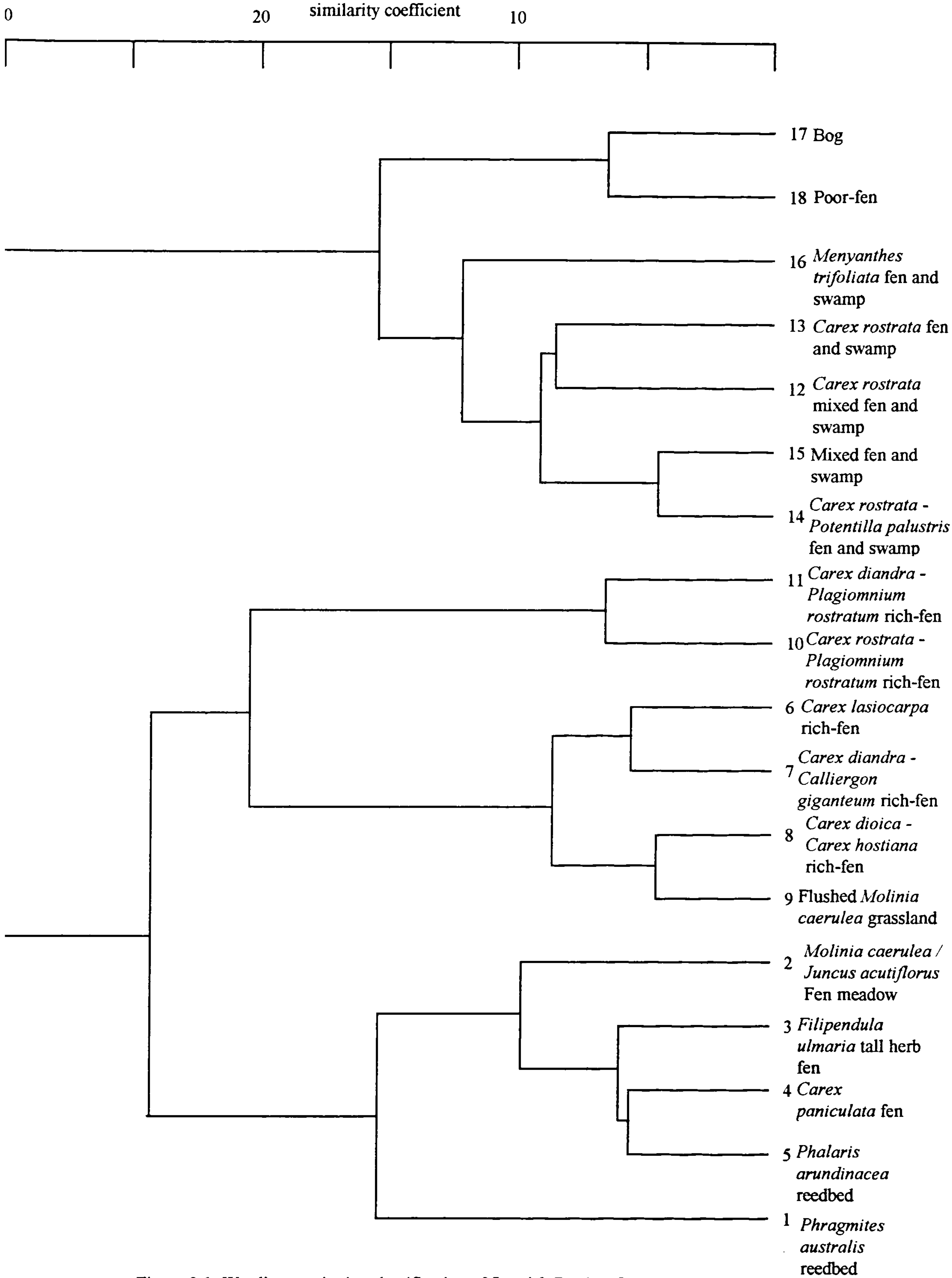


Figure 2.1. Ward's quantitative classification of Scottish Borders fens quadrat data. For descriptions of plant communities see table 2.3.

Table 2.3. Plant communities generated by Ward's quantitative classification of Scottish Borders fens quadrat data. n = number of quadrats; N.V.C. codes are for the communities listed in table 2.6.

End-group *Plant community*	*Constant species (Differential species, (D) Dominant species)*	*n*	*N.V.C. counterpart*
1 *Phragmites australis* reedbed	*Phragmites australis (D), Mentha aquatica, Galium palustre*	20	S4
5 *Phalaris arundinacea* reedbed	*Phalaris arundinacea (D)*	5	S28
4 *Carex paniculata* fen	*Carex paniculata(D), Salix cinerea, Agrostis stolonifera, Filipendula ulmaria, Potentilla palustris*	9	S3
3 *Filipendula ulmaria* tall herb fen	*Filipendula ulmaria (D), Carex disticha, Agrostis stolonifera, Angelica sylvestris, Galium palustre*	14	M27
2 *Molinia caerulea / Juncus acutiflorus* fen meadow	*Valeriana dioica, Rumex acetosa, Molinia caerulea, Juncus acutiflorus, Holcus lanatus, Galium uliginosum, Filipendula ulmaria, Carex panicea, Caltha palustris, Calliergon cuspidatum, Angelica sylvestris, Agrostis stolonifera*	22	M23 M25
9 Flushed *Molinia caerulea* grassland	*Carex rostrata, Carex panicea, Eriophorum angustifolium, Molinia caerulea, Equisetum palustre, Equisetum fluviatile*	10	M25
8 *Carex dioica - Carex hostiana* rich-fen	*Carex hostiana, Carex flacca, Carex panicea, Ctenidium molluscum, Carex dioica, Succisa pratensis, Carex lepidocarpa, Carex rostrata, Campylium stellatum, Drepanocaldus revolvens, Carex diandra, Equisetum palustre, Eriophorum angustifolium, Juncus articulatus, Molinia caerulea, Menyanthes trifoliata*	11	M10
7 *Carex lepidocarpa Carex diandra* rich-fen	*Carex lepidocarpa, Calliergon giganteum, Carex diandra, Eriophorum angustifolium, Calliergon cuspidatum, Campylium stellatum, Carex rostrata, Drepanocladus revolvens, Menyanthes trifoliata, Scorpidium scorpioides*	15	M9 M9b
6 *Carex lasiocarpa* rich-fen	*Carex lasiocarpa, Calliergon cuspidatum, Caltha palustris, Campylium stellatum, Carex lepidocarpa, Carex rostrata, Drepanocladus revolvens, Menyanthes trifoliata, Phragmites australis, Scorpidium scorpioides*	12	M9 M9a

Table 2.3 cont.

End-group *Plant community*	*Constant species (Differential species, (D) Dominant species)*	*n*	*N.V.C. counterpart*
10 *Carex rostrata-Plagiomnium rostatum* rich-fen	*Carex rostrata, Plagiomnium rostratum, Epilobium palustre, Equisetum fluviatile, Agrostis stolonifera, Angelica sylvestris, Caltha palustris, Filipendula ulmaria, Galium palustre, Menyanthes trifoliata, Potentilla palustris*	18	M9b S27a
11 *Carex diandra* rich-fen	*Carex diandra, Calliergon cuspidatum, Caltha palustris, Carex rostrata, Carex lepidocarpa, Plagiomnium rostratum, Potentilla palustris, Equisetum fluviatile, Galium palustre, Menyanthes trifoliata, Juncus acutiflorus*	31	M9b
14 *Carex rostrata -Potentilla palustris -Calliergon cuspidatum* fen and swamp	*Carex rostrata, Potentilla palustris, Calliergon cuspidatum, Galium palustre, Epilobium palustre*	16	S27a
15 *Carex rostrata - Carex nigra* mixed fen and swamp	*Carex rostrata, Epilobium palustre, Galium palustre, Carex nigra, Equisetum fluviatile, Juncus effusus*	13	S27
12 *Carex rostrata* mixed fen and swamp	*Carex rostrata, Equisetum fluviatile, Eleocharis palustris, Agrostis stolonifera, Caltha palustris, Mentha aquatica*	24	S9 S27
13 *Carex rostrata* swamp	*Carex rostrata (D), Equisetum fluviatile, Galium palustre, Juncus effusus*	37	S9a
16 *Menyanthes trifoliata* fen and swamp	*Menyanthes trifoliata (D), Carex rostrata, Equisetum fluviatile*	36	S9b
18 *Carex rostrata - Sphagnum recurvum* community	*Sphagnum squarrosum, Sphagnum recurvum, Potentilla palustris, Menyanthes trifoliata, Carex curta, Aulacomnium palustre, Eriophorum angustifolium,Carex rostrata*	10	M4 M5
17 *Eriophorum vaginatum - Sphagnum papillosum* community	*Calluna vulgaris, Eriophorum vaginatum, Eriophorum angustifolium, Sphagnum papillosum, Sphagnum capillifolium, Aulacomnium palustre, Carex rostrata*	10	M18 M21

occur widely, so that several disparate stands were grouped together, apparently on the basis of their dissimilarity from the other samples, not on their similarity to one another. A feature of Ward's analysis is its use of joint absence as well as joint presence to calculate the similarity of samples which often results in the grouping together of species-poor samples on the basis of the large number of species they *do not* contain.

2.3.2.3 Binary Ward's Analysis

The binary Ward's analysis (figure 2.2 and table 2.4) produced a more complicated classification than the quantitative Ward's classification with the samples divided into a larger number of rich-fen clusters, on the basis of overall floristic composition rather than dominance. However the species-poor swamp and fen samples were divided into only five clusters which were not easily differentiated. These quadrats represented vegetation which was dominated by a single species and the binary classification uses composition only to cluster the data. Therefore species-poor vegetation was clustered on the basis of negative scores (the species which were *not* present in each quadrat) and were therefore classed as similar, apparently because of their dissimilarity to samples in other clusters. However this classification did reflect the variability and continuum of vegetation types actually seen in the field and distinguished some distinctive plant communities (e.g. the *Carex diandra - Sphagnum contortum* community) which were not identified by the other classification procedures.

The plant communities defined by the binary and quantitative Ward's classifications communities are summarised below (table 2.5).

2.3.2.4 National Vegetation Classification

The N.V.C. communities and sub-communities found represented in the Scottish Borders fens are listed in table 2.6. These were recognised using MATCH, a computer programme which lists the N.V.C. communities which most closely resemble each quadrat. Overall 33 N.V.C. plant communities and sub-communities were represented.

The quantitative Ward's classification had more affinities with the N.V.C. mires and swamps and tall herb fen classifications than did the binary Ward's classification, although both classifications generated some groups which had little affinity with any N.V.C. communities. Some groups generated by the above analyses were broadly synonymous with N.V.C. plant communities (table 2.7).

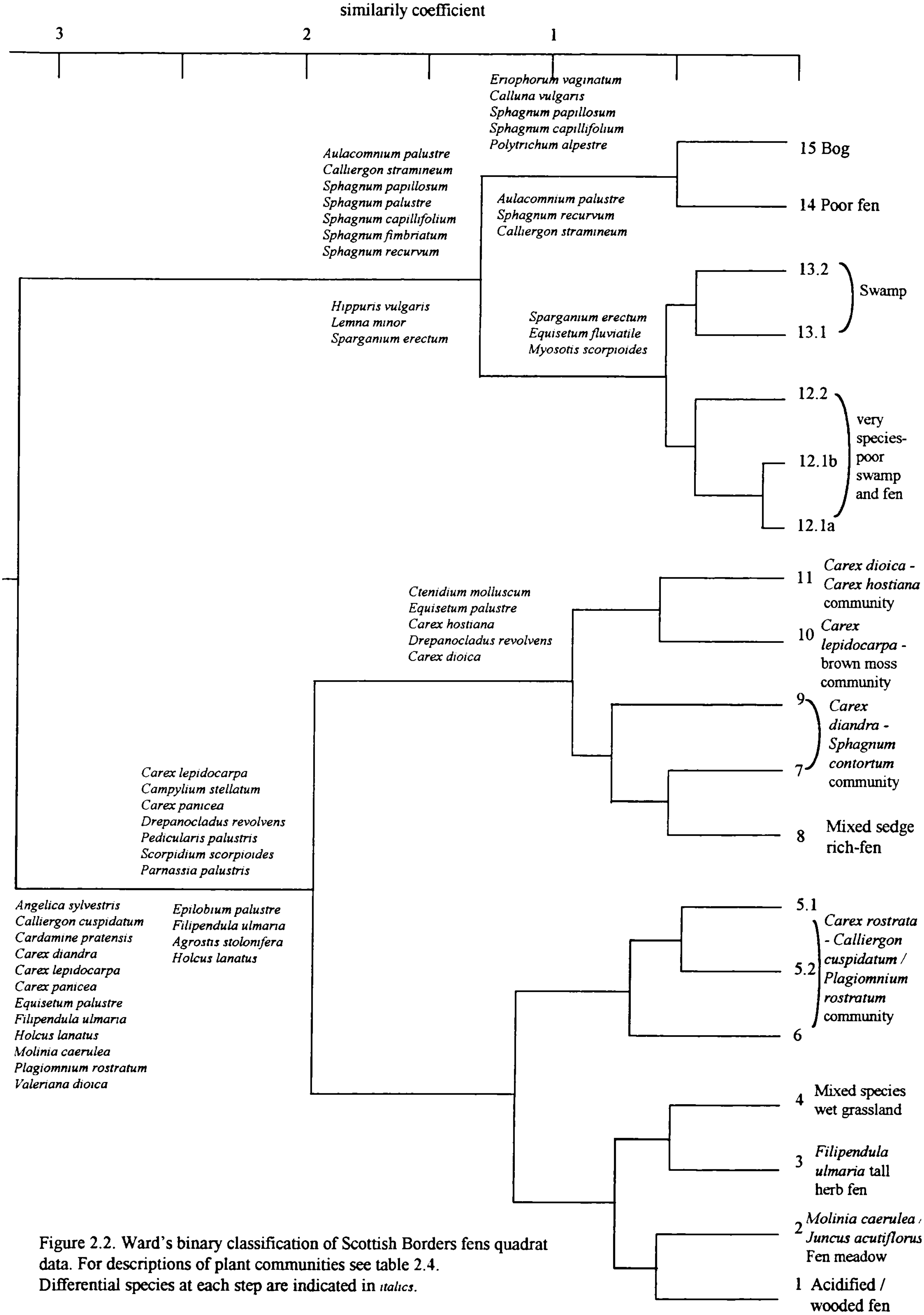


Figure 2.2. Ward's binary classification of Scottish Borders fens quadrat data. For descriptions of plant communities see table 2.4. Differential species at each step are indicated in *italics*.

Table 2.4. Plant communities generated by Ward's binary classification of Scottish Borders fens quadrat data. n = number of samples; N.V.C. codes are for the communities listed in table 2.6. Differential species have at least a 25% higher frequency in the community than in other communities. Weakly differential species are confined to a community or variant but have an occurrence within the community less than 25%.

End-group / plant community	*Description*	*Constant species (differential species; [weakly differential] species)*	*n*	*N.V.C code*
1 Acidified / wooded fen	Species-poor fen and fen carr.	*Agrostis stolonifera, Holcus lanatus, Molinia caerulea, Eriophorum angustifolium, Galium palustre, Sphagnum subnitens, Viola palustris*	8	
2 *Molinia caerulea / Juncus acutiflorus* fen meadow	Species-rich rush pasture with open structure, numerous herbs and a mixture of sedge species but scattered bryophytes	*Juncus acutiflorus (D), Epiloobium palustre, Filipendula ulmaria, Holcus lanatus, Caltha palustris, Galium uliginosum, Molinia caerulea, Carex panicea, Luzula multiflora, Rumex acetosa, Lychnis flos-cuculi, Anthoxanthum odoratum, Phragmites australis, Succisa pratensis, Angelica sylvestris, Potentilla erecta Achillea ptarmica, [Cirsium palustre], [Centaurea nigra]*	10	M23
3 *Filipendula ulmaria* tall herb fen	Tall herb fen vegetation dominated by tall, dense *Filipendula ulmaria* with tall herbs and monocots. *Carex paniculata* is often prominent and there is often some scrub development	*Filipendula ulmaria (D), Agrostis stolonifera, Holcus lanatus, Juncus acutiflorus, Epilobium palustre, Carex rostrata, Juncus effusus, Rumex acetosa, Lychnis flos-cuculi, Angelica sylvestris, Carex disticha, Equisetum fluviatile[Poa trivialis], [Stachys palustris]*	15	M27
4 Mixed wet grassland	Indistinctive species-poor vegetation with a rather limited variety of sedges and grasses and tussocks of *Juncus conglomeratus*	*Filipendula ulmaria, Agrostis stolonifera, Holcus lanatus, Calliergon cuspidatum, Epilobium palustre, Carex rostrata, Carex nigra, Juncus conglomeratus*	18	
5 &6 *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community	Rather variable rich-fen vegetation characterised by a basic suite of species.	*Carex rostrata, Menyanthes trifoliata, Equisetum fluviatile, Potentilla palustris, Caltha palustris, Galium palustre, Calliergon cuspidatum, Plagiomnium rostatum*	23	M9/S27
5.2 *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, Typical variant	Species-poor variant lacking differential species.		19	M9/S27

Table 2.4 cont.

End-group / plant community	*Description*	*Constant species (differential species; [weakly differential] species)*	*n*	*N.V.C code*
5.1 *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant	Species-rich variant where the sward is enriched by mixed sedges and the bryophyte layer includes scattered brown moss species	*Molinia caerulea, Carex diandra, Carex nigra, Ranunculus flammula, Juncus articulatus, Sagina nodosa, Carex lepidocarpa*	19	M9
6 *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, Miscellaneous variant	Miscellaneous variant includes stands which do not fit easily into the other two, well defined variants.	*Epilobium palustre, Juncus effusus, Dactylorhiza fuchsii, Cirsium palustre, Holcus lanatus, Myosotis scorpioides*	23	M9/S27
8 Mixed sedge rich-fen community	Rich-fen vegetation with a sward composed of a variety of small sedge species with plentiful herbs and a bryophyte layer including locally abundant brown moss species.	*Menyanthes trifoliata, Calliergon cuspidatum, Carex lepidocarpa, Eriophorum angustifolium, Succisa pratensis, Valeriana dioica, Molinia caerulea, Carex panicea, Carex rostrata, Potentilla palustris, Filipendula ulmaria, Galium uliginosum, Cardamine pratensis, Caltha palustris, Carex diandra, Lychnis flos-cuculi, Epilobium palustre, Plagiomnium rostratum, Angelica sylvestris, Agrostis stolonifera*	13	M9b
7+9 *Carex diandra - Sphagnum contortum* community	Rich fen vegetation characterised by a rich bryophyte layer containing brown moss species and base-tolerant *Sphagnum* species *Sphagnum contortum and Sphagnum warnstorfii* beneath an open sward of sedges.	*Menyanthes trifoliata, Calliergon cuspidatum, Carex lepidocarpa, Eriophorum angustifolium, Succisa pratensis, Campylium stellatum, Pedicularis palustris, Scorpidium scorpioides, Potentilla palustris, Cardamine pratensis, Caltha palustris, Carex diandra, Parnassia palustris Sphagnum contortum, Rhizomnium pseudopunctatum, [Sphagnum warnstorfii]*	17	M9a? M9 M8
10 *Carex lepidocarpa* - brown moss rich-fen community	Rich fen characterised by small sedges and rich-fen bryophytes. Some stands are transitional to the *Carex dioica - Carex hostiana* community	*Menyanthes trifoliata, Calliergon cuspidatum, Carex lepidocarpa, Eriophorum angustifolium, Molinia caerulea, Carex panicea, Campylium stellatum, Carex rostrata, Equisetum palustre, Drepanocladus revolvens*	17	M9a
11 *Carex dioica - Carex hostiana* community	Rich-fen vegetation growing in spring discharge and seepage areas within fens. This vegetation is characterised by a low-growing and open sward, and is very species rich.	*Carex hostiana, Juncus bulbosus, Pinguicula vulgaris, Carex dioica, Eleocharis quinqueflora, Fissidens adianthoides, Triglochin palustris, Briza media, Carex flacca, Ctenidium molluscum, Euphrasia officinalis, Luzula multiflora*	11	M10

Table 2.4 cont.

End-group / plant community	*Description*	*Constant species (differential species; [weakly differential] species)*	*n*	*N.V.C code*
12.1a Species-poor swamp and fen *Phragmites* dominated	Very species-poor swamp and fen vegetation containing no distinctive set of species	*Carex rostrata, Phragmites australis (D), Urtica dioica*	28	S4/S28/S9
12.1 *Potentilla palustris* variant	*Carex rostrata* monoculture accompanied by scattered swamp species	*Carex rostrata, Potentilla palustris*	11	S9
12.2 *Menyanthes trifoliata* dominant	Dominant *Menyanthes trifoliata* occurs with scattered blades of *Carex rostrata* and spikes of *Equisetum fluviatile*	*Carex rostrata, Menyanthes trifoliata (D), Equisetum fluviatile, Ranunculus lingua*	33	S9b
13.1 *Carex rostrata-Equisetum fluviatile* swamp and fen *Carex nigra-Juncus* variant	Species-poor vegetation dominated *by Carex rostrata* with a small suite of associated species. This variant includes vegetation enriched by a small number of additional species	*Carex rostrata, Equisetum fluviatile, Myosotis scorpioides, Mentha aquatica, Carex nigra, Epilobium palustre, Juncus acutiflorus, Caltha palustris*	27	S9/S27
13.2 *Cicuta virosa-Lemna* variant	Usually very wet vegetation with aquatic species and open water	*Cicuta virosa, Lemna minor, Polygonum amphibium*	26	S9
14 *Carex rostrata - Sphagnum recurvum* community	Poor fen vegetation characterised by dominant *Sphagnum* species typical of base-poor conditions.	*Carex rostrata, Aulacomnium palustre, Eriophorum angustifolium, Sphagnum recurvum, Potentilla palustris, Menyanthes trifoliata, Juncus effusus, Sphagnum fimbriatum, Calliergon stramineum*	10	M4/M5
15 *Eriophorum vaginatum - Sphagnum papillosum* community	Bog vegetation with *Sphagnum* species typical of ombrogenous habitats.	*Carex rostrata, Aulacomnium palustre, Eriophorum angustifolium, Calluna vulgaris, Eriophorum vaginatum, Sphagnum papillosum, Erica tetralix, Drosera rotundifolia, Sphagnum capillifolium, Luzula multiflora, Polytrichum alpestre*	8	M18/M21

Table 2.5. Summary of the plant communities derived from the binary and quantitative Ward's analyses of the Scottish Borders fens vegetation data.

<table>
<tr><th></th><th>Ward's Classification</th><th></th></tr>
<tr><th>Habitat type</th><th>Binary</th><th>Quantitative</th></tr>
<tr><td rowspan="3">Rich-fen</td><td>• Carex dioica - Carex hostiana community
• Carex lepidocarpa - brown moss community
• Carex diandra - Sphagnum contortum community
• Mixed sedge rich-fen
• Carex rostrata - Calliergon cuspidatum - Plagiomnium rostratum community (3 variants)</td><td>• Carex dioica - Carex hostiana community
• Carex lepidocarpa - brown moss community (Carex diandra - Calliergon giganteum variant; Carex lasiocarpa variant)
• Carex rostrata - Plagiomnium rostratum community (Carex diandra - Carex lepidocarpa variant)</td></tr>
<tr><td>• Juncus acutiflorus / Molinia caerulea fen meadow
• Poorly defined species poor +/- tussocky wet grassland
• Poorly defined acidified fen and wet grassland with Sphagnum subnitens and Viola palustris</td><td>Juncus acutiflorus - Molinia caerulea fen meadow
Flushed Molinia caerulea wet grassland</td></tr>
<tr><td>Filipendula ulmaria tall-herb fen</td><td>Filipendula ulmaria tall-herb fen</td></tr>
<tr><td>Poor-fen</td><td>Carex rostrata - Sphagnum recurvum community</td><td>Carex rostrata - Sphagnum recurvum community</td></tr>
<tr><td>Bog</td><td>Eriophorum vaginatum - Sphagnum papillosum community</td><td>Eriophorum vaginatum - Sphagnum papillosum community</td></tr>
<tr><td rowspan="2">Species-poor fen and swamp</td><td>5 undifferentiated communities</td><td>• Carex paniculata community
• Carex rostrata - Potentilla palustris community
• Carex rostrata mixed community
• Carex rostrata dominated community
• Menyanthes trifoliata dominated community
• Miscellaneous mixed fen and swamp (contains stands which do not fit into the above communities)</td></tr>
<tr><td>Phragmites australis reedbed</td><td>Phragmites australis reedbed
Phalaris arundinacea reedbed</td></tr>
</table>

Table 2.6. National Vegetation Classification (N.V.C.)communities and sub-communities represented by Scottish Border Fens quadrat data.

N.V.C code	*N.V.C. community name*
M4	*Carex rostrata - Sphagnum recurvum* mire
M5	*Carex rostrata - Sphagnum squarrosum* mire
M6	*Carex echinata - Sphagnum recurvum/auriculatum* mire
M6a	*Carex echinata* sub-community
M9	*Carex rostrata - Calliergon cuspidatum* mire
M9a	*Campylium stellatum - Scorpidium scorpioides* sub-community
M9b	*Carex diandra - Calliergon giganteum* sub-community
M10	*Carex dioica - Pinguicula vulgaris* mire
M10aii	*Carex demissa - Juncus bulbosus* sub-community: *Carex hostiana - Ctenidium molluscum* variant
M10bii	*Briza media - Primula farinosa* sub-community: *Molinia caerulea - Eriophorum latifolium* variant
M15a	*Scirpus cespitosus - Erica tetralix* wet heath: *Carex panicea* sub-community
M18	*Erica tetralix - Sphagnum papillosum* raised and blanket mire
M21	*Narthecium ossifragum - Sphagnum papillosum* valley mire
M21b	*Spahgnum recurvum - Vaccinium oxycoccus* sub-community
M23	*Juncus effusus/acutiflorus - Galium palustre* rush pasture
M23a	*Juncus acutiflorus* sub-community
M25	*Molinia caerulea - Potentilla erecta* mire
M25b	*Anthoxanthum odoratum* sub-community
M26	*Molinia caerulea - Crepis paludosa* mire
M27	*Filipendula ulmaria - Angelica sylvestris* mire
S3	*Carex paniculata* swamp
S4	*Phragmites australis* swamp and reed beds
S4c	*Menyanthes trifoliata* sub-community
S7	*Carex acutiformis* swamp
S9a	*Carex rosrata* swamp: *Carex rostrata* sub-community
S9b	*Menyanthes trifoliata - Equisetum fluviatile* sub-community
S10	*Equisetum fluviatile* swamp
S10b	*Carex rostrata* sub-community
S14	*Sparganium erectum* swamp
S14b	*Alisma plantago-aquatica* sub-community
S14c	*Mentha aquatica* sub-community
S14d	*Phalaris arudinacea* sub-community
S19	*Eleocharis palustris* swamp
S19a	*Eleocharis palustris* sub-community
S22b	*Glyceria fluitans* swamp: *Sparganuium erectum - Mentha aquatica* sub-community
S26a	*Phragmites australis - Urtica dioica* tall herb fen: *Filipendula ulmaria* sub-community
S27	*Carex rostrata - Potentilla palustris* tall herb fen
S27a	*Carex rostrata - Equisetum fluviatile* sub-community
S28	*Phalaris arudinacea* tall herb fen
W3	*Salix pentandra - Carex rostrata* fen carr

Table 2.7. Affinities of plant communities generated by the binary and quantitative Ward's analyses of the Scottish Borders fens quadrat data and National Vegetation Classification plant communities.

Scottish Borders fens community	*National Vegetation Classification community*
Carex dioica -*Carex hostiana* rich-fen	M10 *Carex dioica* - *Pinguicula vulgaris* mire
Carex rostrata - *Sphagnum recurvum* poor-fen	M4 *Carex rostrata* - *Sphagnum recurvum* mire
Filipendula ulmaria tall herb fen	M27 *Filipendula ulmaria* - *Angelica sylvestris* mire
Eriophorum vaginatum - *Sphagnum papillosum* bog	M18 *Erica tetralix* - *Sphagnum papillosum* raised and blanket mire M21 *Narthecium ossifragum* - *Sphagnum papillosum* valley mire

Rich-fen meadow communities dominated by *Juncus acutiflorus* and *Molinia caerulea* were not well differentiated by either Ward's classification although the quantitative classification did separate a community with affinities to the N.V.C. M25a *Molinia caerulea* - *Potentilla erecta* mire, *Erica tetralix* sub-community. The N.V.C. M9 *Carex rostrata* - *Calliergon cuspidatum* mire community showed few affinities to the corresponding vegetation types identified in the Ward's classification procedures although the communities identified in the quantitative Ward's classification showed more affinities to M9 *sub*-communities than did the corresponding communities produced by the binary Ward's classification. The species-poor fen, swamp and reedbed communities identified by the quantitative Ward's analysis showed more affinities to the swamp and tall herb fen N.V.C. communities than did the binary Ward's analysis because these vegetation types tend to be characterised by the dominant species and the binary Ward's analysis does not distinguish communities on this basis.

2.3.3 A CLASSIFICATION OF THE PLANT COMMUNITIES OF THE SCOTTISH BORDERS FENS

The classification of the Scottish Borders fens vegetation data developed here is based on the binary Ward's classification for most samples, but using a dominance classification of species-poor samples. The results of the binary Ward's analysis were chosen because this dealt most effectively with the continuity of the data, where samples often contained a similar range of constant species but were *characterised* and therefore differentiated by the suite of associated species they contained. These differential species are often not dominant or abundant in the vegetation. The use of binary data as the basis for calculating the similarity of samples ensures that the dominance of particular species will not mask the more subtle differences in the overall floristic composition of the samples. The subtle differences in species composition are often responsible for the differences in the character of the vegetation and they may more accurately reflect ecological differences between plant communities than would classifications based on species dominance (Williams & Lambert 1959). However this approach fails with species-poor data where the vegetation is often characterised only by the dominant species. The tendency of

Ward's method to use joint absence as well as joint presence in the calculation of similarity indices results in species-poor data being grouped as a large group of un-related samples. Therefore in the following classification the samples in the species-poor fen and swamp communities have been grouped on the basis of dominance. A summary table of the composition of the plant communities of the Scottish Borders fens generated by this classification is presented in table 2.8. The main plant communities identified are outlined below.

2.3.3.1 Rich-fen plant communities

Acidified and wooded fen (table 2.9)

Constant species: *Agrostis stolonifera*, *Potentilla erecta*, *Viola palustris*

[*Holcus lanatus*, *Molinia caerulea*, *Galium palustre*, *Eriophorum angustifolium*, *Sphagnum subnitens*]

This plant community represents rich-fen vegetation with poor-fen elements. It is often wooded, *Salix cinerea* (occasionally accompanied by *Salix pentandra*) and *Betula pubescens* often form a shrub layer and sometimes a canopy. The vegetation is often hummocky resulting from tree growth and colonisation around the roots by *Molinia caerulea* and other grasses. *Sphagnum* species (typically *Sphagnum subnitens*, *Sphagnum squarrosum*, *Sphagnum palustre*) form carpets between tussocks and sometimes occur as cushions. *Phragmites australis* is frequently prominent. This vegetation is frequently found at the centre of sites and within areas of fen carr although at Branxholm Wester Loch it occurs as a raft of fen carr along the margins of the Loch.

Filipendula ulmaria Tall Herb Fen (table 2.10)

Constant species: *Filipendula ulmaria* (dominant), *Agrostis stolonifera*, *Angelica sylvestris*, *Juncus acutiflorus*

[*Holcus lanatus*, *Carex rostrata*, *Carex disticha*, *Equisetum fluviatile*, *Epilobium palustre*, *Juncus effusus*, *Rumex acetosa*, *Lychnis flos-cuculi*]

Tall, rather rank vegetation usually dominated by *Filipendula ulmaria* although some stands contain very prominent *Juncus acutiflorus*. This vegetation type frequently occurs along the margins of sites and near drains and ditches especially where silt has been deposited. These areas frequently experience large fluctuations in the water table and the constant species can be accompanied by a range of other species depending on the conditions. *Carex rostrata* and *Equisetum fluviatile* occur in wetter situations, *Deschampsia cespitosa* and *Juncus effusus* under drier conditions. However, most associated species are scattered beneath the dominant species and bryophytes never attain significant cover due to the closed nature of the vegetation.

Table 2.8. Summary table of species composition of plant communities of the Scottish Borders fens.

The frequency of occurrence of species is indicated in roman numerals: I 5-20%; II 21-40%; III 41-60%; IV(constant) 61-80%; V(constant) 81-100%.

The median abundance (Domin scale 1-10) follows the frequency score.

PLANT COMMUNITY CODE*	FAW		FM		FTH		FWG		RFC	RFCm		RFCa		RFCb		RFM		RFS		RFB	
number of samples	8		10		15		18			23		19		19		13		17		17	
mean species-richness / quadrat	26		26		19		18			24		16		22		32		31		20	
Species																					
Viola palustris	V	3	I	2	I	1	I	2	I	I	2			II	1	I	2	II	2	I	1
Sphagnum subnitens	IV	4	II	2														I	1	I	1
Potentilla erecta	V	3	IV	3			II	3	I	I	2	I	2	I	1	II	2	I	2	I	3
Luzula multiflora	III	2	IV	2	I	1	I	2	I	I	1			I	1	II	1	II	1		
Achillea ptarmica			III	2	I	1	I	3	I					I	1	I	1	I	1	I	1
Plagiomnium undulatum			III	2			I	1								I	1				
Anthoxanthum odoratum	I	3	III	3			II	3	I	I	3			I	1	II	2	I	1		
Crepis paludosa	II	1	III	4	II	3	I	3	I	I	4	I	2	II	2	II	1	I	2	I	1
Pseudoscleropodium purum	II	2	III	4														I	1		
Rumex acetosa			IV	3	IV	2	I	1	I	I	2			I	3	II	3				
Carex disticha	I	1	III	5	IV	4			I	I	5	I	7	I	5						
Galium uliginosum	I	2	V	3	III	3	III	3	I	II	2	I	1	II	2	IV	3	II	2	I	2
Juncus acutiflorus	II	3	V	5	V	3	III	3	II	III	2	I	3	II	3	III	3	I	1	III	3
Cirsium palustre			V	2	III	1	I	1	II	III	1	I	1			I	2	II	1	I	1
Angelica sylvestris	III	2	V	3	V	4			II	III	2	III	1	II	2	IV	3	II	2	II	2
Deschampsia cespitosa	I	1	II	1	III	2	III	2	I	II	2			I	1	I	1				
Carex nigra	III	1	III	4	II	2	V	4	II	II	2	I	1	IV	3	III	1	II	2	III	3
Juncus conglomeratus	III	3	II	1	I	2	IV	2	I	I	2	I	1	I	1						
Holcus lanatus	IV	3	V	4	IV	3	V	3	III	V	2	II	2	II	2	II	3	III	3	I	2
Agrostis stolonifera	V	3	III	2	V	3	IV	3	III	III	3	II	2	IV	3	IV	2	II	2		
Filipendula ulmaria	III	3	V	3	V	7	IV	3	IV	IV	3	IV	2	III	2	IV	4	II	2	II	1
Epilobium palustre	II	2	IV	3	IV	3	IV	3	IV	V	2	III	3	III	2	IV	2	II	1	II	1
Juncus effusus	II	1	I	1	IV	1	II	1	II	IV	2	I	1	I	1	II	1	I	1	I	1
Lychnis flos-cuculi			IV	2	IV	2	I	3	II	III	3	II	2	II	2	IV	3	III	2	I	1
Molinia caerulea	IV	4	V	3	II	5	III	3	II	I	2	I	3	III	3	IV	3	III	3	IV	4
Calliergon cuspidatum	III	5	V	3	III	2	IV	4	IV	IV	5	IV	3	IV	4	V	4	IV	3	IV	3
Caltha palustris	I	2	V	2	III	2	III	3	IV	IV	3	IV	3	V	2	V	3	IV	2	II	1
Plagiomnium rostratum			I	1	III	2	II	2	IV	IV	4	IV	3	IV	3	V	3	III	2	III	3
Ranunculus flammula	I	2	I	1			II	3	III	III	2	I	1	V	2	III	1	I	2	I	3
Carex diandra	I	2			I	3	I	2	III	III	5	II	5	V	5	V	4	V	4	II	3
Carex lepidocarpa			I	1	I	2	I	1	II	I	2	I	3	III	5	V	3	V	3	V	4
Eriophorum angustifolium	IV	4	III	3	II	3	I	1	II	II	4	I	3	IV	2	V	3	IV	3	V	3
Calliergon giganteum	I	2			I	2	I	4	III	II	3	II	3	III	5	III	3	III	3	II	3
Salix cinerea (g)	II	1			I	1	I	1	II	I	1	II	1	I	1	III	1	I	1		1
Dactylorhiza purpurella			I	2					I	I	2			I	2	III	1	I	2	I	1
Cardamine pratensis	II	1			II	2	II	2	III	III	2	II	2	II	2	V	2	III	2	I	1
Valeriana dioica	II	3	V	3	I	3	I	2	II	I	3	II	2	II	2	IV	2	III	2	I	1

PLANT COMMUNITY CODE*	RFF		FSCb		FSCa		FSA		RPG		RPL		FSM		FSG		FSE		FSS		FSQ		POR		BOG	
number of samples	11		16		18		2		10		5		41		4		5		4		6		10		8	
mean species-richness / quadrat	28		7		9		9		8		7		13		12		10		10		7		16		17	
Species																										
Viola palustris																			V	7	I	4	I	1	I	2
Sphagnum subnitens																							I	3	II	3
Potentilla erecta	II	2																							III	2
Luzula multiflora	II	1																					I	1	IV	1
Achillea ptarmica	I	1																								
Plagiomnium undulatum																										
Anthoxanthum odoratum	III	1																					II	3	I	1
Crepis paludosa	II	1																								
Pseudoscleropodium purum																										
Rumex acetosa													<5	1					II	2			I	1		
Carex disticha	I	6	I	4	II	2			I	1			II	1			I	3					I	2	III	3
Galium uliginosum	I	3																								
Juncus acutiflorus	II	2	I	1	I	2			I	1			III	2	III	2					I	7	I	3	I	6
Cirsium palustre	I	1													II	1										
Angelica sylvestris	II	1							I	1	III	1	<5	4			I	1					I	2		
Deschampsia cespitosa	I	1			I	1					I	1	<5	1	II	1					I	5				
Carex nigra	II	2	II	1	I	4							II	5			I	7					I	1	II	3
Juncus conglomeratus	I	1	I	1	I	2							<5	3												
Holcus lanatus	I	2			I	1			I	2			<5	2	III	2							III	1	I	3
Agrostis stolonifera	I	2	I	2	II	3			I	2	I	2	III	3	II	2	II	6					I	1		
Filipendula ulmaria	II	3			I	1	III	2	II	4	II	6	II	1												
Epilobium palustre			I	1	II	2		1	I	2	I	4	III	2	IV	3	I	1					I	2		
Juncus effusus			I	1	II	1					I	1	II	2	V	2	I	1	V	3	V	8	IV	2	I	1
Lychnis flos-cuculi											I	1	<5	1							I	2	II	1		
Molinia caerulea	V	4																					I	1	II	1
Calliergon cuspidatum	III	4			I	1		1	III	2	I	2	II	1			I	2	III	3	I	2	I	1		
Caltha palustris			I	1	II	3	III	2	I	1			II	2		2	II	2								
Plagiomnium rostratum	III	3											I	3			I	1								
Ranunculus flammula			I	1	I	1							II	1	II	5	II	2								
Carex diandra			I	3									I	5					II	5			I	6		
Carex lepidocarpa	IV	4																								
Eriophorum angustifolium	V	3	II	1									II	3									IV	4	V	3
Calliergon giganteum			I	3	I	2							I	2			I	3								
Salix cinerea (g)			I	1			V	1					I	1									II	2	I	1
Dactylorhiza purpurella	II	1											<5	2					II	3						
Cardamine pratensis	II	1							I	2			<5	2					II	2						
Valeriana dioica	III	3							I	1													I	1		

PLANT COMMUNITY CODE*	FAW		FM		FTH		FWG		RFC	RFCm		RFCa		RFCb		RFM		RFS		RFB		RFF		FSCb		FSCa		FSA		RPG		RPL		FSM		FSG		FSE		FSS		FSQ		POR		BOG	
Succisa pratensis	III	3	III	3	I	1			I	I	1	I	1	I	1	IV	3	IV	3	II	3	V	2																					II	4	II	1
Carex panicea	III	4	V	3	I	4	II	3	II	II	3	I	3	III	3	V	3	II	3	IV	4	V	4	I	2									<5	3												
Rhizomnium pseudopunctatum	II	4			I	8			I	II	3	I	3	I	4			III	2	I	2													I	1												
Drosera rotundifolia																		III	3			I	1																					I	3	V	2
Sagina nodosa									I					II	2	II	2	III	2	I	3	I	1																								
Sphagnum contortum	II	4							I	I	3			I	1			IV	3	I	3	I	4																								
Parnassia palustris									I			I	4	I	1	II	1	IV	3	I	3	III	4																								
Campylium stellatum	I	3					I	1	I			I	1			II	3	IV	6	IV	3	V	3											<5	2												
Pedicularis palustris	I	1			I	1	I	1	I	I	2	I	2	I	1	II	2	IV	1	III	2	III	3											<5	1			I	1	II	3						
Scorpidium scorpioides									I					I	2	II	2	IV	4	III	5	III	2											<5	7												
Equisetum palustre	II	2	III	3	III	3	II	3	II	I	2	II	2	III	2	II	2	III	2	IV	2	V	2											I	2			I	3	II	3	I	1	I	1	II	2
Juncus articulatus			II	2			I	2	II	I	3	II	1	III	2	III	2	I	2	III	2	IV	3	I	3	I	2							<5	2			I	3	II	4						
Drepanocladus revolvens									I	I	1	I	4	II	3	II	4	III	4	IV	3	V	5											<5	1												
Briza media			II	2			I	1								I	3	I	2			IV	1																								
Carex dioica																		I	2	I	3	IV	4																								
Carex flacca	I	2			I	2			I					I	3	I	1	I	2	I	3	V	3																								
Carex hostiana	I	2																I	1	II	3	IV	4																								
Ctenidium molluscum									I	I	1			I	4			I	1	II	3	V	3																								
Fissidens adianthoides									I	I	2			I	3			II	3	II	3	IV	3																								
Pinguicula vulgaris																		II	1			III	3			I	1		1			V	10	<5	1											I	3
Juncus bulbosus	I	1					I	2	I	I	1					I	1					III	2																					I	1	I	1
Phragmites australis	III	5	III	5	I	1			I			II	4			III	3	II	4	III	3					I	3			V	10			I	6	II	2			II	3	III	2	I	6	I	2
Galium palustre	IV	2	I	3	II	1	III	3	IV	IV	3	V	3	IV	3	II	2	III	2	I	3					II	2			IV	2	I	2	IV	2	II	1	III	3					I	1		
Carex rostrata	II	3	II	4	IV	3	IV	6	V	V	5	V	4	V	3	V	3	III	4	IV	3	V	3	V	7	V	9		1	II	2			V	5	V	3	V	5					V	5	IV	3
Equisetum fluviatile			II	2	IV	3	II	3	IV	IV	3	V	3	V	3	III	3	II	2	III	2	I	1	IV	3	IV	5		3	II	4	II	3	IV	3	III	4	I	3					III	3	I	2
Potentilla palustris	II	3	III	3	II	1	II	3	V	V	3	IV	3	V	2	IV	3	IV	3	III	2	I	1	II	1	I	3				2	I	3	IV	3	II	3	I	3					V	2	I	3
Menyanthes trifoliata	II	2	II	1	II	3	I	2	V	V	5	V	5	V	5	V	4	V	4	V	3	IV	4	V	7	I	5							III	4			II	4					IV	5	II	2
Mentha aquatica	II	1			III	2	I	3	III	II	2	IV	3	III	3	II	1	II	2	I	4	I	3	II	2	II	5			III	4	I	1	III	3	III	3	III	3			I	1	I	2		
Cicuta virosa									I	I	2			I	1									I	1							I	1	I	5												
Myosotis scorpioides			I	1	I	2	II	2	II	IV	3	II	3	II	2	II	2	I	1	I	2			I	2	IV	1	V	2	II	3			III	2	II	1	II	4								
Typha latifolia																														I	1			<5	5												
Carex acutiformis																										I	1	V	10											III	5	V	5				
Eleocharis palustris																								I	1	I	5							I	5	III	5	V	9	II	3						
Glyceria fluitans																										I	3							<5	1	V	5			II	1						
Hippuris vulgaris																								III	2	III	3	III	1	I	3			II	1			IV	2								
Urtica dioica					I	1	I	1	I	I	2	I	1													I	1			I	1	II	3	<5	2												
Lemna minor									I	II	3	I	2											II	2	II	3			I	3	I	3	II	3	II	3	I	2			I	1				
Polygonum amphibium									I			I	1	I	1									I	1	II	3			I	1	I	3	I	1			I	2								
Ranunculus lingua	I	1							I	I	3	II	2	I	2	I	1									I	2							I	5					II	5						
Sparganium erectum									I	I	2									I	1			I	3	II	3	III	1	I	3			II	3	IV	3	I	3								
Aulacomnium palustre	III	3	I	5					I	II	2					I	2	III	3			I	1																					V	3	IV	4
Carex curta									I	I	3							II	4																									III	3	II	2
Sphagnum fimbriatum	I	5							I	I	2							I	3																									IV	3	I	3
Sphagnum palustre	II	6																I	1			I	6																					III	7	II	2
Calliergon stramineum																		I	3															<5	1					II	2			III	2		
Sphagnum recurvum	II	4					I	5	I	I	2			I	3	II	2	II	5															<5	2									IV	5	III	8

PLANT COMMUNITY CODE*	FAW		FM		FTH		FWG		RFC	RFCm		RFCa		RFCb		RFM		RFS		RFB		RFF		FSCb		FSCa		FSA		RPG		RPL		FSM		FSG		FSE		FSS		FSQ		POR		BOG	
Vaccinium oxycoccos																		I	3			I	2																							III	3
Sphagnum capillifolium	I	1																				I	1																					I	1	V	3
Erica tetralix	II	2	II	2														I	1			II	2																							IV	4
Sphagnum papillosum																																														V	5
Calluna vulgaris	I	5																I	1			I	5																							V	3
Eriophorum vaginatum																																														V	3
Polytrichum alpestre																																														III	2
Deschampsia flexuosa	I	1			I	4																																						II	1	III	2

* FAW Acidified wooded fen
FTH *Filipendula ulmaria* tall herb fen
FM *Molinia caerulea / Juncus acutiflorus* Fen meadow
FWG Mixed species wet grassland
RFC *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community
RFCa typical variant
RFCb *Carex diandra* variant
RFC m miscellaneous variant
RFM Mixed sedge rich-fen community
RFS *Carex diandra - Sphagnum contortum* community
RFB *Carex lepidocarpa* - brown moss community
RFF *Carex dioica - Carex hostiana* community

FSC *Carex rostrata* species-poor community
FSCa *Carex rostrata* variant
FSCb *Menyanthes trifoliata* variant
FSA *Carex acutiformis* species-poor community
RPG *Phragmites australis* reedbed
RPL *Phalaris arundinacea* reed bed
FSM *Carex rostrata - Potentilla palustris* species-poor community
FSG *Glyceria fluitans* species-poor community
FSE *Eleocharis palustris* species-poor community
FSS *Sparganium erectum - Agrostis stolonifera* species-poor community
FSQ *Equisetum fluviatile* species-poor community
POR *Carex rostrata - Sphagnum recurvum* community
BOG *Eriophorum vaginatum - Sphagnum papillosum* community

Table 2.9. Vegetation table showing the species composition of individual quadrats representing the Acidified, wooded community

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats							
Agrostis stolonifera	V	1-6	1	3	3	2	3	2	6	3
Potentilla erecta	V	1-3	1	1	3	2	2	3	3	3
Viola palustris	V	1-3	1	3	1	2	3	3	3	
Holcus lanatus	IV	1-6	1		5	3	3	3	6	
Molinia caerulea	IV	2-6			6	2	3	5	3	5
Galium palustre	IV	1-3	2	3	3	1	2	2		
Eriophorum angustifolium	IV	2-5			5	2	5	4		4
Sphagnum subnitens	IV	4-6	4		6		4	4		4
Filipendula ulmaria	III	2-4	3	2	3				4	
Calliergon cuspidatum	III	3-5	4	5	5			3		
Carex panicea	III	2-6			6		3	4		3
Luzula multiflora	III	1-3		1	2		2	3		
Carex nigra	III	1-3	1		1	3			1	
Juncus conglomeratus	III	1-3			3		3		1	3
Phragmites australis	III	1-9	8	9	2	1				
Succisa pratensis	III	1-5	2	3	5	1				
Angelica sylvestris	III	2-5	2	2	5				2	
Aulacomnium palustre	III	1-5	1	5		3		3		
Carex rostrata	II	1-6		3			6	1		
Potentilla palustris	II	2-3	3	3	2					
Equisetum palustre	II	1-4	2	1				4		
Menyanthes trifoliata	II	1-6	6			2	1			
Rhytidiadelphus squarrosus	II	1-3				1		3		3
Cardamine pratensis	II	1-3	1		1			3		
Carex echinata	II	3-4					3	4		3
Salix cinerea (c)	II	5-7	7			5			7	
Polytrichum commune	II	2-3				3	2		3	
Sphagnum palustre	II	5-7				7			5	6
Erica tetralix	II	1-5				1		2		5
Valeriana dioica	II	1-4	1	3	4					
Juncus acutiflorus	II	3			3			3		
Epilobium palustre	II	1-2	1					2		
Juncus effusus	II	1				1			1	
Crepis paludosa	II	1		1			1			
Mentha aquatica	II	1		1					1	
Salix cinerea (g)	II	1		1			1			
Sphagnum squarrosum	II	4-6				4	6			
Sphagnum contortum	II	2-6		6	2					
Betula pubescens (s)	II	2-6	6	2						
Dicranum scoparium	II	1-3							1	3
Mnium hornum	II	1-2	2						1	
Pleurozium schreberi	II	1-2							1	2
Dryopteris dilatata	II	1-4	1						4	
Rhytidiadelphus triquetrus	II	3-5				3			5	
Pseudoscleropodium purum	II	1-2						2		1
Thuidium tamariscinum	II	2				2			2	
Carex pulicaris	II	2-3					2	3		
Betula pubescens (c)	II	5-8				8			5	
Rhizomnium pseudopunctatum	II	3-5	5					3		
Sphagnum recurvum	II	1-6	6			1				
Salix repens agg.	II	3		3	3					
Number of species per sample			27	27	27	25	24	27	26	21

(c) Canopy

(g) Ground layer

(s) Shrub layer

Table 2.10. Vegetation table showing the species composition of individual quadrats representing the *Filipendula ulmaria* tall herb fen community.

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats												
Filipendula ulmaria	V	1-10	10	10	8	1	5	6	6	4	8	3	8	7	7
Agrostis stolonifera	V	1-8	6	1	3	3	3	3	3	3	8	4	3	1	
Angelica sylvestris	V	1-8	4	4	4		1	3	8	2	4	4	2	4	1
Juncus acutiflorus	V	1-5	1	1	1	5	1	2		4		1	3	4	4
Holcus lanatus	IV	1-6		1	4	2	3	4	6	4	1			3	
Carex rostrata	IV	1-4	2			3	4	3	2	1		4	3	2	
Carex disticha	IV	1-8			4	2	8	6		4	1	3		1	7
Equisetum fluviatile	IV	1-5	3			3	1	3		1	5	2	3		3
Epilobium palustre	IV	1-3		1		2	2	1	3	3	3			1	
Juncus effusus	IV	1-4		4	3					4	1	1	1	1	1
Rumex acetosa	IV	1-6	1		5				6	3		1	2	2	1
Lychnis flos-cuculi	IV	1-3				1	2	2	3	3		3	2	2	
Caltha palustris	III	1-3	1			1		2	3	2		1		1	
Deschampsia cespitosa	III	1-3	2							3	3	1	1	1	1
Mentha aquatica	III	1-4	1	1		4	2	3		3					2
Cirsium palustre	III	1-3	1	1	3			1						2	1
Calliergon cuspidatum	II	1-3						3				1	1	3	1
Galium uliginosum	II	2-3						3	3			3	3	2	
Galium palustre	II	1-4	1	2	1						1				4
Plagiomnium rostratum	II	1-3						2		1		2		2	3
Carex nigra	II	1-3						2		1		1	3		
Equisetum palustre	II	2-3								3		3	3	2	
Lathyrus pratensis	II	1-4		1	4							2	1		
Eriophorum angustifolium	II	2-4					4	2				2			
Potentilla palustris	II	1								1		1	1		
Poa trivialis	II	1-2								1	2		2		
Stachys palustris	II	1-3	1	3							1				
Molinia caerulea	I	4-5										5	4		
Crepis paludosa	I	1-4										1		4	
Menyanthes trifoliata	I	1-3					1	3							
Carex lasiocarpa	I	1-8						8	1						
Cardamine pratensis	I	1-2											2	1	
Salix cinerea (g)	I	1				1								1	
Calliergon giganteum	I	1-3						3	1						
Alnus glutinosa (c)	I	1					1	1							
Geum rivale	I	1-4		1										4	
Valeriana dioica	I	2-3										3	2		
Calliergon cordifolium	I	4-5	5						4						
Urtica dioica	I	1									1				1
Number of species per sample			16	13	12	13	16	25	16	24	15	32	23	24	16

Molinia caerulea wet grassland and *Juncus acutiflorus* rush pasture (table 2.11)

Constant species: *Juncus acutiflorus*, *Filipendula ulmaria*, *Holcus lanatus*, *Galium uliginosum*, *Molinia cearulea*, *Angelica sylvestris*, *Valeriana dioica*

[*Calliergon cuspidatum*, *Caltha palustris*, *Carex panicea*, *Cirsium palustre*, *Epilobium palustre*, *Luzula multiflora*, *Rumex acetosa*, *Lychnis flos-cuculi*, *Potentilla erecta*.]

Variable, generally open and fairly diverse vegetation characterised either by prominent *Molinia caerulea* (*Molinia caerulea* wet grassland) or *Juncus acutiflorus* (*Juncus acutiflorus* rush pasture). Both variants are accompanied by the same suite of species. A variety of grasses and small dicotyledonous species are frequent and the bryophyte *Calliergon cuspidatum* is frequently found, sometimes accompanied by *Pseudoscleropodium purum*, *Brachythecium rutabulum* and *Climacium dendroides*. This vegetation type occurs mainly in the marginal areas of sites or where the drainage is relatively good and the peat surface has become mineralised.

Mixed wet grassland (table 2.12)

Constant species: *Carex nigra*, *Holcus lanatus*

[*Calliergon cuspidatum*, *Juncus conglomeratus*, *Carex rostrata*, *Filipendula ulmaria*, *Agrostis stolonifera*, *Epilobium palustre*]

This community represents stands of vegetation which are rather rank and which contain a mixture of species which are separately more characteristic of other communities. Generally the vegetation is composed mainly of grasses and sedges, in particular *Holcus lanatus*, *Molinia caerulea* and *Agrostis stolonifera* with *Carex nigra* and *Carex rostrata*. *Carex paniculata* tussocks occur in some stands and the vegetation is often tussocky with small herbs such as *Potentilla erecta*, *Galium uliginosum* growing on the tussocks with species such as *Carex rostrata*, *Equisetum fluviatile*, *Caltha palustris*, *Ranunculus flammula* inhabiting the wetter areas in between. It is therefore a rather patchy community occurring in poorly drained areas with an uneven substratum, often around the margins of a site.

Carex dioica - *Carex hostiana* community (table 2.13)

Constant species: *Succisa pratensis*, *Eriophorum angustifolium*, *Campylium stellatum*, *Equisetum palustre*, *Drepanocladus revolvens*, *Molinia caerulea*, *Carex panicea*, *Carex rostrata*, *Carex flacca*, *Ctenidium molluscum*

[*Carex lepidocarpa*, *Briza media*, *Carex hostiana*, *Carex dioica*, *Juncus articulatus*, *Fissidens adianthoides*, *Menyanthes trifoliata*]

This vegetation type is typically very open and characterised by a short sward of sedges and grasses with brown mosses and small dicotyledonous species forming the ground layer. It occurs on flushed peat and mineralised soils around the margins of sites and near spring discharge areas.

Table 2.11. Vegetation table showing the species composition of rich-fen meadow communities (*Molinia caerulea* wet grassland and *Juncus acutiflorus* rush pasture)

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats									
Juncus acutiflorus	V	2-7	5	2	3	5	4	5	7	7	5	4
Filipendula ulmaria	V	1-5		3	2	5	1	1	2	5	5	4
Holcus lanatus	V	2-6		6	2	4	2	3	4	4	5	4
Galium uliginosum	V	2-3	3	2	3	2		3	2	3	3	3
Molinia caerulea	V	1-7	4	6	6	7	3	3		3	3	1
Angelica sylvestris	V	2-5	4		5	3	2	5	4	3	3	3
Valeriana dioica	V	1-4	1	4	4		3	2	4	3	3	3
Calliergon cuspidatum	IV	1-5	3	5	3	3		3		1	5	5
Caltha palustris	IV	1-5		5	2	1		2	2	2	2	2
Carex panicea	IV	1-5	4	2	1	3	5	2		5		2
Cirsium palustre	IV	1-3		1		2	1	2	2	1	1	3
Epilobium palustre	IV	1-6		3	6	1	2	1	3			3
Luzula multiflora	IV	1-2	1		2	2	1		2	2	2	
Rumex acetosa	IV	1-3	1			1		3	2	3	3	3
Lychnis flos-cuculi	IV	1-4	1		2	1		2	2		4	3
Potentilla erecta	IV	2-3	2	3	2		2	3		3	3	
Agrostis stolonifera	III	2-3				2	2		3	2		2
Equisetum palustre	III	1-3	3	1				2	3	3		
Anthoxanthum odoratum	III	1-3		3	2			1		3	3	
Pseudoscleropodium purum	III	2-5				2	2		5	4	4	
Eriophorum angustifolium	II	1-3	2	3	1							3
Carex nigra	II	2-6		6	2					4	3	
Potentilla palustris	II	2-5					3	3	5			2
Crepis paludosa	II	1-4	4					4		1	3	
Phragmites australis	II	2-7	2				6	3				7
Succisa pratensis	II	1-3	3	1					3			3
Carex disticha	II	2-5			2			4			5	5
Achillea ptarmica	II	1-3		3		1		3				1
Plagiomnium undulatum	II	1-3				1			2	2	3	
Juncus conglomeratus	II	1		1			1					1
Deschampsia cespitosa	II	1-2				1			1		2	
Menyanthes trifoliata	II	1-2		1			1					2
Ranunculus acris	II	1-3						1		3	2	
Climacium dendroides	II	1-3	3	2				1				
Brachythecium rutabulum	II	1-2						1		2	2	
Centaurea nigra	II	1-3	3					3				1
Carex rostrata	I	1-6		6	1							
Rhytidiadelphus squarrosus	I	4							4	4		
Carex echinata	I	3-5	5								3	
Salix cinerea (c)	I	1					1		1			
Sphagnum subnitens	I	1-3					3		1			
Erica tetralix	I	1-3				1	3					
Thuidium tamariscinum	I	3-4				4	3					
Geum rivale	I	1-2								1	2	
Cerastium fontanum	I	1-2		1						2		
Hylocomium splendens	I	3-4					3	4				
Vicia cracca	I	1-2						1		2		
Juncus articulatus	I	2	2							2		
Briza media	I	1-3			1					3		
Rhinanthus minor	I	2	2					2				
Lathyrus pratensis	I	1						1		1		
Equisetum fluviatile	I	1-2				1						2
Number of species per sample			21	23	23	23	26	33	24	32	26	28

Table 2.12. Vegetation table showing the species composition of individual quadrats representing the Mixed species wet grassland community

Species	Frequency score	Range of abundance	Domin abundance score (1-10) for individual quadrats																	
Carex nigra	V	1-8	8		1	1	6	5	7	2	6		5	4	4	4	1	4	6	4
Holcus lanatus	V	1-6	2	6		4	3			2	4	3	1	2	3	3	3	1	1	5
Calliergon cuspidatum	IV	1-7	4			5	5	7	3	5	4	7	1	5		3	4	2	4	
Juncus conglomeratus	IV	1-3	3	1	3			1	2	1	2	1	3		3		2	3		1
Carex rostrata	IV	1-9	8				6	7	4	9	7	5	1	6	4	3	8		5	
Filipendula ulmaria	IV	1-8	1	7	5	6	6	2	1				1		3		3	8	2	
Agrostis stolonifera	IV	1-5	1	4	5	5	3			1	2	1			3		3		1	4
Epilobium palustre	IV	2-5	5			2	2	3	2			2	3	2	3	2		3	3	
Deschampsia cespitosa	III	1-4				1					1		4	1	1	2	3	4	1	2
Juncus acutiflorus	III	1-6		6	3	3	3					3	1	3	4		1			
Galium palustre	III	1-7	3				3	4	3	2			3	1	3				7	
Galium uliginosum	III	1-3		3	3	3				3	3	3				2	1			
Caltha palustris	III	1-5		1	2	3	3	3			1				1				5	
Molinia caerulea	III	1-6	3	6		3	3	1		1			6							6
Equisetum palustre	II	1-4		3		3			1						4	4	3			1
Cardamine pratensis	II	1-3	3							2		1		2	1		3		2	
Potentilla palustris	II	2-8		2	2	3		6	8				3							
Ranunculus flammula	II	1-5								5		1		4	1		2		4	
Potentilla erecta	II	1-5					5		2	1	3		1							4
Myosotis scorpioides	II	1-3					1	3	2			1		1					2	
Equisetum fluviatile	II	1-4								2	1			3	4		1		4	
Carex panicea	II	1-7		1		7					3						1			3
Juncus effusus	II	1-2										1		1		1		2	1	
Veronica scutellata	II	1-3						2		3	1			2					2	
Anthoxanthum odoratum	II	1-5		3												2			1	5
Plagiomnium rostratum	II	1-2	1					2								2	1			
Rumex acetosa	I	1-3			1	3												1		
Luzula multiflora	I	1-4									2	1								4
Carex lasiocarpa	I	4-8						8	4				7							
Carex echinata	I	1-3									2	3							1	
Ranunculus repens	I	1-2														2		1	1	
Pedicularis palustris	I	1								1		1							1	
Cirsium palustre	I	1		1								1					1			
Climacium dendroides	I	1-3	1								3	1								
Juncus articulatus	I	2-3								2		2				3				
Bryum pseudotriquetrum	I	1-3								2	3			1						
Valeriana dioica	I	1-3	1			3														
Viola palustris	I	2				2	2													
Achillea ptarmica	I	2-3				2	3													
Eriophorum angustifolium	I	1	1										1							
Calliergon giganteum	I	2-5	2											5						
Festuca rubra	I	3														3				3
Carex diandra	I	1-2															2		1	
Juncus bulbosus	I	1-2								2		1								
Sphagnum recurvum	I	5						5	5											
Brachythecium rutabulum	I	1-3														3	1			
Trifolium repens	I	1-2														2			1	
Dactylorhiza fuchsii	I	1		1											1					
Myosotis laxa caespitosa	I	1-2													2	1				
Cratoneuron commutatum	I	1	1							1										
Hippuris vulgaris	I	2-3								3				2						
Potamogeton polygonifolius	I	1	1							1										
Glyceria fluitans	I	1													1	1				
Carex paniculata	I	10			10															
Number of species per sample			18	15	11	19	16	15	14	23	18	19	16	20	19	21	21	18	23	12

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Table 2.13. Vegetation table showing species composition of individual quadrats representing *Carex dioica - Carex hostiana* community

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats										
Eriophorum angustifolium	V	1-6		3	3	5	3	5	3	1	6	3	4
Succisa pratensis	V	1-4	2	4	1	2	3	2	3	3		1	1
Campylium stellatum	V	2-7	5	3	2	5	2	3		7	3	3	4
Equisetum palustre	V	1-3	1	1	3	3	2		2	2	3	3	2
Drepanocladus revolvens	V	1-7	5	3	7	6	1	5		5	6	4	3
Molinia caerulea	V	2-7	2	6	3	4	7	3	3		6		4
Carex panicea	V	2-5	4	4		3	4	2	5		5	4	4
Carex rostrata	V	1-4	4	3	1	3	3	2	1	1			4
Carex flacca	V	1-5	3	1	3	2	3	3	5	2	5		
Ctenidium molluscum	V	2-5	5		2	3	3	3		3	2	3	3
Carex lepidocarpa	IV	1-6	6	1		6	1	3		3	4	4	
Briza media	IV	1-3		1		1	1	2	3	2		1	1
Carex hostiana	IV	2-5			3	2		4	3	4	4	4	5
Carex dioica	IV	1-6	2		4	4		4	1	6	3		
Juncus articulatus	IV	1-4	3		1	3	2	3		4			2
Fissidens adianthoides	IV	2-5	3		3	3	5	3		4	2		
Menyanthes trifoliata	IV	3-6	3	4	3	6		4		3			5
Valeriana dioica	III	1-4		4			3	2	4			1	1
Parnassia palustris	III	1-4				4	4	4	3	3			1
Carex pulicaris	III	1-6		3	2	1		6		1			3
Plagiomnium rostratum	III	1-4				1	3	3	4	2			2
Pinguicula vulgaris	III	1-3		1	3			3		2		3	2
Juncus bulbosus	III	2-3	2			2		2	3	2	2		
Calliergon cuspidatum	III	1-5		3			1	5	5				4
Pedicularis palustris	III	1-3	3	3				1	3	2			
Scorpidium scorpioides	III	1-3	3	1				1		3			2
Anthoxanthum odoratum	III	1-3		3	1		1		2	1			
Filipendula ulmaria	II	1-5					5	2	3				1
Bryum pseudotriquetrum	II	2-3			2		3	2	3				
Carex nigra	II	1-4		4	2	1	2						
Luzula multiflora	II	1-2		2			1	1					1
Dactylorhiza purpurella	II	1-2			1			1		2			1
Angelica sylvestris	II	1-2	1						2	1			1
Eleocharis quinqueflora	II	2-5	3		5	3				2			
Euphrasia officinalis agg	II	1-2			2			1	1	2			
Crepis paludosa	II	1-2							2	1			1
Juncus acutiflorus	II	1-6		1					6				2
Potamogeton polygonifolius	II	1-4	1		1							4	
Cardamine pratensis	II	1-3		3								1	1
Aneura pinguis	II	1-2	2			1				1			
Potentilla erecta	II	2		2			2						2
Selaginella selaginoides	II	2-3			3			3		2			
Erica tetralix	II	2-3	2	3	2								
Triglochin palustris	II	1-2						1	2	1			
Dactylorhiza fuchsii	II	1-3				1			1		3		
Galium uliginosum	I	2-3		3			2						
Holcus lanatus	I	1-3		3									1
Mentha aquatica	I	2-3					3	2					
Carex demissa	I	3-4			4								3
Dactylorhiza incarnata	I	1-3	3									1	
Narthecium ossifragum	I	1	1	1									
Juncus conglomeratus	I	1						1					1
Number of species per sample			25	36	29	27	29	36	25	32	15	15	35

Molinia caerulea is sometimes prominent, creating a tussocky zonation to the community; where it is absent the bryophytes are more abundant. *Campylium stellatum* and *Drepanocladus revolvens* are the main bryophyte species but these can be accompanied by *Scorpidium scorpioides, Bryum pseudotriquetum, Calliergon cuspidatum* and *Cratoneuron commutatum* and *C. filicinum* with *Ctenidium molluscum* and *Fissidens adianthoides* abundant around the stem bases of sedges and grasses. The sedges *Carex panicea, Carex rostrata, Carex flacca, Carex lepidocarpa, Carex hostiana* and *Carex dioica* are sometimes accompanied *by Carex pulicaris, Eriophorum latifolium, Eleocharis quinqueflora* and *Triglochin palustris. Juncus articulatus* is frequently found and often accompanied by the rare hybrid *Juncus alpino-articulatus*. Small dicotyledonous species are characteristic of this community. *Succisa pratensis* is prominent and often accompanied by *Valeriana dioica, Parnassia palustris, Pinguicula vulgaris* and *Pedicularis palustris*.

<u>*Carex lepidocarpa* - brown moss community (table 2.14)</u>

Constant species: *Carex lepidocarpa, Menyanthes trifoliata, Eriophorum angustifolium*

[*Calliergon cuspidatum, Drepanocladus revolvens, Campylium stellatum, Carex panicea, Carex rostrata, Molinia caerulea, Equisetum palustre*]

This community is characterised by an open sward of sedges, in particular, *Carex lepidocarpa, Carex rostrata, Eriophorum angustifolium* and *Carex panicea. Carex lasiocarpa* is sometimes prominent and *Carex diandra* sometimes occurs although it is never abundant. Tussocks of *Molinia caerulea* sometimes occur and support species typical of drier flush communities. *Menyanthes trifoliata, Potentilla palustris* and *Equisetum fluviatile* form the understorey to the sedge sward and beneath this brown mosses form the ground cover and are often quite expansive. *Campylium stellatum, Calliergon cuspidatum* and *Drepanocladus revolvens* are most frequently found but can be accompanied by *Scorpidium scorpioides, Plagiomnium rostratum* and *Calliergon giganteum* at low cover. This community frequently occurs as large stands either as a raft over soft peat and muds or on solid, flushed peat.

<u>*Carex diandra - Sphagnum contortum* community (table 2.15)</u>

Constant species: *Carex diandra, Carex lepidocarpa, Menyanthes trifoliata*

[*Eriophorum angustifolium, Potentilla palustris, Parnassia palustris, Pedicularis palustris, Succisa pratensis, Caltha palustris, Calliergon cuspidatum, Campylium stellatum, Scorpidium scorpioides, Sphagnum contortum*]

This community is species rich and characterised by an open sward of sedges with a ground cover of lawns and hummocks of base-tolerant *Sphagnum* species (*Sphagnum contortum* and *Sphagnum warnstorfii*) occurring as a small scale mosaic with *Drepanocladus revolvens* and

Table 2.14. Vegetation table showing the species composition of individual quadrats representing the *Carex lepidocarpa* - brown moss community

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats																
Menyanthes trifoliata	V	1-7	2	1	3	7	6	5	1	1	3	1	3	7	3	5	3	3	5
Carex lepidocarpa	V	1-6	4	5		2	5	3	5	6	1	1	1	5	1	4	4	1	
Eriophorum angustifolium	V	1-6	6	2	4		3		2		3	3	3	3	1	2	3	2	3
Calliergon cuspidatum	IV	1-4	3	3	4		2		3	1	1	2	4	4		3		4	
Drepanocladus revolvens	IV	1-6	3	2	6	4		3	4	1	3		3	4		2	1		
Campylium stellatum	IV	1-5	1	5		5	4	1	4	2	3		3			4		1	
Carex panicea	IV	1-8		1	4	3	6		4	4		6	4		8	2		4	5
Carex rostrata	IV	1-7	4		7	3	4	4	3	3	1	2				2	5	1	
Molinia caerulea	IV	1-7		3	3		4		4			7	4	1	5	3	1		6
Equisetum palustre	IV	1-4			1			3	3	4	2	3	1	1	3	1		1	
Equisetum fluviatile	III	1-3	3	1		2		2			1			1		3	2	3	
Scorpidium scorpioides	III	1-5	3	5			4	5			2			5		5	1		
Potentilla palustris	III	1-3					3	2	1		2		3		1		3	1	
Carex nigra	III	1-6			3		2		3	6	1			2			3	4	
Juncus acutiflorus	III	1-7	1		7				1	3	2					3	1	3	
Potamogeton polygonifolius	III	1-6		3		4	2		1	6	1						5	1	
Phragmites australis	III	1-6		3					1		2		4		5	3		6	3
Plagiomnium rostratum	III	1-4	1						2				4	3	2	3	1	3	
Juncus articulatus	III	1-4				2	2		3	2				1	4		1		4
Pedicularis palustris	III	1-3		2	2		1		3				2		1			1	
Carex lasiocarpa	III	1-7		7		8		7			7		6	1				7	
Carex diandra	II	1-4					1	3		3	3			4			3		
Ctenidium molluscum	II	1-4	1	3					3					2		4			4
Succisa pratensis	II	3-5					3		3				3	3					5
Filipendula ulmaria	II	1-3		1				1					3				1	2	
Bryum pseudotriquetrum	II	2-3				3			2	2			3			3			
Caltha palustris	II	1-3		1							2	3	1					1	
Angelica sylvestris	II	1-3											1		2	3		2	3
Carex hostiana	II	1-4			3				1				1		4				4
Carex pulicaris	II	1-4					1						4					2	2
Calliergon giganteum	II	2-5				2	3	5			2								
Epilobium palustre	II	1-2									1		1	2			1		
Eurhynchium praelongum	II	2-3													2	2		3	3
Fissidens adianthoides	II	1-5		4			1					1	5						
Valeriana dioica	I	1-3		1								3	1						
Parnassia palustris	I	2-3					3									2			3
Galium uliginosum	I	2											2	2		2			
Holcus lanatus	I	1-2							1			2		2					
Crepis paludosa	I	1-3					1					1				3			
Carex echinata	I	1-3			3				2		1								
Ranunculus flammula	I	2-5					3		2	5									
Carex paniculata	I	1-5						1						5			1		
Mentha aquatica	I	3-4										4			3				
Cirsium palustre	I	1										1					1		
Cardamine pratensis	I	1					1				1								
Galium palustre	I	3			3							3							
Potentilla erecta	I	2-3							2				3						
Cratoneuron commutatum	I	3-4	4			3													
Sagina nodosa	I	2-3	2													3			
Rhizomnium pseudopunctatum	I	1-2		1										2					
Carex flacca	I	2-3					2					3							
Carex dioica	I	2-3							2							3			
Number of species per sample			14	23	14	13	25	17	29	15	23	18	29	24	20	24	23	24	13

Table 2.15. Vegetation table showing the species composition of individual quadrats representing the *Carex diandra - Sphagnum contortum* community

Species	Frequency score	Range of abundance	Domin abundance scores for individual quadrats																
Carex diandra	V	1-7	6	7	1	5	3	4	5	6	4	4	2	4	3	2		3	1
Carex lepidocarpa	V	1-5	3	4	3	4	3	5	5	1	1	1				5	3	3	3
Menyanthes trifoliata	V	2-7		4		3	4	4	5	7	5	6	3	3	2	4	2	3	2
Eriophorum angustifolium	IV	1-6	3	3	1		2	2		3		1	6	5	4	4	5	4	
Potentilla palustris	IV	1-5			3	2	2		2	5	3	4	5	2	3	1		2	
Parnassia palustris	IV	1-5	2		5		1	3	4	1					3	3	3	1	3
Pedicularis palustris	IV	1-5			1		1	2	1	1	1		1		5	2	3	1	
Succisa pratensis	IV	1-4	3	1	3				3	4		3	3	3	5	3	3	1	4
Caltha palustris	IV	1-3	2			2	2	1	3	3		2	3		1	3	2	2	1
Calliergon cuspidatum	IV	1-7				2	2		3	7	4	4	1	2	3	3	4	2	5
Campylium stellatum	IV	2-8	6	8	6		5	7	3		3	2				6	6	4	3
Scorpidium scorpioides	IV	1-5	5	4		5	5	4			1			4		3	3	3	2
Sphagnum contortum	IV	1-6		3		2	3	1	6	2	5			1	6			7	1
Calliergon giganteum	III	1-4	3	2	3	3	4	3	4	2				2		1			
Drepanocladus revolvens	III	1-5			5	3	1	4	4		1					5	5		5
Rhizomnium pseudopunctatum	III	1-3	2		2	1		2	2	2	1	3	3	3					
Plagiomnium rostratum	III	1-5				1	1	3	2					1	2				5
Aulacomnium palustre	III	1-8	2	2		1					3	8	3	3	6		1	1	
Drosera rotundifolia	III	1-4	3	3	4	1			1	3	1		3	1	2				
Carex rostrata	III	2-6				3	4		4	6	3	3		4		2			4
Carex lasiocarpa	III	2-6	5		2										3	6	6	6	4
Valeriana dioica	III	1-3			3				2	2		3			3	1	3	1	2
Equisetum palustre	III	1-3		2		2	3	3	2				2		1	1	2		
Holcus lanatus	III	1-4	1		2						3	3	4	3	3				2
Molinia caerulea	III	3-5	3		3							4			3	3	4		5
Galium palustre	III	1-3	1				2		3	3			1	1	2				
Lychnis flos-cuculi	III	1-5	2					2		5	4	3	1		2	3		1	2
Sagina nodosa	III	1-3			3	1	1	2	2				1	2					
Cardamine pratensis	III	1-3			1		2	1	2				1	2	1	1		3	2
Carex curta	II	2-6								6	2	4	4	2				3	
Carex pulicaris	II	1-5	2		5											1			3
Carex echinata	II	1-2			2						2			1				1	
Sphagnum squarrosum	II	1-5				1		1			4	3	5	5					
Sphagnum recurvum	II	1-7				1				7	7	2							
Salix repens agg.	II	2-4	2												2	3	4	2	
Viola palustris	II	1-3							1	1		2	3						
Bryum pseudotriquetrum	II	2-3	2	2			2							3		3			2
Carex panicea	II	2-6									2				3	6	5		3
Potamogeton polygonifolius	II	1-6				6	6	4					2	5		1			
Utricularia minor	II	1-4				3	4	3						2				1	
Phragmites australis	II	2-5	3												5	5	3	2	4
Epilobium palustre	II	1-3		1						3		1		2	1				
Equisetum fluviatile	II	1-3							3	2			2		1			2	
Mentha aquatica	II	1-3			2		1		3										2
Carex nigra	II	1-4	1	4		1	3												2
Cirsium palustre	II	1-2		1						1	1	2				1			
Agrostis stolonifera	II	1-4			2					4	2				2	1			
Galium uliginosum	II	1-2									2	2				2		1	1
Luzula multiflora	II	1-3			1							2	3	1	1				
Filipendula ulmaria	II	1-3					2		1	1					3	2			2
Angelica sylvestris	II	1-4													2	2	4		1
Selaginella selaginoides	II	1-3			3											2		1	2
Dactylorhiza incarnata	II	1								1							1	1	1
Fissidens adianthoides	II	2-3	3		3													2	3
Pinguicula vulgaris	II	1-3	3	1	1			1											
Crepis paludosa	I	1-2			1											2	2		
Juncus acutiflorus	I	1-2							1					2		1			
Betula pubescens (g)	I	2-3	2													3	2		
Aneura pinguis	I	1											1			1	1		
Philonotis calcarea	I	1-4	4					2								1			
Climacium dendroides	I	1-2							1	2	1								
Philonotis fontana	I	1-4			2						1			4					
Vicia cracca	I	1-2													2	1			1
Salix cinerea (s)	I	1-2													2			1	1
Dactylorhiza purpurella	I	1-2					2		1						2				
Homalothecium nitens	I	1-6					1		6							2			
Sphagnum subnitens	I	1-8								8	1						1		
Pyrola rotundifolia	I	2-6													6	2	2		
Sphagnum warnstorfii	I	1-5													5		1	1	
Vaccinium oxycoccos	I	2-3														2	3	3	
Briza media	I	1-2			2										2	1			
Carex limosa	I	2-3													2			3	
Number of species per sample			28	19	31	23	28	25	33	34	29	24	28	32	43	52	32	36	38

Campylium stellatum. The rare bryophytes *Homalothecium nitens* and *Cinclidium stygium* occur within this community at one site. *Aulacomnium palustre* and *Drosera rotundifolia* are found scattered through the *Sphagnum* hummocks and the bryophyte *Rhizomnium pseudopunctatum* is frequently found at the base of the *Sphagnum* hummocks. *Carex diandra* and *Carex lepidocarpa* are the most abundant sedges, accompanied by *Eriophorum angustifolium* although *Carex lasiocarpa* and *Carex rostrata* can be prominent and sometimes abundant. *Carex curta*, *Carex pulicaris* and *Carex echinata* are locally frequent and *Carex limosa* is occasionally found. Small herbs *Parnassia palustris*, *Pedicularis palustris*, *Valeriana dioica*, *Lychnis flos-cuculi*, *Sagina nodosa* and *Cardamine pratensis* grow around the margins of hummocks. This community is typically found on vegetation rafts over shallow fluid peat, near the edges of sites, or on small sites.

Mixed sedge rich-fen community (table 2.16)

Constant species: *Menyanthes trifoliata*, *Callergon cuspidatum*, *Carex lepidocarpa*, *Carex panicea*, *Carex rostrata*, *Caltha palustris*, *Carex diandra*, *Eriophorum angustifolium*, *Cardamine pratensis*, *Plagiomnium rostratum*

[*Potentilla palustris*, *Galium uliginosum*, *Lychnis flos-cuculi*, *Epilobium palustre*, *Filipendula ulmaria*, *Angelica sylvestris*, *Agrostis stolonifera*, *Succisa pratensis*, *Valeriana dioica*, *Molinia caerulea*]

A rather variable community characterised by an open sward of mixed sedges *Carex diandra*, *Carex rostrata*, *Carex panicea*, *Carex lepidocarpa*, *Eriophorum angustifolium* with an understorey of *Menyanthes trifoliata*, *Caltha palustris*, *Potentilla palustris* and a mixture of herbs including *Galium uliginosum*, *Lychnis flos-cuculi*, *Epilobium palustre* and *Filipendula ulmaria*. The ground layer comprises patches of *Calliergon cuspidatum* and *Plagiomnium rostratum*, sometimes accompanied by *Calliergon giganteum*, *Calliergon cordifolium* all of which can be locally abundant, with more scattered patches of *Campylium stellatum* and *Drepanocladus revolvens*.

Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community

A vary variable community, occurring on solid peat and as quaking vegetation rafts. *Carex rostrata* is usually the most prominent component in the sward but is often accompanied by *Carex diandra* and *Eriophorum angustifolium*. A range of species are characteristic in the understorey notably *Menyanthes trifoliata*, *Equisetum fluviatile* and *Potentilla palustris*. In some areas, especially in the *Carex diandra* variant, the bryophyte cover is luxuriant with abundant *Calliergon cuspidatum* and *Plagiomnium rostratum* frequently accompanied by *Calliergon giganteum* and *Calliergon cordifolium* in wetter areas. Cushions of *Sphagnum*

Table 2.16. Vegetation table showing the species composition of individual quadrats representing the Mixed sedge rich-fen community

	Frequency score		Domin abundance scores (1-10) for individual quadrats												
Species	Range of abundance														
Menyanthes trifoliata	V	2-7	4	3	3	7	5	2		2	2	6	5	5	2
Calliergon cuspidatum	V	3-7	3		3	7	3	2	5	3	5	5	4	5	3
Carex lepidocarpa	V	1-6	3	1	1	2	5	6		1	3	4	3	1	3
Carex panicea	V	1-4	1	2	1	1	3	3	4	3	3	3	2	5	
Carex rostrata	V	1-5	5	5		2	1	2	2	3	3	4	2	3	2
Caltha palustris	V	1-4	3	2	3	1	3	2	3	3	4	3		3	3
Carex diandra	V	1-6	6	4	3	5	4	1		4	6	3	3	3	3
Eriophorum angustifolium	V	2-7		2		7	5	5	4	3	3	3	4	2	3
Cardamine pratensis	V	1-3	2	1		2		3	2	1	3	2	2	1	2
Plagiomnium rostratum	V	1-7	5	3	3	3	5	1	6	3	1	1	7		
Potentilla palustris	IV	2-5	2				2	4	2	3	3	4	3	3	5
Galium uliginosum	IV	1-3	3	2	2	3			3		2	1	2	3	3
Lychnis flos-cuculi	IV	1-4	3	1	3	3			2	3		3	4	2	4
Epilobium palustre	IV	1-3		1	3		1	3	2	3	3	1	2	1	
Filipendula ulmaria	IV	1-5	3	2		5		1	5	4	1	4		4	
Angelica sylvestris	IV	2-5	3	4	3	3	2	2	3		4				5
Agrostis stolonifera	IV	1-5	1	2	1	5		4		2	5		2	3	
Succisa pratensis	IV	1-3		1			1	1	3	3			2	3	3
Valeriana dioica	IV	1-3	2				2	1	3	1		3	3	2	
Molinia caerulea	IV	1-4	3	3			4	3	4	3		1		3	
Carex nigra	III	1-4		4	1	1	3			1	1	4			
Ranunculus flammula	III	1-3			1			1		2	3	2	1	1	
Equisetum fluviatile	III	1-3			1	3			3				1	3	3
Juncus acutiflorus	III	1-4	1	3					3	2	1	4			
Phragmites australis	III	1-10			10		3	1	3	3	1				
Calliergon giganteum	III	1-4	2	4		1	5	3		2					
Dactylorhiza purpurella	III	1-3				3	1			2		1		1	1
Salix cinerea (g)	III	1-2	1				2	1	2	1				1	
Juncus articulatus	III	1-3					3	2		3	1	2			2
Parnassia palustris	II	1-3		1			1	1		3	1				
Sagina nodosa	II	1-3	2				3	2			1		2		
Juncus effusus	II	1-2						1	2	1			1	1	
Myosotis scorpioides	II	1-2				2	2			1		1		2	
Equisetum palustre	II	1-3		1			3							2	2
Holcus lanatus	II	2-3		3									3	2	3
Bryum pseudotriquetrum	II	2-3	2					3				3		3	
Carex pulicaris	II	3-4						3					3	3	4
Crepis paludosa	II	1					1			1		1		1	
Carex echinata	II	1-4		1				1	4					3	
Hydrocotyle vulgaris	II	1-9	2		9		4			1					
Galium palustre	II	2-3						3	2			2		2	
Luzula multiflora	II	1-2		1									2	1	1
Potentilla erecta	II	1-3		1					2				1	3	
Salix repens agg.	II	1-3	1					1	3	1					
Calliergon cordifolium	II	2-5					2			5	5	3			
Rumex acetosa	II	1-3		3					2					1	3
Campylium stellatum	II	3-4	4				3	3							
Pedicularis palustris	II	1-2		2			2					1			
Scorpidium scorpioides	II	1-2	3					1					2		
Drepanocladus revolvens	II	3-6						6			4		3		
Mentha aquatica	II	1-3				3		1			1				
Sphagnum recurvum	II	1-3		3	2							1			
Hylocomium splendens	II	2-3											2	3	3
Marchantia polymorpha	II	1-2				1			2	1					
Carex paniculata	II	2-3				3	3						2		
Rhytidiadelphus squarrosus	II	2-5				2								2	5
Ranunculus acris	II	1		1		1									1
Anthoxanthum odoratum	II	2-3											3	2	2
Cirsium palustre	I	1-2				1									2
Achillea ptarmica	I	1		1	1										
Aulacomnium palustre	I	1-3											3	1	
Climacium dendroides	I	2-3	2										3		
Carex lasiocarpa	I	3-8	3	8											
Cerastium fontanum	I	1-2						2							1
Rhinanthus minor	I	2											2		2
Prunella vulgaris	I	2		2						2					
Dactylorhiza fuchsii	I	1-3	1			3									
Number of species per sample			29	35	20	29	33	38	30	36	28	32	34	41	31

squarrosum and *Aulacomnium palustre* are occasionally found. Small herbs such as *Caltha palustris, Epilobium palustre, Mentha aquatica* and *Ranunculus flammula* are frequently found.

a) Typical variant (table 2.17)

Constant species: *Carex rostrata, Menyanthes trifoliata, Equisetum fluviatile, Galium palustre*

[*Calliergon cuspidatum, Plagiomnium rostratum, Filipendula ulmaria, Potentilla palustris, Mentha aquatica, Caltha palustris*]

Rather swampy vegetation, usually occurring as a raft. The vegetation has a fairly open structure but is generally quite species-poor. *Carex rostrata* is the main sedge species, sometimes accompanied by *Carex lasiocarpa* and *Carex diandra* which can be locally abundant. *Menyanthes trifoliata, Equisetum fluviatile* and *Potentilla palustris* form the main components of the herb layer accompanied by *Mentha aquatica, Caltha palustris* and with scattered individuals of species such as *Epilobium palustre, Lychnis flos-cuculi* and *Cardamine pratensis. Ranunculus lingua* is found in this community. *Calliergon cuspidatum* and *Plagiomnium rostratum* are often found in the ground layer and they are sometimes abundant; *Calliergon giganteum* and *Calliergon cordifolium* are sometimes found scattered among the stem bases. *Phragmites australis* can be a prominent species in this community and *Salix cinerea* seedlings and shrubs are frequently found. At some sites this community is also found beneath willow carr.

b) *Carex diandra* variant (table 2.18)

Constant species: *Carex rostrata, Carex diandra, Menyanthes trifoliata, Potentilla palustris, Caltha palustris, Ranunculus flammula*

[*Equisetum fluviatile, Plagiomnium rostratum, Calliergon cuspidatum, Eriophorum angustifolium, Agrostis stolonifera, Galium palustre, Carex nigra*]

This community is characterised by a sedge sward with abundant *Carex diandra, Carex rostrata* and *Eriophorum angustifolium* and sometimes prominent *Carex nigra*, beneath which is a dense understorey of *Menyanthes trifoliata, Caltha palustris* and *Potentilla palustris. Ranunculus flammula, Equisetum fluviatile, Agrostis stolonifera* and *Galium palustre* are all constant but rather sparse. *Calliergon cuspidatum* and *Plagiomnium rostratum* form the main components of the ground layer and they can both be abundant. *Calliergon giganteum* is also locally abundant. This is a widespread community mainly occurring on solid peat, or a 'grounded' vegetation raft.

Table 2.17. Vegetation table showing the species composition of individual quadrats representing the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant.

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats																		
Menyanthes trifoliata	V	1-9	8	3		7	3	3	4	4	5	6	9	1	9		3	5	3	6	8
Carex rostrata	V	1-10	3	8	3		10	4	3	4	3	5		5	7	3		4	8	1	4
Equisetum fluviatile	V	1-7	5	5	3	3	1	3	1	7		1	3		4	7	1		3	5	3
Galium palustre	V	1-4	4	3	2	3	1	3		2	3	2	2	3	2	3	3			3	3
Calliergon cuspidatum	IV	1-6	3	6	4	2		3		1	4	3		5	1	4		4		3	3
Filipendula ulmaria	IV	1-7		5	4		1	4	1	2		2		1	1	2	7		1	1	3
Plagiomnium rostratum	IV	1-9	2	8	3			3		5	7	6		2	1	2			1	9	4
Mentha aquatica	IV	1-7	6	4	7	1	2	3			3	3	3		5	4			1		3
Potentilla palustris	IV	1-6			3	5		2	1	2		4	2	6	1			3	3		1
Caltha palustris	IV	1-4	2	2	2	3				3	3	3				2	2	1		4	4
Epilobium palustre	III	1-5		3			1				4	3	2	1		3		2			5
Angelica sylvestris	III	1-4	4	2		1	1	1	1								1	1			
Agrostis stolonifera	II	1-5	3	2							1	1	2			3	5				
Cardamine pratensis	II	1-2				2		2		2	1	1			1			2			
Calliergon giganteum	II	1-5	3			3		2		2	5				1	3					
Equisetum palustre	II	1-4	4				1			1			4				2	2		4	
Salix cinerea (g)	II	1						1	1		1	1		1					1		1
Carex lasiocarpa	II	1-6	5			6	3		6	4			1	6							
Carex diandra	II	4-9				5				4	5		9	7					4	7	
Phragmites australis	II	1-10		1	10	6		8	5							3					
Juncus articulatus	II	1-4									1	1	2		1			4			
Carex paniculata	II	1-6				3					1	1				3					6
Lychnis flos-cuculi	II	1-4					1				2		2							4	
Valeriana dioica	II	1-3	2	2		3					1										
Ranunculus lingua	II	1-6	1							2					2	6					
Holcus lanatus	II	2-3	2								2	2								3	
Myosotis scorpioides	II	1-3						1			3	2				3					
Juncus acutiflorus	I	3-5	5										3		3						
Carex lepidocarpa	I	3				3							3					3			
Carex panicea	I	2-3											2					3			
Drepanocladus revolvens	I	3-4		3		4															
Bryum pseudotriquetrum	I	3-5				3				5											
Marchantia polymorpha	I	2-3	2							3											
Potentilla erecta	I	1-2	2											1							
Pedicularis palustris	I	1-3				3													1		
Eurhynchium praelongum	I	2		2		2															
Nasturtium officinale	I	2-3													2			3			
Dactylorhiza incarnata	I	1				1						1									
Salix cinerea (c)	I	4-7			7											4					
Calliergon cordifolium	I	1-3						3							1						
Number of species per sample			19	19	12	23	11	17	9	19	22	20	16	12	18	17	10	14	13	13	15

Table 2.18. Vegetation table showing the species composition of individual quadrats representing the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats																		
Carex rostrata	V	1-8	3	6		3	2	3	3	7	8	1	3	3	3	2	2	7	4	5	4
Menyanthes trifoliata	V	1-8	7	8	5	3	8	6	5	3	8	1	1		5	3	3	5	4	7	7
Potentilla palustris	V	1-3	2	2	2	3	3	3	3	3	2	2	3		3	3	2	2	2	2	1
Caltha palustris	V	2-4	2	2	2	2	3		3	2	2	4	2		3	2	2	4		3	3
Ranunculus flammula	V	1-3			1	2	2	2	3	3	1		1	2	1	3	3	3	2	2	1
Carex diandra	V	1-9	3	1	7	3	9	7			3	8		1	7	6	6	1	2	7	4
Equisetum fluviatile	IV	1-4	4	3	4		4	4		4	1	4	1		3	1	1	3		3	3
Plagiomnium rostratum	IV	1-6	2	3	5	5	6	5		3	5	1			4	2	2		1	3	5
Calliergon cuspidatum	IV	1-6	6		3	5		3	4	4	1	1		1	4		6		1	5	5
Agrostis stolonifera	IV	1-5	3	1	3	3	3	4	4	3		1	2		5	2		2			
Galium palustre	IV	1-3	3	2		2	3	3	3			2	1		3	3				2	2
Eriophorum angustifolium	IV	1-8	2	1				2		5	2			8	1		1	2	4	3	4
Carex nigra	IV	1-6	3	1		5	2	1	6						3	2	5	1		3	3
Filipendula ulmaria	III	1-5	5	1	4						1	1	1		4	3		1		2	4
Juncus articulatus	III	1-5	2				3	4	5	2	2	2	1	3		2	3				
Carex lepidocarpa	III	2-8			2	3		4	6			6	5		2	2	5	5	8		
Calliergon giganteum	III	1-7		3	5			4	5		1	3	1		6	7	5				
Equisetum palustre	III	1-3	2				3						2	1	2	1	1	1		3	2
Carex panicea	III	1-6				2		1				4	6	5		2	5		1	1	3
Mentha aquatica	III	1-5	2	1								1	5		3	5	3			1	3
Epilobium palustre	III	1-2	2		1	2				2	2	1		2				2	1		
Molinia caerulea	III	1-5	1									2	3	5	2	5	3	3			1
Cardamine pratensis	II	2-3			2		2	3	3	2				3	2						
Juncus acutiflorus	II	1-5	5			4	2					1			5					1	
Sagina nodosa	II	1-3			1	2		2	3	2				2							
Galium uliginosum	II	1-3			2									3		2		1	1		
Drepanocladus revolvens	II	1-5							3					1	1		3		5		
Bryum pseudotriquetrum	II	2-3			3	3		3	3								2				
Myosotis laxa caespitosa	II	1-2			1	2	1	2	2												
Holcus lanatus	II	1-3				2			2	2				3					1		
Myosotis scorpioides	II	1-2		1							2	1		2				2			
Angelica sylvestris	II	1-5	5	1							3	1									
Lychnis flos-cuculi	II	2-3		2								2								2	3
Valeriana dioica	II	1-4										1	4		1						2
Crepis paludosa	II	1-2	2		2		1									1					
Viola palustris	II	1-2		1	2							1	1								
Salix cinerea (g)	I	1		1		1							1								
Succisa pratensis	I	1-3															3	1			1
Potentilla erecta	I	1-2											1				2	1			
Rhizomnium pseudopunctatum	I	2-6			6											2					
Carex disticha	I	2-7											2			7					
Veronica scutellata	I	1																		1	1
Parnassia palustris	I	1													1		1				
Carex lasiocarpa	I	6	6	6																	
Deschampsia cespitosa	I	1	1														1				
Potamogeton polygonifolius	I	3-5								3	5										
Climacium dendroides	I	1									1								1		
Fissidens adianthoides	I	2-3													3		2				
Scutellaria galericulata	I	2			2	2															
Prunella vulgaris	I	2												2			2				
Scorpidium scorpioides	I	1-3			1														3		
Juncus effusus	I	1				1														1	
Number of species per sample			27	21	28	22	17	21	18	17	21	27	25	19	25	23	26	20	16	21	21

c) Miscellaneous variant (table 2.19)

Constant species: *Carex rostrata, Menyanthes trifoliata, Potentilla palustris, Epilobium palustre, Holcus lanatus*

[*Galium palustre, Equisetum fluviatile, Plagiomnium rostratum, Calliergon cuspidatum, Caltha palustris, Filipendula ulmaria*]

This community contains samples representing very variable vegetation. It represents the samples which could not be included in the previous two, better defined, variants and is therefore named a miscellaneous variant. Generally this community is characterised by a dense sward of *Carex rostrata* with locally abundant *Carex diandra, Carex paniculata* and *Eriophorum angustifolium* accompanied by *Menyanthes trifoliata, Potentilla palustris, Equisetum fluviatile Galium palustre* and *Caltha palustris*. This herb layer is enriched by *Holcus lanatus, Epilobium palustre, Filipendula ulmaria* and *Myosotis scorpioides*. This community often occurs beneath a canopy or shrub layer of *Salix cinerea* and/or *Alnus gluinosa*; in these situations the sedge sward is less dense due to shading. The main components of the ground layer are *Calliergon cuspidatum* and *Plagiomnium rostratum*. Bryophytes tend to occur as localised cushions amongst the vascular plants. *Calliergon giganteum, Sphagnum squarrosum, Aulacomnium palustre* and *Rhizomnium pseudopunctatum* can all be locally abundant.

2.3.3.2 Bog

<u>*Eriophorum vaginatum - Sphagnum papillosum* community (table 2.20)</u>

Constant species: *Eriophorum angustifolium, Calluna vulgaris, Eriophorum vaginatum, Sphagnum papillosum, Drosera rotundifolia, Sphagnum capillifolium*

[*Carex rostrata, Aulacomnium palustre, Erica tetralix, Luzula multiflora*]

This vegetation type is typical of bogs where the vegetation surface is irrigated by meteoric water rather than telluric water. It is a very distinctive vegetation type with tussocks of *Calluna vulgaris* and *Eriophorum vaginatum* and lawns and cushions of *Sphagnum* species, in particular *Sphagnum papillosum*. Other *Sphagnum* species occur in pools (*Sphagnum cuspidaum*) and as lawns between the hummocks (*Sphagnum recurvum, Sphagnum palustre*). Cushions of *Polytrichum commune* and *Polytrichum alpestre* are sometimes found. *Narthecium ossifragum* and *Vaccinium oxycoccos* are locally frequent. This community is frequently found at the centre of sites, usually over solid peat, but one stand was recorded from a raft of vegetation over a recolonised peat cutting.

Table 2.19. Vegetation table showing the species composition of individual quadrats representing the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, miscellaneous variant

Species	Frequency score	Range of abundance	Domin abundance scores (1-10) for individual quadrats																						
Menyanthes trifoliata	V	1-8	5	3	3			2	5	1	5	5		3	5	5	3	4	5	5	8	6	1	5	8
Potentilla palustris	V	2-6	3	2	3	2	4		2		3	3	6	2	2	3	3	2		2		2	5	4	4
Epilobium palustre	V	1-4	1		3	2	3	1		3	2	2	3	3		1	3		2	2	4	1	2	3	3
Carex rostrata	V	1-7	4	3	3		7			6	6	6	5	6	4	1		4	7	7	4	7	5	3	4
Holcus lanatus	V	1-4	1	2		1	2	1	4	2	4		1	2	2	3		3	3	1	3	1		2	1
Galium palustre	IV	1-4		2			3	3	3	3	3	3	3	3		3	2	3	3	3	2		1		4
Equisetum fluviatile	IV	2-5		2	2			3		5		5		2	2	2	4	4		3	5	3	3	2	3
Plagiomnium rostratum	IV	1-7	7		4	4	1						6	2	4	3	2	3	4	2	3			4	6
Filipendula ulmaria	IV	1-6		1	3	3		3	5		1	6		2		6	6	5	1	1		2	4		
Calliergon cuspidatum	IV	1-7	4			4			5				5		5	7	3	5	5	1	4	7	7	4	4
Caltha palustris	IV	1-5					3	2	3	3	3	3	1	2		2			5		3	2	4	2	4
Juncus effusus	III	1-7	1	3	7		5	2				1	1	1	2	2	2			1			1		4
Myosotis scorpioides	III	1-8				8	3			3	4		1	3	2		3	3	3	5	1			3	1
Juncus acutiflorus	III	1-5	2				3					5	1		1	2		1	1	1	2	1		2	3
Agrostis stolonifera	III	1-6	3	2	6			1	4				3	4		3			3	4	3				3
Cirsium palustre	III	1-3	1							2			1		1	1	2	3		1	1	1	2	1	
Angelica sylvestris	III	1-7	2	2	5				3	7	4	5				1			1	1					1
Salix cinerea (c)	III	1-9				9		1	7					1	1	1	5		1	1		5	3		
Cardamine pratensis	III	1-3									1		3	1	2	2	3		1		2		2	2	2
Lychnis flos-cuculi	III	1-5					4			3	5	3			3	3	3	3	3				1	3	
Carex diandra	III	2-6					5			2	5		5		6	6	3	5		3	6			4	
Ranunculus flammula	III	1-5						2	2						1		1	2	5	3		1		2	1
Calliergon giganteum	II	1-8			4			3		8	8	6								1		3	3	3	
Eriophorum angustifolium	II	1-7	6	3			4							7				5	4	3	3			1	
Dactylorhiza fuchsii	II	1-3	1	1								2			3	1	3				1				1
Carex nigra	II	1-4						1	1						4	3			4		2			1	
Aulacomnium palustre	II	1-3		2	3					1	1			1										3	
Mentha aquatica	II	1-5							1	2		5			2			5				2			
Lemna minor	II	1-3										3	3								2		1	1	3
Calliergon cordifolium	II	1-4	2							1				3						2				3	4
Rhizomnium pseudopunctatum	II	2-5	2		5						5				3			2							
Sphagnum squarrosum	II	1-7	3	7	3						2			1											
Marchantia polymorpha	II	2-4	3		2		3					3												4	
Carex paniculata	II	1-7				4		1	5								7	2							
Galium uliginosum	II	1-4													2	2	4					1		3	
Carex panicea	II	1-5													5	3			3		1	3			
Deschampsia cespitosa	II	1-3		3					1					2				1					2		
Dryopteris carthusiana	II	1-3	1	2					3									1					1		
Juncus conglomeratus	I	1-4		2	4												1							1	
Eurhynchium praelongum	I	1-4			2	2						4					1								
Sparganium erectum	I	1-2				2	2						1								1				
Equisetum palustre	I	1-4							2		4										1			1	
Juncus articulatus	I	3													3				3					3	3
Valeriana dioica	I	1-3							2		3	3										1			
Carex disticha	I	1-7						7														1	3		6
Rumex acetosa	I	1-3								3				1	1		2								
Dactylorhiza purpurella	I	1-3								3	3				1									1	
Climacium dendroides	I	1-2													1			2				1	1		
Carex curta	I	1-3	2	3										3				1							
Brachythecium rivulare	I	1-4					1						4								3				1
Mylia anomala	I	1-4	4		3																				1
Carex lepidocarpa	I	1-4													2							4		1	
Salix cinerea (g)	I	1-3																3						1	1
Pedicularis palustris	I	2-3												2	2			3							
Veronica scutellata	I	2						2	2						2										
Salix cinerea (s)	I	1-2	2	1							1														
Geum rivale	I	1														1						1	1		
Salix pentandra	I	1-3													1		1	3							
Utricularia vulgaris	I	1-3									3		3											1	
Ranunculus lingua	I	2-3	3		2																				
Cicuta virosa	I	1-3	3		1																				
Poa trivialis	I	3				3											3								
Molinia caerulea	I	1-2														1		2							
Drepanocladus revolvens	I	1													1									1	
Bryum pseudotriquetrum	I	1-3													3									1	
Crepis paludosa	I	3-4						4	3																
Potentilla erecta	I	1-2																				1	2		
Viola palustris	I	1-3						1															3		
Hippuris vulgaris	I	1-2									2													1	
Potamogeton polygonifolius	I	1-2							1						2										
Carex echinata	I	1						1										1							
Scutellaria galericulata	I	1-2	2												1										
Rhytidiadelphus squarrosus	I	1-4												4								1			
Polytrichum commune	I	4-8		8										4											
Betula pubescens (g)	I	1	1												1										
Alnus glutinosa (c)	I	7-10						10	7																
Stellaria alsine	I	1												1				1							
Number of species per sample			26	20	20	15	18	22	25	19	24	19	19	28	39	26	25	31	23	23	23	27	23	37	26

Table 2.20. Vegetation table showing the species composition of individual quadrats representing the *Carex rostrata - Sphagnum recurvum* community and the *Eriophorum vaginatum - Sphagnum papillosum* community.

Species	Frequency score / Range of abundance: POR		BOG		Domin abundance scores (1-10) for individual quadrats: *Carex rostrata - Sphagnum recurvum* community (POR)										*Eriophorum vaginatum - Sphagnum papillosum* community (BOG)							
Carex rostrata	V	2-7	IV	2-4	4	2	5	7	4	3	7	3	7	6	2	3	3				4	2
Aulacomnium palustre	V	1-4	IV	1-5	2	4	1	4	1	3	4	3	1	4	1	5	4				5	2
Eriophorum angustifolium	IV	2-6	V	2-7	2	6		5		5		4	3	3	3	2		7	3	3	2	5
Sphagnum recurvum	IV	4-10	III	5-10	10	4		4	10	5	4	5			5	8	10			8		
Potentilla palustris	V	1-4	I	3	1	1	1		2	2	2	3	3	4			3					
Menyanthes trifoliata	IV	1-8	II	1-2	3	1				5	3	5	8	7	2		1	2				
Juncus effusus	IV	1-7	I	1	2		6		7	2	1	1		1			1					
Sphagnum fimbriatum	IV	1-10	I	3	1	2	10	8			4	1		3		3						
Sphagnum squarrosum	III	1-5			3	2	3				3		1	5								
Calliergon stramineum	III	1-3				2			3	2	3	1		1								
Lychnis flos-cuculi	II	1-2									1	2		1								
Equisetum fluviatile	III	1-3	I	2		2	3				1	1	3	3		2						
Holcus lanatus	III	1-3	I	3		1	1			3		3		1					3			
Betula pubescens (g)	III	1-4	I	1			1				4	3	2	4	1							
Galium palustre	I	1											1	1								
Agrostis stolonifera	I	1					1				1											
Epilobium palustre	I	1-3										3		1								
Mentha aquatica	I	1-3							1				3									
Rumex acetosa	I	1					1						1									
Eleocharis palustris	I	1									1	1										
Calliergon cuspidatum	I	1											1									
Angelica sylvestris	I	2											2									
Carex diandra	I	6										6										
Salix cinerea (s)	I	1			1																	
Brachythecium rutabulum	I	1											1									
Aneura pinguis	I	1								1												
Valeriana officinalis	I	1					1															
Mylia anomala	I	2								2												
Alnus glutinosa (g)	I	1											1									
Carex limosa	I	5								5												
Calluna vulgaris			V	2-5											5	5	2	2	3		5	2
Eriophorum vaginatum			V	1-7											2	4		1	7	3	3	5
Sphagnum papillosum			V	2-9												4	2	2	9	5	6	6
Erica tetralix			IV	1-5											4			3	1		5	5
Drosera rotundifolia	I	2-3	V	1-4		2				3					2	1	1	4	2	2	2	3
Sphagnum capillifolium	I	1	V	3-5								1			5	3	3	3		3	3	3
Luzula multiflora	I	1	IV	1-4		1										1	1	1	4			1
Carex echinata	I	2	III	2-3		2									3		2	2				3
Potentilla erecta			III	1-3											2			1	1			3
Vaccinium oxycoccos			III	1-4											4					1	3	3
Narthecium ossifragum			III	1-3											1			1			3	3
Polytrichum alpestre			III	1-8												3	1	1	8			
Cladonia squamules/sp			II	2-3											3			2			2	
Salix repens agg.			I	1											1							
Pinguicula vulgaris			I	3																		3
Dicranum scoparium			I	2																	2	
Lophocolea bidentata			I	3																3		
Calypogeia muelleriana			I	2																	2	
Sphagnum palustre	III	1-9	II	1-2		8			1	9	7	7			1					2		2
Carex curta	III	1-5	II	1-3	3	5					3	1		5	1					3		
Salix cinerea (g)	II	1-2	I	1			1					1	2	2	1							
Anthoxanthum odoratum	II	1-4	I	1		1				4		3		2					1			
Molinia caerulea	I	1	II	1-3							1	1			3			1	1			
Dryopteris carthusiana	I	1	II	1-2							1	1				1			2	2		
Equisetum palustre	I	1	II	1-2							1				1		2	2				
Carex nigra	I	1	II	2-3		1												3				2
Sphagnum subnitens	I	3	II	3							3				3	3						
Deschampsia flexuosa	II	1-4	III	2-5		1			4		1				2	5	2					2
Succisa pratensis	II	1-4	II	1	1							3	4	4	1							1
Polytrichum commune	II	1-4	II	2-4	3				4					1						4	2	2
Juncus acutiflorus	I	2-3	I	6								2	3				6					
Phragmites australis	I	6	I	2				6												2		
Viola palustris	I	1	I	2										1								2
Dactylorhiza fuchsii	I	1	I	1										1	1							
Juncus bulbosus	I	1	I	1		1									1							
Betula pubescens (s)	I	1	I	2	1															2		
Number of species per sample					14	20	13	6	10	15	21	25	18	22	27	16	16	17	13	14	15	21

2.3.3.3 Poor-fen

Carex rostrata - Sphagnum recurvum community (table 2.20)

Constant species: *Carex rostrata, Aulacomnium palustre, Potentilla palustris*

[*Eriophorum angustifolium, Sphagnum recurvum, Menyanthes trifoliata, Juncus effusus, Sphagnum fimbriatum*]

This community is characterised by a dominant ground cover of *Sphagnum* species forming lawns between the vascular plants. *Sphagnum recurvum, Sphagnum fimbriatum* and *Sphagnum palustre* are the most frequently dominant species and they also occur as mixtures. *Sphagnum squarrosum* is also frequent but not dominant. Cushions of *Polytrichum commune* are occasionally found. The main vascular species are those typical of fen and swamp vegetation: *Carex rostrata, Eriophorum angustifolium, Potentilla palustris* and *Menyanthes trifoliata*. These are accompanied by *Carex curta* and tussocks of *Juncus effusus*. This vegetation is developed as often rather treacherous rafts over water, usually at the centre of sites, sometimes as "islands" or around bog vegetation.

2.3.3.4 Species-poor fen and swamp

These vegetation types usually have standing water for most of the year. Bryophytes are scarce in these vegetation types.

Carex rostrata-Potentilla palustris species-poor community (table 2.21)

Constant species: *Carex rostrata*

[*Equisetum fluviatile, Potentilla palustris, Galium palustre*]

[*Menyanthes trifoliata, Myosotis scorpioides, Epilobium palustre, Mentha aquatica, Juncus acutiflorus, Agrostis stolonifera*]

Mixed fen with *Carex rostrata, Menyanthes trifoliata, Equisetum fluviatile* and *Potentilla palustris*. This can be transitional to *Carex rostrata* rich-fen especially where the sward is enriched by *Carex diandra*, and where bryophytes occur. However, bryophytes are generally more scarce in this community and there is usually more standing water. Many species occur as scattered individuals in this community. *Eleocharis palustris, Juncus effusus, Typha angustifolia, Carex acutiformis, Carex disticha, Carex nigra* and *Carex paniculata* can all be locally abundant. *Cicuta virosa* and *Ranunculus lingua* also occur in some stands. This community can occur in an impoverished form beneath fen carr.

Table 2.21. Vegetation table showing the species composition of individual quadrats representing the *Carex rostrata - Potentilla palustris* species-poor community

Species	Frequency	Range of abundance	Domin abundance scores for individual quadrats (1-10)																																							
Carex rostrata	V	1-10	3	4	6	1	7	8	5	5	5	3	5	6	10		6	6	5	9	7	7	4	5	6	5	9	6	5		5	1	3		1	5	3	5	6	5	6	2	4
Equisetum fluviatile	IV	1-7	2		5			3						1	5	6	7	3	1	3	3	4	2	3	4	1	3	3		3	2	2	1	3	3	2	3	4	5	5	4	3	3
Galium palustre	IV	1-5			1		1			2	1	2	2	1		4	2	2	3	3	3	2	1	2	1	2	5	4	2		1	4	3		1	4	3	4	3		3	4	3
Potentilla palustris	IV	1-10	2		7		6	5	3	2	3	3	9	3	3	5	10	6	1		1	3	7	2			1				3		7			1				2		4	
Menyanthes trifoliata	III	1-8	8	3	3	5				7		1		5	6	4	5		3			6	2	3	1				3	6	3			3			4			3	5		6
Myosotis scorpioides	III	1-6				1			1		2	3						1	1		3	1	1	2	4	3	2	6			2		2		3	2	1	2	6				1
Epilobium palustre	III	1-3		2	1	2	1		3				1				1	2	1	2	2	3		3	3			1	1		2			2		1	3						3
Mentha aquatica	III	1-6			1	3			6			3			2	1	1		2	4				5	5			6			3	3		3	3		5	5	1	3	2		
Juncus acutiflorus	III	1-5	3	2	5					1	1			2			4	1	3		1	1		3							2	1		5	1			1				3	5
Agrostis stolonifera	III	1-7						2	6			3				7		5				3		3	7	3	3				5	3		2	1		6	5	2				3
Caltha palustris	II	1-5			2						2						1	4	2	3	2	1	1	4				3			2			2	5	3			1				
Juncus effusus	II	1-6			1		1		6		4		2					1	1		4		4		2	6	2		6			1										1	4
Carex nigra	II	1-10					5		4											1	4		3								7	8	10	10	1	1						6	
Hippuris vulgaris	II	1-5		1								1	1		3					1		2	1					5	1										1	3			2
Calliergon cuspidatum	II	1-7		1			1		3	1			7						1								1						6				4		1				3
Filipendula ulmaria	II	1-5	1								1		1				1	1				1		3								3								1	5	5	
Ranunculus flammula	II	1-2	2								2						1	2				1	1					1			1				1	1	1						
Eriophorum angustifolium	II	1-10	2		3		1	6		3									10			1		3					5		6				1								
Lemna minor	II	1-5				2															2	3			3		2	1	5							3	2						3
Sparganium erectum	II	1-5				1								5								1			3	3		5							2					1			3
Carex disticha	II	1-10	1								5		1	6								1	1							10					1							4	
Cicuta virosa	I	3-7														4									3	6	5		5								3		7				4
Calliergon cordifolium	I	1-10						1		3		10	1										1		1												3						
Calliergon giganteum	I	1-7			7					2										3					1	1	3									2							
Ranunculus lingua	I	4-6						6							5	4														4									6	4	6		
Veronica scutellata	I	1-3			2															3		1						1			2			3				2					
Phragmites australis	I	1-8		7	2							1												5																8	8		
Plagiomnium rostratum	I	1-7			3															5																	7				1	2	
Eleocharis palustris	I	1-7																			5							3				5						7					1
Polygonum amphibium	I	1-3														3					3		1		1														1				
Carex paniculata	I	1-10				10			1									7								6	2																
Carex diandra	I	3-6	6		5			3		5																																	
Salix cinerea (c)	I	1-10										10										1		1																			
Iris pseudacorus	I	1-10																			1														10	8							
Potamogeton polygonifolius	I	1-8				1				8				7																													
Number of species per sample			15	10	16	11	11	10	11	14	12	13	11	10	7	12	11	14	13	13	17	21	15	20	15	13	15	14	9	4	16	14	8	9	16	14	22	10	15	10	9	13	16

Carex rostrata species-poor community

This fen differs from the above in the abundance of the main species and lack of additional species. *Carex rostrata* forms the main component of the vegetation and can form a very dense sward. In the *Menyanthes trifoliata* variant *Menyanthes trifoliata* attains dominance with a more sparse cover of *Carex rostrata*.

a) Dominant *Carex rostrata* variant (table 2.22)

Constant species: *Carex rostrata*, *Equisetum fluviatile*

[*Myosotis scorpioides*]

Carex rostrata forms a dense sward with few associates.

b) Dominant *Menyanthes trifoliata* variant (table 2.22)

Constant species: *Carex rostrata*, *Menyanthes trifoliata*

[*Equisetum fluviatile*]

Menyanthes trifoliata forms a dense, low-growing cover with sparse shoots of *Carex rostrata* and *Equisetum fluviatile*. This community often occurs as a precarious raft over open water representing an early phase in hydroseral succession.

Equisetum fluviatile species-poor community (table 2.23)

Constant species: *Equisetum fluviatile*, *Carex rostrata*

[*Lemna minor*]

Characterised by a dense sward of *Equisetum fluviatile* spikes with few associated species this community is found at the edges of areas of open water and around the edges of very wet sites.

Glyceria fluitans species-poor community (table 2.23)

Constant species: *Glyceria fluitans*, *Carex rostrata*, *Juncus effusus*

[*Nasturtium officinale*, *Epilobium palustre*, *Sparganium erectum*]

This community frequently occurs in ditches and drains.

Eleocharis palustris species-poor community (table 2.23)

Constant species: *Eleocharis palustris*, *Carex rostrata*

[*Hippuris vulgaris*]

Areas dominated by Eleocharis palustris frequently occur at the edges of sites and within the *Carex rostrata - Potentilla palustris* species-poor community.

Table 2.22. Vegetation table showing the species composition of quadrats representing the *Carex rostrata* species-poor community

Species	Frequency / Range of abundance: FSCb		FSCa	
Carex rostrata	V	1-10	V	7-10
Equisetum fluviatile	IV	2-6	IV	2-7
Menyanthes trifoliata	V	5-10	I	1-5
Myosotis scorpioides	I	2	IV	1-4
Epilobium palustre	I	1	II	1-3
Galium palustre			II	1-3
Hippuris vulgaris	III	1-3	III	1-6
Potentilla palustris	II	1-5	I	3-5
Carex nigra	II	1-5	I	1-7
Eriophorum angustifolium	II	1-3		
Mentha aquatica	II	1-4	II	3-6
Lemna minor	II	1-3	II	2-5
Potamogeton polygonifolius	II	1-4	I	1-5
Juncus effusus	I	1-4	II	1-3
Juncus acutiflorus	I	1	I	2
Ranunculus flammula	I	1	I	1-4
Caltha palustris	I	1	II	1-5
Sparganium erectum	I	1-5	II	1-5
Agrostis stolonifera	I	1-3	II	2-5
Carex disticha	I	1-6	II	1-5
Iris pseudacorus	I	1	I	1-4
Algal mat	I	2-3	I	1-4
Juncus articulatus	I	2-3	I	2
Carex panicea	I	1-3		
Polygonum amphibium	I	1	II	2-3
Calliergon giganteum	I	3	I	1-3
Eleocharis palustris	I	1	I	4-5
Nasturtium officinale	I	4	I	2-3
Calliergon cuspidatum			I	1-2
Filipendula ulmaria			I	1-2
Phalaris arundinacea			I	1
Ranunculus lingua			I	1-5
Alisma plantago-aquatica			I	1
Glyceria fluitans			I	1-5
Phragmites australis			I	1-4
Bryum pseudotriquetrum			I	1-2
Urtica dioica			I	1
Epilobium hirsutum			I	1

Carex rostrata species-poor swamp: *Menyanthes trifoliata* variant (FSCb) — Domin abundance scores (1-10) for individual quadrats

Species																	
Carex rostrata	7	4	2	4	6	8	9	7	7	10	1	2	10	7	3	8	8
Equisetum fluviatile		3		4			2	5	2	3	3	2	3	6	4	3	5
Menyanthes trifoliata	5	9	5	9	6	5	8	5	10	4	5	10	5	8	10	8	7
Myosotis scorpioides				2													
Epilobium palustre				1													
Galium palustre																	
Hippuris vulgaris	1			3		1	1			2	3						2
Potentilla palustris				1	1	1									1	5	
Carex nigra	5				1	5	1						1				
Eriophorum angustifolium	3			1	1	1						1					
Mentha aquatica							1								1	4	3
Lemna minor				3	1										3		1
Potamogeton polygonifolius	2		4				1		1								
Juncus effusus				1		1											1
Juncus acutiflorus				1		1		1									
Ranunculus flammula	1			1		1											
Caltha palustris							1							1			
Sparganium erectum							1	5									
Agrostis stolonifera				1									3				
Carex disticha					6	1											
Iris pseudacorus					1	1											
Algal mat			3	2													
Juncus articulatus	3											2					
Carex panicea	3				1												
Polygonum amphibium																	1
Calliergon giganteum		3															
Eleocharis palustris													1				
Nasturtium officinale																4	
Calliergon cuspidatum																	
Filipendula ulmaria																	
Phalaris arundinacea																	
Ranunculus lingua																	
Alisma plantago-aquatica																	
Glyceria fluitans																	
Phragmites australis																	
Bryum pseudotriquetrum																	
Urtica dioica																	
Epilobium hirsutum																	
Number of species per sample	10	6	4	14	9	11	10	7	4	4	4	5	6	5	6	6	9

Carex rostrata species-poor swamp: *Carex rostrata* variant (FSCa)

Species																		
Carex rostrata	8	10	10	9	9	8	8	10	7	9	9	10	7	10	9	9	8	8
Equisetum fluviatile	4	3			2			7	3	5	5	2		6	6	3	5	
Menyanthes trifoliata							5		5	1								
Myosotis scorpioides	4			1	1		2	1				1	1	2	4	1	1	3
Epilobium palustre	1				1	2	1			3	2							3
Galium palustre	2			1	2		2					1				1		3
Hippuris vulgaris				3		6	3	5				3	1		4			3
Potentilla palustris		5	3								3							
Carex nigra									7				1					
Eriophorum angustifolium																		
Mentha aquatica					5		5	3			6	5	3		3			
Lemna minor							2			3				5		3	2	3
Potamogeton polygonifolius						5				1								
Juncus effusus	1	1	1	3								1					1	
Juncus acutiflorus					2						2		2					
Ranunculus flammula						4				1			1					
Caltha palustris					1	3			1		3	5	2					
Sparganium erectum					5		1	2									3	4
Agrostis stolonifera	3							5	2			2						
Carex disticha					1							2	5				1	
Iris pseudacorus												1				1		4
Algal mat										1			4					
Juncus articulatus						2												
Carex panicea																		
Polygonum amphibium									3						2	3	2	
Calliergon giganteum					3										1			
Eleocharis palustris									4									5
Nasturtium officinale					2							3						
Calliergon cuspidatum	1					1												2
Filipendula ulmaria	2												1				1	
Phalaris arundinacea					1											1	1	
Ranunculus lingua					5				2			1						
Alisma plantago-aquatica					1							1	1					
Glyceria fluitans						1					5							
Phragmites australis	1	4																
Bryum pseudotriquetrum	1									2								
Urtica dioica																	1	1
Epilobium hirsutum												1						1
Number of species per sample	12	5	4	5	15	10	9	7	9	10	8	15	15	4	8	8	11	13

Table 2.23. Vegetation table showing the species composition of individual quadrats representing species-poor plant communities.

Species	Plant community* FSE	FSQ	FSG	FSS	FSA	FSE (*Eleocharis palustris*)					FSQ (*Equisetum fluviatile*)						FSG (*Glyceria fluitans*)				FSS (*Sparganium erectum*)				FSA (*Carex acutiformis*)	
	Frequency score					Domin abundance scores for individual quadrats																				
Carex rostrata	V	V	V	III		5	5	5	3	3	4	5		5	8	6	3	3	1	2			1	9	1	
Eleocharis palustris	V	I	III	II		9	7	5	10	10					1		4		5		3					
Hippuris vulgaris	IV	I			III	3	3		1	1					1											1
Equisetum fluviatile	I	V	III	V				3			9	6	5	9	8	8	4		3		4	2	3	1	3	
Lemna minor	I	IV	II			2						3		3	1	2			3							
Ranunculus lingua		III		II							4	8	6								6					
Glyceria fluitans			V														7	4	6	1						
Juncus effusus	I	I	V	II			1									1	2	1	1	2				4		
Nasturtium officinale			IV															8	5	8						
Epilobium palustre	I		IV	II			1										3	3		2		3			1	
Sparganium erectum	I	I	IV	V	III		3									2	6	3		3	8	2	9	2		1
Agrostis stolonifera	II	I	II	V				9		3			4				2				8	7	7	4		
Carex acutiformis					V																				10	10
Myosotis scorpioides	II	I	II	III	V			6		2				5					1				1	3	2	1
Caltha palustris	II	I	III	III	III			1		3						2	2	1			5			1		2
Galium palustre	III	III	II	II		5	3			2		1	5			2			1					3		
Mentha aquatica	III	II	III	II		5	3			3			1			2	3	3				3				
Menyanthes trifoliata	II	III		II		6				2	5	9	5								1					
Polygonum amphibium	I	II		II				2							2	3								1		
Potentilla palustris	I	I	II			3										1	3									
Ranunculus flammula	II		II	II					2	1									5					1		
Calliergon cuspidatum	I				III				2																1	
Carex nigra	I						7																			
Utricularia vulgaris	I					6																				
Calliergon giganteum	I					3																				
Carex disticha	I	I						3					2													
Veronica scutellata	I		II		III					3									2						1	
Veronica beccabunga	I		III					2										1		1						
Phalaris arundinacea		I		III												3					1			2	1	
Eurhynchium praelongum		I											5													
Algal mat		I												7												
Potamogeton polygonifolius		I													6											
Juncus acutiflorus			III	II													2		1			2				
Deschampsia cespitosa cespitos			II	II																1		3				
Holcus lanatus			III	II															1	2		5				
Eriophorum angustifolium				II																				3		
Cicuta virosa				II																				5		
Carex paniculata				II																				2		
Epilobium angustifolium				II																				4		
Salix cinerea (g)				II	V																			1	1	1
Filipendula ulmaria				II	III																			1		2
Number of species per sample						12	12	9	6	11	4	8	9	5	7	11	12	10	15	9	8	8	5	18	11	7

Table 2.24. Vegetation table showing the species composition of individual quadrats representing *Phragmites australis* and *Phalaris arundinacea* reedbed vegetation

Species	Frequency score		*Phragmites australis* reedbed — Domin abundance scores for individual quadrats										*Phalaris arundinacea* reedbed				
	RPG	RPL															
Phragmites australis	V		10	6	9	10	10	8	10	10	10	10					
Galium palustre	IV	I		1	1	1	1	2		3	2	2					2
Mentha aquatica	III	I			6		5	1	3	3		8					1
Calliergon cuspidatum	III	I	2		4	1				4	2				2		
Phalaris arundinacea		V											10	8	8	10	10
Angelica sylvestris	I	III	I										1	1	3		
Equisetum fluviatile	II	II	3			2	5					5			2		3
Filipendula ulmaria	II	II	2		4						5			7	5		
Agrostis stolonifera	I	I								1	2						2
Potentilla palustris	I	I		3	1												3
Polygonum amphibium	I	I										1			3		
Salix cinerea (c)	I	II		9	9								2	4			
Urtica dioica	I	II						1			1		5	1			
Lemna minor	I	I					3					3				3	
Epilobium palustre	I	I								2							4
Caltha palustris	I						1		1								
Calliergon cordifolium	I			5						2							
Eurhynchium praelongum	I							8	1								
Hippuris vulgaris	I			1								4					
Carex rostrata	II			2	1							5					
Myosotis scorpioides	II								3		2	5					
Juncus acutiflorus	I				1												
Sparganium erectum	I											3					
Carex disticha	I				1												
Valeriana dioica	I				1												
Thuidium tamariscinum	I				1												
Betula pubescens (c)	I				2												
Myosotis laxa caespitosa	I						1										
Typha latifolia	I								1								
Cardamine pratensis	I									2							
Holcus lanatus	I										2						
Dryopteris carthusiana	I				1												
Mnium hornum	I				3												
Brachythecium rutabulum	I										1						
Juncus effusus		I														1	
Lychnis flos-cuculi		I													1		
Valeriana officinalis		I													3		
Galium aparine		II											1	3			
Calypogeia muelleriana		I													2		
Arrhenatherum elatius		I													2		
Cicuta virosa		I															1
Deschampsia cespitosa		I														1	
Carex paniculata		I												5			
Epilobium angustifolium		I													2		
Plagiomnium affine		I															3
Number of species per sample			5	7	15	4	7	5	6	8	9	10	5	7	11	4	9

Sparganium erectum-Agrostis stolonifera species-poor community (table 2.23)

Constant species: *Sparganium erectum, Agrostis stolonifera, Equisetum fluviatile*

Frequently found at the edges of sites, along drains or around shallow pools within sites.

Carex acutiformis species-poor community (table 2.23)

Constant species: *Carex acutiformis, Myosotis scorpioides*

A community sometimes found at the edges of sites, or bodies of open water.

Phalaris arundinacea reedbed (table 2.24)

Constant species: *Phalaris arundinacea*

Reedbeds dominated by *Phalaris arundinacea* often occur in dried out areas at the edges of sites and on the banks of open water.

Phragmites australis reedbed (table 2.24)

Constant species: *Phragmites australis*

[*Galium palustre*]

This community occurs in both very wet and very dry conditions. The reeds are often very tall and dense and often only thinned if the community occurs beneath fen carr when sometimes some *Veronica beccabunga* and *Calliergon cordifolium* can gain a foothold. *Galium palustre* often straggles amongst the reeds and *Eurhynchium praelongum* sometimes grows epiphytically on exposed rhizomes.

2.3.4 SYNONYMY WITH OTHER CLASSIFICATION SCHEMES

The synonymy between the Ward's classification and other comprehensive mire classification schemes is presented in table 2.25. The *Carex dioica - Carex hostiana* community, *Carex rostrata - Sphagnum recurvum* community and the *Filipendula ulmaria* tall herb fen defined above correspond well with the N.V.C. M10 *Carex dioica -Pinguicula vulgaris* mire, M4 *Carex rostrata - Sphagnum recurvum* mire and M27 *Filipendula ulmaria - Angelica sylvestris* tall herb fen communities respectively. Other communities show broad similarities to N.V.C communities but are not adequately described by these alone. The M9 *Carex rostrata - Calliergon cuspidatum* rich-fen community comprises two sub-communities but the classification of the Borders fens vegetation data identifies 3 communities, one with 3 variants, which could all be subsumed within M9. The latter community, the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, has clear similarities with M9b *Carex diandra-Calliergon cuspidatum* sub-community and incorporates the *Circuetosum* subassociation of the *Acrocladio-Caricetum*

Table 2.25. The plant communities of the Scottish Borders fens and their affinities to communities described in recent comprehensive classifications of rich-fen vegetation (Wheeler 1975, 1980a,b,c) and mire vegetation (National Vegetation Classification, Rodwell 1991, 1994).
* The cluster (end-group) in the Ward's classification procedure from which the plant communities were derived. The species-poor fen and swamp communities were subjectively grouped on the basis of dominance of particular species.

HABITAT TYPE / PLANT COMMUNITY	*CODE*	*Ward's Binary cluster**	*Counterpart N.V.C. community*	*Counterpart rich-fen community (Wheeler 1980a, b, c)*
Rich-fen				
Acidified and wooded fen	FAW	1		
Filipendula ulmaria tall herb fen	FTH	3	M27 *Filipendula ulmaria - Angelica sylvestris* mire	Filipendulion
Juncus acutiflorus rush pasture	FRP	2	M23 *Juncus acutiflorus - Galium palustre* rush pasture	
Molinia caerulea wet grassland	FMC	2	M25 *Molinia caerulea - Potentilla erecta* mire	Fen meadow
Mixed wet grassland	FWG	4	M26 *Molinia caerulea - Crepis paludosa* mire	*Carex nigra - Sangusorba officinalis* community
Carex dioica - Carex hostiana community	RFF	11	M10 *Carex dioica - Pinguicula vulgaris* mire	*Pinguiculo-Caricetum dioicae*
Carex diandra - Sphagnum contortum community	RFS	7&9	M8 *Carex rostrata - Sphagnum warnstorfii* mire	*Acrocladio-Caricetum diandrae* subassociation *Sphagnetosum*
Carex lepidocarpa - brown moss community	RFB	10	M9a *Carex rostrata - Calliergon cuspidatum* mire, *Campylium stellatum - Scorpidium scorpioides* subcommunity	*Acrocladio-Caricetum diandrae*
Mixed sedge rich-fen	RFM	8	M9 *Carex rostrata - Calliergon cuspidatum* mire	*Acrocladio-Caricetum diandrae*
Carex rostrata-Calliergon cuspidatum community	RFC	5-6	M9 *Carex rostrata - Calliergon cuspidatum* mire	*Acrocladio-Caricetum diandrae*
a) Typical variant (no differentials)	RFCa	5.2	M9 *Carex rostrata - Calliergon cuspidatum* mire and S 27a *Carex rostrata - Potentilla palustris* tall herb fen, *Carex rostrata - Equisetum fluviatile* sub-community	*Acrocladio-Caricetum diandrae* subassociation *Cicutosum*
b) *Carex diandra* variant	RFCb	5.1	M9b *Carex rostrata - Calliergon cuspidatum* mire, *Carex diandra - Calliergon giganteum* sub-community	*Acrocladio-Caricetum diandrae*
m) Miscellaneous variant	RFCm	6		

Table 2.25 cont.

HABITAT TYPE / PLANT COMMUNITY	*CODE*	*Ward's Binary cluster**	*Counterpart NVC community*	*Counterpart rich-fen community (Wheeler 1980a, b, c)*
Bog				
Eriophorum vaginatum - Sphagnum papillosum community	BOG	14	M18 *Erica tetralix - Sphagnum papillosum* raised and blanket mire M21 *Narthecium ossifragum - Sphagnum papillosum* valley mire	
Poor-fen				
Carex rostrata - Sphagnum recurvum community	POR	15	M4 *Carex rostrata - Sphagnum recurvum* mire	
Species-poor fen and swamp				
Carex rostata - Potentilla palustris species-poor community	FSM	13	S27a *Carex rostrata - Potentilla palustris* tall herb fen, *Carex rostrata - Equisetum fluviatile* sub-community	*Potentillo-Caricetum rostratae* community
Carex rostata species-poor community	FSC	12.1	S9 *Carex rostrata* swamp	
a) Dominant *Carex rostata* variant	FSCa	12	S9a *Carex rostrata* swamp, *Carex rostrata* sub-community	
b) Dominant *Menyanthes trifoliata* variant	FSCb	12.2	S9b *Carex rostrata* swamp, *Menyanthes trifoliata* sub-community	
Equisetum fluviatile Species-poor community	FSQ	12.2	S10b *Equisetum fluviatile* swamp	
Eleocharis palustris species-poor community	FSE	13	S19 *Eleocharis palustris* swamp	*Potentillo-Caricetum rostratae* community
Carex acutiformis species-poor community	FSA	13	S7 *Carex acutiformis* swamp	
Glyceria fluitans species-poor community	FSG	13	S22 *Glyceria fluitans* swamp	
Sparganium erectum - Agrostis stolonifera species-poor community	FSS	13	S14 *Sparganium erectum* swamp	
Phragmites australis reedbed	RPG	12.11	S4 *Phragmites australis* swamp and reedbeds	Species-poor community dominated by *Phragmites australis*
Phalaris arundinacea reedbed	RPL	12.11	S28 *Phalaris arundinacea* tall herb fen	

diandrae identified by Wheeler (1980b) as the typical variant (a). The mixed sedge community and the *Carex lepidocarpa* - brown moss communities represent respectively species-rich and relatively species-poor versions of base-rich rich-fen vegetation. These vegetation types are often developed as quaking vegetation rafts and in seepage areas on solid peat many examples are transitional to the *Carex dioica - Carex hostiana* community in their composition. They are broadly synonymous with the *Acrocladio - Caricetum diandrae* association of Wheeler (1980b) and base-rich examples of M9 generally. Another related community identified in the Scottish Borders data is the *Carex diandra - Sphagnum contortum* community. Wheeler described this community from Beanrig Moss (Wheeler 1980b) and placed it within the *Acrocladio - Caricetum diandrae* nodum as the *Sphagnetosum* subassociation. This community appears to be synonymous with the N.V.C. M8 *Carex rostrata-Sphagnum warnstorfii* mire which is described as an exclusively upland community in the N.V.C. description, based on the data of McVean and Ratcliffe (1962). The examples of this related *Carex diandra - Sphagnum contortum* community in the Borders fens may represent a lowland expression of this community.

The reedbed and species-poor fen and swamp communities presented are broadly synonymous with their N.V.C. counterparts.

Rich-fen meadow communities comprise *Juncus acutiflorus* rush pasture, *Molinia caerulea* wet grassland, Mixed wet grassland (*Carex nigra - Holcus lanatus*) community (this contains vegetation placed in the *Carex nigra-Sanguisorba officinalis* community described by Wheeler (1980c)) and acidified wet grassland. Samples within these communities correspond to N.V.C. M23a *Juncus acutiflorus - Galium palustre* rush pasture, M25 *Molinia caerulea-Potentilla erecta* mire and M26 *Molinia caerulea - Crepis paludosa* mire communities although these communities were not distinguished by the classification procedure.

Some N.V.C. communities assigned by the MATCH analysis to samples of vegetation were not identified by the classification procedures. Most of these, for example the M5 *Carex rostrata - Sphagnum squarrosum* mire community, were under-represented in the data and where this type of vegetation occurred it was often as a mosaic of *Sphagnum* hummocks within *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* fen or *Carex rostrata - Potentilla palustris* species-poor fen and swamp vegetation and was included in these plant communities.

Fen carr vegetation (N.V.C. W3 *Salix pentandra - Carex rostrata* fen carr) was also not distinguished as a distinct community in the classification procedures probably because trees tend to occur as a canopy over a wide range of vegetation types and their main impact is on the structure, and not necessarily the floristic composition, of the vegetation.

2.3.5 SPECIES RICHNESS AND ENVIRONMENTAL CONDITIONS ASSOCIATED WITH SCOTTISH BORDERS FENS PLANT COMMUNITIES

Mire plant communities often occur under a range of environmental conditions and are not easily separated on the basis of the range of values of pH and conductivity of the mire waters in which they occur, or on the numbers of characteristic species they contain (Sjors 1950). Each vegetation type can occur under a wide range of environmental conditions (table 2.26) and the numbers of characteristic species present in each vegetation type is very variable (Table 2.27). Generally the pH and electrical conductivity of fen water recorded from quadrats representing acidified plant communities (*Carex rostrata - Sphagnum recurvum* poor-fen, *Eriophorum vaginatum - Sphagnum papillosum* bog and acidified and wooded rich-fen) were lower than those recorded from quadrats representing other rich-fen and species-poor plant communities. Rich-fen and species poor fen and swamp vegetation are difficult to differentiate on the basis of pH and electrical conductivity of the interstitial water with which they are associated.

Rich-fen communities contain the most species per unit area and species-poor fen and swamp the least (figure 2.3). Rare fen species are also concentrated in the rich-fen communities (figure 2.4). Many nationally and locally scarce plant species occur in the Scottish Borders fens (table 2.28). These tend to be more abundant in rich-fen communities, in particular the *Carex dioica - Carex hostiana* community and the *Carex diandra - Sphagnum contortum* community.

Table 2.28. Nationally rare plant species and their occurrence within plant communities in the Borders fens.

Species	*Plant community*
Eriophorum latifolium	*Carex dioica - Carex hostiana* community
Pyrola rotundifolia	*Carex diandra - Sphagnum contortum* community
Calamagrostis stricta	*Molinia caerulea* fen meadow community
Cicuta virosa	*Carex rostrata - Potentilla palustris* species poor fen and swamp
Cinclidium stygium	*Carex diandra/lepidocarpa* - brown moss rich-fen
Homalothecium nitens	*Carex diandra - Sphagnum contortum* community *Carex dioica - Carex hostiana* community
Sphagnum contortum	*Carex diandra - Sphagnum contortum* community
Sphagnum imbricatum	*Eriophorum vaginatum - Sphagnum papillosum* community

If certain plant communities were confined to a narrow range of environmental conditions then the variation in the measurements of environmental variables recorded from different communities would be small between samples representing the same community. If this was the case then the variation found in measurements of pH and electrical conductivity from samples within communities derived from different classifications could be used as a basis for assessing the validity of the plant community classifications. The 'best' classification would have the lowest variation in environmental values in each community. However the different classifications derived in this study cannot be easily separated on the basis of differences in the co-efficient of variation for pH and conductivity of the interstitial water. The co-efficients of variation for the

Table 2.26. Mean values of pH and electrical conductivity (E.C., µS cm $^{-1}$) of fen waters from quadrats representing different plant communities.

		pH			*µS cm^{-1}*			C.O.V.	
Plant community	*code*	mean	*min*	*max*	mean	*min*	*max*	*pH*	*E.C.*
Acidified / wooded fen	FAD	**5.5**	4.80	5.97	**156.2**	82	287	9.2	46.2
Filipendula ulmaria tall herb fen	FTH	**6.8**	6.38	7.32	**445.0**	196	823	4.3	42.5
Molinia caerulea / Juncus acutiflorus fen meadow	FM	**6.5**	6.06	7.14	**264.7**	122	455	6.5	41.1
Mixed wet grassland	FWG	**6.2**	4.98	7.28	**334.6**	95	603	9.5	48.5
Carex rostrata - Calliergon cuspidatum miscellaneous variant	RFCm	**6.4**	4.76	7.57	**225.2**	83	432	9.2	45.4
Carex rostrata - Calliergon cuspidatum typical variant	RFCa	**6.6**	5.62	7.33	**363.9**	171	601	7.0	29.8
Carex rostrata - Calliergon cuspidatum community ,Carex diandra variant	RFCb	**6.4**	5.58	6.96	**348.6**	127	578	5.7	41.2
Carex lepidocarpa - brown moss rich-fen	RFB	**6.6**	6.24	7.40	**343.2**	104	471	4.6	27.2
Mixed sedge rich-fen	RFM	**6.2**	5.30	7.10	**249.4**	107	477	7.6	50.6
Carex dioica - Carex hostiana community	RFF	**6.5**	5.86	7.16	**332.0**	161	444	8.2	33.3
Carex diandra - Sphagnum contortum community	RFS	**6.2**	5.20	7.02	**296.5**	83	478	10.2	47.8
Carex rostrata - Sphagnum recurvum community	POR	**5.0**	3.79	6.56	**114.3**	59	360	20.4	83.3
Eriophorum vaginatum - Sphagnum papillosum community	BOG	**4.7**	3.49	6.45	**214.9**	73	685	21.6	105.2
Carex rostrata - Potentilla palustris species-poor community	FSM	**6.5**	5.40	7.13	**327.2**	90	665	6.0	53.0
Carex rostrata species-poor community, *Carex rostrata* variant	FSCa	**6.5**	6.02	6.99	**344.0**	162	652	4.8	36.0
Carex rostrata species-poor community, *Menyanthes trifoliata* variant	FSCb	**6.5**	5.64	7.53	**449.6**	113	857	7.9	45.0
Equisetum fluviatile species-poor community	FSQ	**6.4**	5.74	6.82	**353.0**	231	449	7.1	23.6
Eleocharis palustris species-poor community	FSE	**5.8**	5.40	6.02	**223.7**	98	328	5.7	52.1
Carex acutiformis species-poor community	FSA	**6.6**	6.40	6.71	**293.0**	240	346	3.3	25.6
Sparganium erectum- Agrostis stolonifera species-poor community	FSS	**6.8**	6.57	7.14	**423.7**	259	550	4.2	35.2
Glyceria fluitans species-poor community	FSG	**6.8**	6.26	7.43	**436.5**	365	571	7.3	21.1
Phragmites australis reedbed	RPG	**6.5**	5.64	7.12	**382.0**	142	695	8.1	55.9
Phalaris arundinacea reedbed	RPL	**6.4**			**401**				

Table 2.27. Mean species-richness per quadrat of different Scottish Borders fen plant communities.

		Total species richness			Rare fen species richness			Bog species richness			Poor-fen species richness			Rich-fen species richness		
Plant community	*code*	*mean*	*min*	*max*	*mean*	*min*	*max*	*mean*	*min*	*max*	*mean*	*min*	*max*	*mean*	*min*	*max*
Acidified / wooded fen	FAW	**25.5**	21	27	**1.6**	0	3	**4.8**	2		**11.1**	6	14	**14.1**	6	20
Filipendula ulmaria tall herb fen	FTH	**19.2**	12	32	**0.5**	0	3	**0.7**	0	2	**6.8**	2	11	**13.5**	7	22
Mixed wet grassland	FWG	**17.7**	11	23	**1.2**	0	4	**0.8**	0	2	**7.4**	3	11	**11.6**	4	17
Molinia caerulea wet grassland	FMC	**22.5**	21	23	**0.5**	0	2	**2.3**	2	3	**8.8**	8	10	**14.8**	13	18
Juncus acutiflorus rush pasture	FRP	**28.2**	24	33	**0.5**	0	1	**2.2**	1	4	**7.7**	5	12	**15.8**	13	21
Carex rostrata - Calliergon cuspidatum miscellaneous variant	RFCm	**24.3**	15	39	**2.3**	0	7	**2.1**	0	5	**10.0**	3	18	**18.4**	9	31
Carex rostrata - Calliergon cuspidatum typical variant	RFCa	**15.7**	9	23	**1.5**	0	4	**1.0**	0	2	**7.5**	4	11	**13.8**	9	21
Carex rostrata - Calliergon cuspidatum community Carex diandra variant	RFCb	**21.8**	16	28	**3.4**	2	8	**2.3**	1	4	**11.3**	7	14	**18.9**	13	25
Carex lepidocarpa brown moss rich-fen	RFB	**20.5**	13	29	**3.1**	0	6	**2.6**	1	4	**12.6**	6	19	**18.1**	10	25
Mixed sedge rich-fen	RFM	**32.0**	20	41	**4.0**	0	7	**3.0**	2	6	**13.8**	8	18	**25.1**	16	33
Carex dioica - Carex hostiana community	RFF	**27.6**	15	36	**4.8**	1	9	**3.2**	1	6	**12.6**	8	20	**20.2**	11	29
Carex diandra - Sphagnum contortum community	RFS	**31.5**	19	52	**7.7**	2	13	**4.8**	2	8	**16.5**	11	23	**24.5**	16	39
Carex rostrata - Sphagnum recurvum community	POR	**16.4**	6	25	**0.8**	0	2	**5.1**	2	8	**11.6**	6	18	**9.3**	4	15
Eriophorum vaginatum - Sphagnum papillosum community	BOG	**17.4**	13	27	**0.1**	0	1	**9.3**	7	13	**12.3**	7	18	**7.0**	4	13
Carex rostrata - Potentilla palustris species-poor community	FSM	**12.9**	4	22	**1.3**	0	3	**0.9**	0	3	**6.8**	2	11	**11.0**	4	18
Carex rostrata species-poor community, *Carex rostrata* variant	FSCa	**9.1**	4	15	**0.4**	0		**0.1**	0	1	**4.0**	2	6	**6.9**	3	11
Carex rostrata species-poor community, *Menyanthes trifoliata* variant	FSCb	**6.9**	4	14	**0.3**	0	1	**1.2**	0	2	**4.8**	3	9	**5.7**	3	10
Equisetum fluviatile species-poor community	FSQ	**7.3**	4	11	**0.7**	0	2	**0.5**	0	1	**3.5**	2	5	**5.5**	3	9
Eleocharis palustris species-poor community	FSE	**10.0**	6	12	**0.8**	0	2	**0.4**	0	1	**5.0**	3	6	**8.0**	5	11
Carex acutiformis species-poor community	FSA	**9**	7	11	**1**	0	2	**0**			**2**	0	4	**8**	6	10
Sparganium erectum- Agrostis stolonifera species-poor community	FSS	**9.8**	5	18	**0.8**	0	2	**0.5**	0	1	**3.5**	2	5	**7.5**	4	14
Glyceria fluitans species-poor community	FSG	**11.5**	9	15	**0.5**	0	2	**0**			**5.5**	3	8	**7.75**	4	10
Phragmites australis reedbed	RPG	**7.6**	4	15	**0**			**0**			**3.3**	1	6	**5.8**	3	12
Phalaris arundinacea reedbed	RPL	**7.2**	4	11	**0.2**	0	1	**0**			**1.4**	0	4	**4.6**	2	7

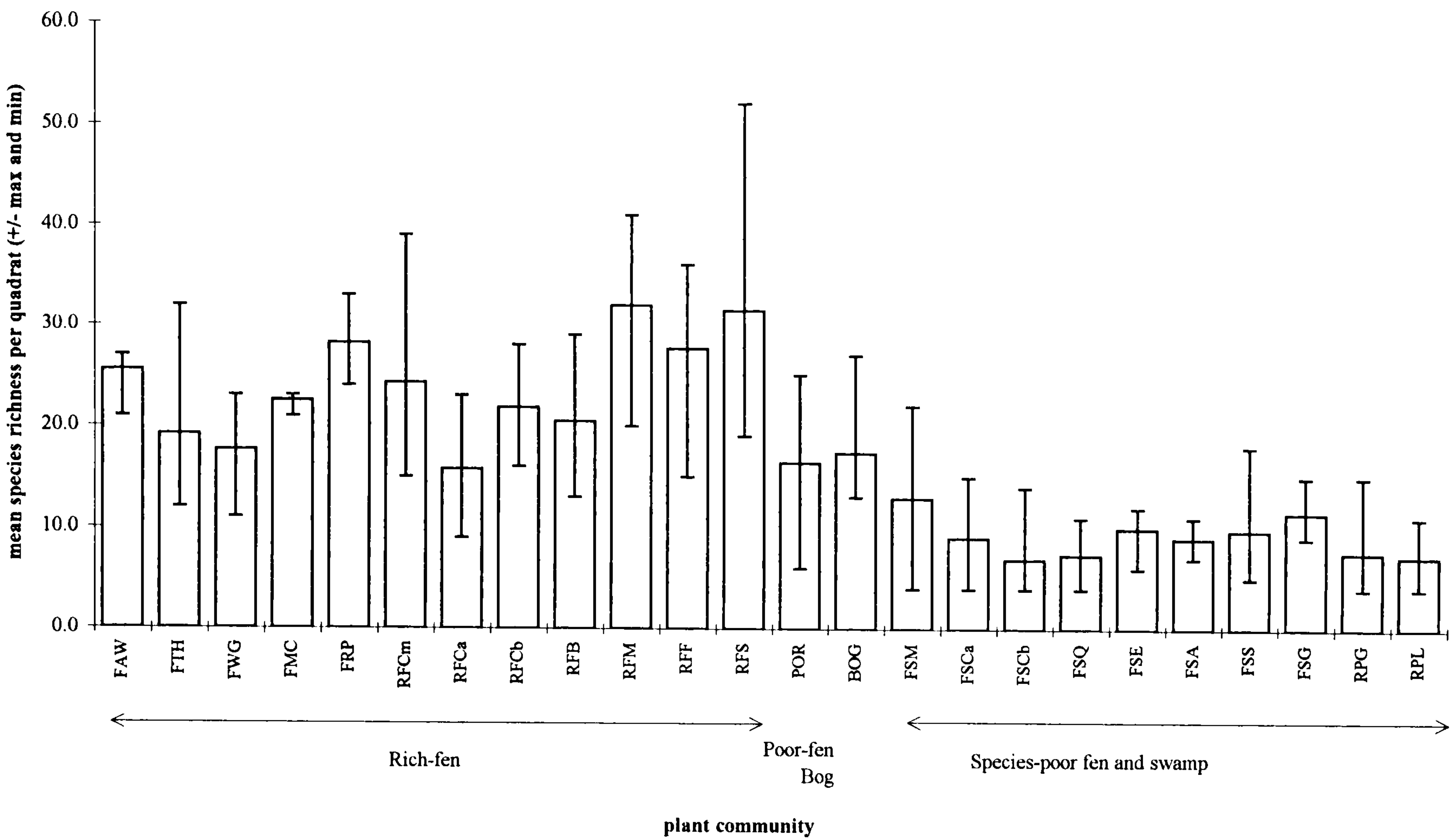


Figure 2.3. Mean total species richness per quadrat (+/- maximum and minimum) of different rich-fen, poor-fen, bog and species-poor fen and swamp plant communities in the Scottish Borders fens. Plant community codes follow those in table 2.25.

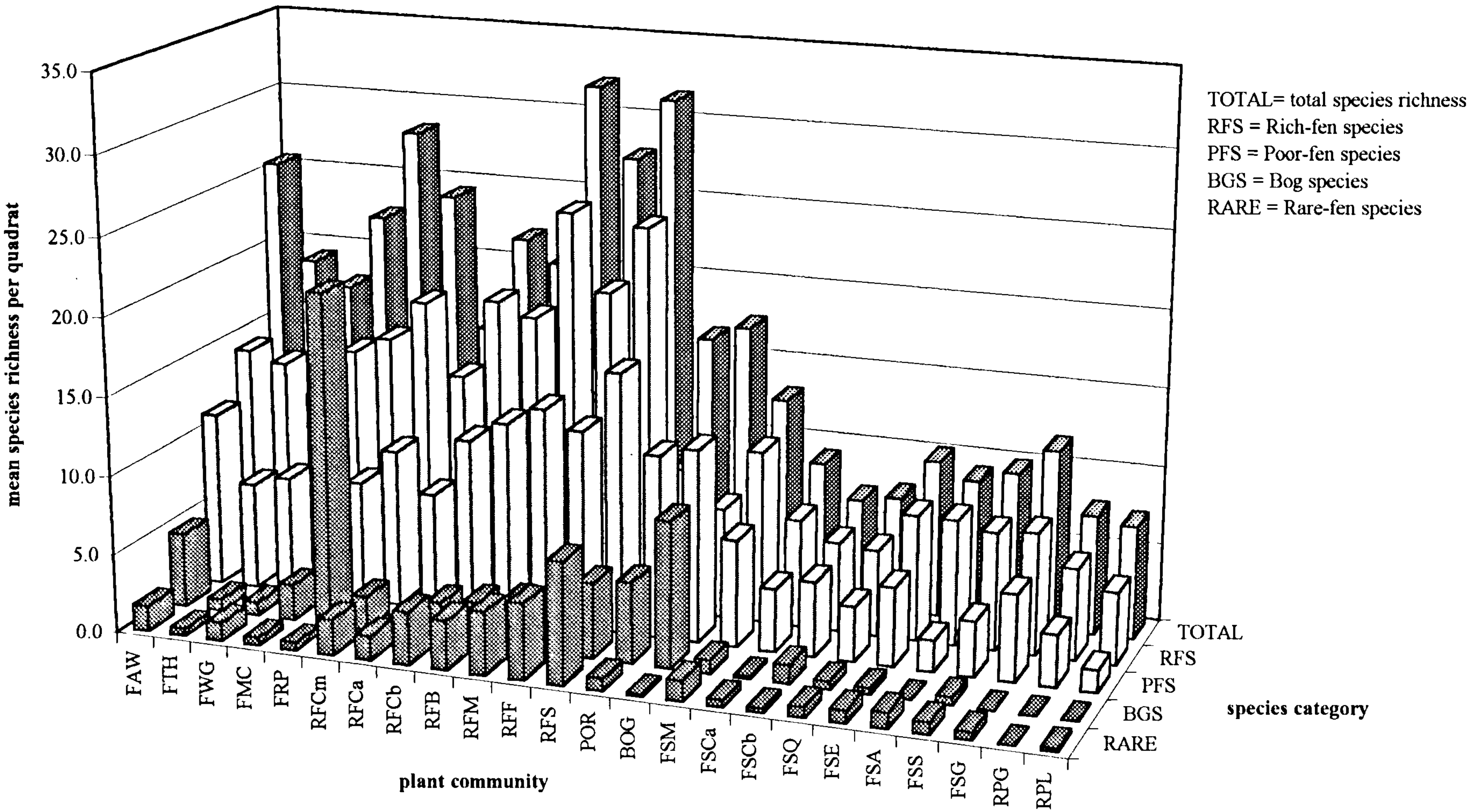


Figure 2.4. Mean species richness of different plant communities recorded from the Scottish Borders fens. Species in each category are listed in Appendix 3. Plant community codes follow table 2.25.

presented plant communities, the Ward's binary and Ward's quantitative classifications are presented in table 2.29. The variation found is probably largely due to microtopographical vegetation zonation and corresponding large vertical variation in water conditions found in the Scottish Borders fens.

Spot measurements of pH and chemical conductivity showed that all the plant communities occurred under a wide range of environmental conditions (table 2.26). The mean pH was 6.32 (range 3.49-7.57) and the mean electrical conductivity was 318 μS/cm (range 59-857). Based on the coefficient of variation (C.O.V.) of pH and electrical conductivity within each community described above the most variable communities were:

- pH - *Carex rostrata* - *Sphagnum recurvum* poor-fen community (C.O.V. 20.4) and *Eriophorum vaginatum* - *Sphagnum papillosum* bog community (C.O.V. 21.6).
- Electrical conductivity - *Carex rostrata* - *Sphagnum recurvum* poor-fen community (C.O.V. 83.3), *Eriophorum vaginatum* - *Sphagnum papillosum* bog community (C.O.V. 105.2), *Phragmites australis* reedbed (55.9), *Carex rostrata-Potentilla palustris* species poor community (C.O.V. 52.1)

The least variable communities were:

- pH - *Carex acutiformis* species- poor fen and swamp (C.O.V. 3.3), *Sparganium erectum* species- poor community (C.O.V. 4.2), *Filipendula ulmaria* tall herb fen (C.O.V. 4.3), *Carex lepidocarpa*- brown moss fen (C.O.V. 4.6), *Carex rostrata* species- poor community (C.O.V. 4.8)
- Electrical conductivity - *Glyceria fluitans* species- poor community (C.O.V. 21.1), *Equisetum fluviatile* species- poor community (C.O.V. 23.6), *Carex acutiformis* species- poor community (C.O.V. 25.6), *Carex lepidocarpa* - brown moss community (C.O.V. 27.2), *Carex rostrata* - *Calliergon cuspidatum* / *Plagiomnium rostratum* community, typical variant (C.O.V. 29.8)

2.3.6 ZONATION AND CONTACT COMMUNITIES

Plant communities often appear as distinct zones. There are two main scales of zonation, small scale, vertical (microtopographical) and large scale, horizontal (macrotopographical). Often a boundary between vegetation types (macrotopographical zonation) occurs as a small scale mosaic with microtopographical zonation. However sometimes small scale mosaics are extensive and the microtopographical zonation is regarded as a feature of the plant community.

Table 2.29. Co-efficient of variation ((standard deviation / mean)*100) of pH and electrical conductivity (E.C.) of interstitial water of quadrats representing broadly synonymous plant communities derived from different classification procedures. Lower values of the co-efficient of variation (C.O.V.) indicate smaller variation. The end-group numbers for the Ward's Quantitative and Binary classifications correspond to those in figure 2.1 and table 2.3, and figure 2.2 and table 2.4 respectively.

	Scottish Borders fens plant communities			Ward's Binary Classification			Ward's Quantitative Classification		
		C.O.V.			C.O.V.			C.O.V.	
PLANT COMMUNITY	Code	pH	E.C.	End-group	pH	E.C.	End-group	pH	E.C
Rich-fen									
Acidified / wooded fen	FAW	9.2	46.2	1	11.9	48.3	-	-	-
Filipendula ulmaria Tall Herb Fen	FTH	4.3	42.5	3	4.3	42.5	3	9.7	37.2
Juncus acutiflorus Rush Pasture	FRP	6.5	41.1	2	7.0	42.9	2	8.2	61.9
Molinia caerulea wet grassland	FMC						2 &9	10.8	54.6
Mixed wet grassland	FWG	9.5	48.5	4	10.7	46.8	2	8.2	61.9
Carex dioica - Carex hostiana community	RFF	8.2	33.3	11	8.2	33.0	8	7.5	29.2
Carex diandra - Sphagnum contortum community	RFS	10.2	47.8	7&9	10.2	47.8	-	-	-
Carex lepidocarpa - brown moss community	RFB	4.6	27.2	10	4.6	27.2	6	6.5	27.8
Mixed sedge rich-fen	RFM	7.6	50.6	8	7.6	50.6	7	7.5	29.2
Carex rostrata-Calliergon cuspidatum community	RFC			5-6			10	10.5	47.5
a)Typical variant (no differentials)	RFCa	7.0	29.8	5.2	7.0	29.8	11	5.9	42.3
b) *Carex diandra* variant	RFCb	5.7	41.2	5.1	5.7	41.2	-	-	-
m) Miscellaneous variant	RFCm	10.7	44.2	6	10.7	44.2	-	-	-
Bog									
Eriophorum vaginatum - Sphagnum papillosum bog	BOG	21.6	105.2	15	21.6	105.2	18	19.4	106.9
Poor-fen									
Carex rostrata - Sphagnum recurvum poor fen	POR	20.4	83.3	14	20.4	83.3	17	19.2	73.8

Table 2.29 cont.

PLANT COMMUNITY	Scottish Borders fens plant communities			Ward's Binary Classification			Ward's Quantitative Classification		
		C.O.V.			C.O.V.			C.O.V.	
	Code	pH	E.C.	End-group	pH	E.C.	End-group	pH	E.C.
Species-poor fen and swamp									
Carex rostata-Potentilla palustris species-poor community	FSM	5.9	52.9	-	-	-	14	7.9	42.8
Carex rostata species-poor community	FSC			12.1	6.5	58.3	12	7.4	39.8
a) Dominant *Carex rostata* variant	FSCa	4.8	35.9				13	8.3	53.7
b) Dominant *Menyanthes trifoliata* variant	FSCb	7.9	45.0	12.2	7.3	44.3	16	7.2	53.2
Equisetum fluviatile species-poor community	FSQ	7.1	23.6	12.2					
Glyceria fluitans species-poor community	FSG	7.3	21.1	13.1	6.8	44.5	15	11.6	20.5
Eleocharis palustris species-poor community	FSE	5.7	52.1						
Sparganium erectum-Agrostis stolonifera species-poor community	FSS	4.2	35.2	13.2	3.9	35.1			
Carex acutiformis species-poor community	FSA	3.3	25.6				5	-	-
Phalaris arundinacea reedbed	RPL	-	-	12.1a	7.9		1	9.4	47.4
Phragmites australis reedbed	RPG	8.1	55.9				15	11.6	47.4

2.3.6.1 Microtopographical zonation

Microtopographical zonation is usually associated with hummock-hollow vegetation where different components of the vegetation within a community create a mosaic over a small area and the vegetation appears complex and heterogeneous in structure and composition. There is often a difference in the derivation of water supplying the different components of the vegetation which is partially responsible for the differing composition . Also species typical of different components may mix because some species are deeper rooting and can grow through the more shallow rooting vegetation merging the components and therefore justifying their classification as one vegetation unit. This situation often occurs on rafts of vegetation where, for example, deep rooting *Phragmites australis*, *Carex rostrata* and *Menyanthes trifoliata* (raft pioneers) can grow though poor fen vegetation which has developed on the surface of the raft (Kulczynski 1949, Van Wirdum 1991).

Microtopographical zonation is frequently found in the *Carex diandra - Sphagnum contortum* community (e.g. Whitehaughmoor Moss, Beanrig Moss, Woolaw Loch, Branxholm Wester Loch), *Carex dioica - Carex hostiana* community (e.g. Beanrig Moss, Mabonlaw Moss, Threephead Moss, Muirfield Moss), local development of bryophyte hummocks within *Carex rostrata - Potentilla palustris* species-poor fen community (e.g. Nether Whitlaw Moss, Long Moss), *Eriophorum vaginatum - Sphagnum papillosum* community (e.g. Blind Moss, Long Moss, Branxholm Wester Loch, Hutlerburn Loch).

2.3.6.2 Macrotopographical zonation

Macrotopographical zonation concerns the arrangement of vegetation types within the fen site. At some sites the vegetation types are arranged in striking, often concentric, zones. Examples of vegetation zonation in the Scottish Borders fens are presented in table 2.30.

Table 2.30. Examples of macrotopographical zonation found at Borders fen sites.

Edge			*Centre*	*Examples*
Carex rostrata Calliergon cuspidatum / Plagiomnium rostratum community	*Carex rostrata* species poor fen with scrub development		Open water pools	Kippilaw Moss Murder Moss Tandlaw Moss
Carex dioica - Carex hostiana community	*Carex diandra-Sphagnum contortum* community	*Carex rostrata-Sphagnum recurvum* community	*Eriophorum vaginatum-Sphagnum papillosum* community	Branxholm Wester Loch Blind Moss Long Moss Hutlerburn Loch Brown Moor Heights
Carex rostrata Calliergon cuspidatum / Plagiomnium rostratum community or *Phragmites australis* reedbed	*Carex rostrata - Sphagnum recurvum* community		(*Eriophorum vaginatum-Sphagnum papillosum* community)	Nether Whitlaw Moss Greenside Moss Groundistone Moss

These patterns of zonation may represent phases in autogenic hydroseral succession where their occurrence is determined by site factors such as basin shape, history and chemical conditions (Van Wirdum *et al.* 1992). However vegetation zones may also be determined by other factors such as fluctuating water levels (Tallis 1973), nutrient inputs from the edges of sites, differential grazing etc. Therefore these sequences may bear little relation to autogenic successional sequences.

2.4 Discussion

2.4.1 LIMITATIONS OF CLASSIFICATIONS AND SAMPLING STRATEGY

The aims of this part of the study were to describe the plant communities of the Scottish Borders fens using a range of multivariate classification procedures, to compare these communities to those described in comprehensive classification schemes of British fen vegetation and to relate the plant communities to broad environmental conditions found in the Scottish Borders fens.

Mire vegetation in Britain and Northern Europe has been broadly categorised into rich-fen, poor fen and bog (Du Rietz 1949, 1954, Sjors 1950). Within these categories several vegetation types have been described and classifications of fen plant communities produced (Wheeler 1980a,b,c). The plant communities described in this part of the study correspond to these habitat categories. Rich-fen habitats in the Scottish Borders fens contain a variety of closely related vegetation types. Poor-fen and bog vegetation types are defined by a small selection of very characteristic vascular plant species and *Sphagnum* species which are not typically abundant in rich-fen vegetation types. Continua between vegetation types were frequently encountered in the Scottish Borders fens. Stands of vegetation which contain elements from more than one plant community (e.g. *Carex diandra - Sphagnum contortum* community) have often been regarded by other workers, and in the National Vegetation Classification, as transitional communities or mosaics so they have been infrequently sampled; however these vegetation types are often very distinctive and persistent and may deserve to be recognised in their own right (Rose 1957, O'Connell 1981).

Some of the problems encountered in the sampling and subsequent classification of the Scottish Borders fens vegetation data were:

- The vegetation at many of the Borders fens has developed as floating rafts of vegetation where the deep rooting, raft-forming species may be receiving a different nutrient supply from the shallow rooting species and bryophyte species growing at the surface. The vegetation in many of these areas is similar sharing the basic suite of pioneer raft species (*Carex rostrata, Carex* *diandra, Menyanthes trifoliata, Equisetum fluviatile*). However subtle differences in the composition of other components of the vegetation, in particular the bryophyte component, may reflect important ecological differences between ostensibly similar vegetation types (Van Wirdum 1991).

- Fen carr is scarce in the Scottish Borders fens. Where present it occurs as a (usually sparse) canopy over various vegetation types with strong compositional parallels to those of open fen. It is difficult to define as a floristically distinct community as it generally has an understorey containing the same species found in the communities without a canopy but the individuals are more scattered and the herb layer and sward is less dense.
- The distinction between plant communities with similar species composition was often blurred, for example between fen meadow and rush pasture where the dominance of either *Molinia caerulea* or *Juncus acutiflorus* became the deciding factor for assigning a sample to a rush pasture or wet grassland community.
- Small scale mosaics of vegetation were also often found, particularly where poor fen was developing within rich-fen and in tussocky vegetation where the tussocks may contain species very different from those of the runnels in-between. These situations were common in the Scottish Borders fens and caused problems when attempting to sample a homogeneous unit of vegetation.

The continuity of the Borders fens vegetation data, much of which consisted of samples that were transitional between different plant communities, caused some problems in its classification. In the classification of vegetation types a data set made up of continuous variables (floristic composition) may become divided on the basis of minor discontinuities or by "arbitrary lines bisecting axes of continuous variation" (Moore 1984). It is consequently difficult to produce a satisfactory classification of vegetation data which represents variations on a unifying theme (O'Connell 1981).

TWINSPAN is known to distort data , particularly beyond the first or second levels of division (van Groenewoud, 1992), and where the quadrats represent a continuum of vegetation types rather than clearly distinctive vegetation types. The TWINSPAN classifications of the Scottish Borders fens quadrat data consisted of a few well defined groups (bog, poor-fen and rich-fen characterised by *Carex dioica*, *Carex flacca* and *Carex hostiana*) fragmented from a large group of samples which were not satisfactorily divided by the programme into smaller units. Therefore the TWINSPAN classifications were disregarded.

The binary Ward's analysis produced a classification on the basis of *floristic* units and where this failed to produce a satisfactory classification (in the case of very species poor fen and swamp vegetation) these samples were subjectively ordered by dominance.

The N.V.C. classification was found to be inadequate in describing the variation found within fine-leaved sedge dominated rich-fen vegetation where 4 distinctive communities described in this study (*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community (3 variants), Mixed sedge rich-fen community, *Carex lepidocarpa* - brown moss community, *Carex diandra - Sphagnum contortum* community) were represented by only 2 sub-communities within the N.V.C. M9 *Carex rostrata - Calliergon cuspidatum* mire community. The communities defined in the N.V.C. appeared to correspond more closely to those derived by the quantitative Ward's analysis. The outcome of this analysis was that in a classification based on quantitative species scores some floristically distinct plant communities were often subsumed into a broader cluster or clusters and the differences in the vegetation which seemed obvious in the field were lost in the classification.

Wheeler's classification of rich-fen vegetation (1980b) described the *Acrocladio cuspidatum-Caricetum diandrae* community with variants more similar to those derived by the Ward's binary classification. Wheeler's (1980a, b, c) classification was based upon an objective binary analysis of the data (Information Analysis) followed by some subjective re-ordering. The National Vegetation Classification was derived by various techniques which included binary and quantitative analyses (Association and Information analysis, Cluster analysis and Indicator species analysis (TWINSPAN)) (Rodwell 1991, 1994), though it is not known exactly what techniques were used for specific parts of the N.V.C. However it appears that at least some of the N.V.C.'s rich-fen communities were derived with an emphasis on species dominance rather than species composition. Also the numbers of samples representative of the M9 community in the N.V.C. were small (24 samples were used to generate M9b (mean species richness 27, range 12-35) and 16 samples were used to generate M9a (mean species richness 23, range 16-33)). It is therefore unlikely that the range of variation found within this community is fully represented in the N.V.C. in its present form.

2.4.2 PROPOSALS FOR THE NATIONAL VEGETATION CLASSIFICATION

Currently the NVC M9a *Carex rostrata - Calliergon cuspidatum* mire, *Campylium stellatum - Scorpidium scorpioides* sub-community contains the most 'base poor' and most 'base rich' examples of this vegetation type. The results of this study suggest that this sub-community should be re-defined to include only 'base-rich' examples and those which are transitional to M10 *Carex* *dioica-Pinguicula vulgaris* community (incorporating the mixed sedge rich-fen community and *Carex lepidocarpa*-brown moss community described in this study).

In addition it is proposed that the *Carex diandra - Sphagnum contortum* community described from the Scottish Borders fens should be included within the NVC M8 *Carex rostrata - Sphagnum warnstorfii* mire as lowland form of the present community and not within M9 *Carex rostrata - Calliergon cuspidatum* mire community.

2.4.3 FEATURES OF THE SCOTTISH BORDERS FENS AND THEIR INFLUENCE ON VEGETATION COMPOSITION

2.4.3.1 Terrestrialization of open water and hydroseral succession

Much of the vegetation of the Scottish Borders fens has developed as quaking vegetation rafts over watery peat or semi-solid peat of varying depths as a result of past excavation of peat and marl deposits. Many plant communities which frequently occur as quaking vegetation rafts share a basic suite of species (*Carex rostrata, Menyanthes trifoliata, Equisetum fluviatile* and *Potentilla palustris*) which are pioneers in raft formation (Van Wirdum 1991). Some of the plant communities described in this part of the study may therefore represent successive stages in the development of a vegetation raft. Plant communities of rafts are often differentiated by their bryophyte flora (which can be very luxuriant) (Segal 1966). As the raft is colonised by additional species, chemical conditions at the vegetation surface may be altered so the vegetation may consist of various components rooted in different layers of the raft and nourished by contrasting water types. The deeper rooting initial raft colonisers, nourished by water beneath the raft, can persist in the vegetation into later successional plant communities (Kulczynski 1949). At Groundistone Moss an area of 'bog' vegetation has developed over a former peat cutting but still has shoots of *Phragmites australis* growing through hummocks of *Sphagnum papillosum*.

The status of sites (cut for peat and / or marl, undisturbed) is investigated in chapter 3 and the processes of raft development are examined in chapter 5 of this study.

2.4.3.2 Fen water chemistry and peat fertility

The Scottish Borders fens are developed in small basins fed by runoff from adjacent land and through discharge of telluric water from the mire margins. The sites are not closed systems; most have inlets and outlets. Where the drainage is effective, usually around the edges of sites, wet grassland and rush pasture vegetation types persist. Species-rich rich-fen vegetation (e.g. *Carex dioica -Carex hostiana* community) thrives on areas of skeletal peat, usually at the mire margins in situations which appear to be affected by seepage of base-rich water. The land surrounding the sites is farmed with varying intensity. Many of the sites are threatened by nutrient enrichment from the surrounding fields. In some areas nutrient inputs have had a dramatic effect on the vegetation of the fens (e.g. rapid expansion and dominance of *Phragmites australis* at Murder Moss) (R. Payne, pers. comm.).

The water chemistry, peat fertility and impact of surrounding land-use on the vegetation of the Scottish Borders fens is investigated in chapter 4 of this study.

2.4.3.3 Site management

Management of fen vegetation can have a dramatic effect on species composition (Wheeler 1983, Wheeler & Shaw 1995a). Most of Scottish Borders fens are fenced and unmanaged although some sites are used as rough grazing for cattle and sheep. Three of the Whitlaw mosses (Beanrig Moss, Blackpool Moss and Murder Moss) are mowed for conservation management. This form of management reduces the dominance of large species which otherwise may shade associates of lower stature. It also prevents the development of scrub. Cattle poaching can create 'hummock-hollow' areas around the margins of sites which can increase the microtopographical zonation of the vegetation. In very wet sites cattle grazing may also be partially responsible for the development of a very swampy 'lagg' around a firm central raft (Selkirk Racecourse Moss, Groundistone Moss, Nether Whitlaw Moss).

The impact of management on the species richness of the Scottish Borders fens is analysed in chapter 6 of this study.

Chapter 3: Stratigraphical Investigations into Past Peat and Marl Extraction and Vegetation Development in the Scottish Borders fens

3.1 Introduction

Peat consists of the partially decomposed remains of plant material. The process of decomposition is retarded due to the decreased activity of aerobic bacteria and soil fauna in waterlogged environments. Plant remains can often be preserved intact in peat for thousands of years and provide a record of the vegetation of the site (macrofossil remains) and of the region (microfossil remains) (Walker 1970).

Peat has been a valuable fuel to humans in lowland Britain before coal became widely available and many fens and bogs have been subject to some degree of peat extraction. In such mires, some or all of the present vegetation has developed in abandoned peat cuttings (White 1930, Lambert *et al.* 1960, Giller & Wheeler 1986, Wheeler & Shaw 1995a). Some sites also contained deposits of marl beneath the peat which was extracted and used as a low grade form of lime to improve agricultural land. There is documentary evidence in the Scottish Borders for both peat and marl extraction at many sites and characteristic drainage structures present at the outflows of sites indicate past peat and / or marl cutting activity (Dodgshon 1978, Robson 1985).

Peat cuttings in fens contain a wide range of vegetation types, many of which are conservationally important (Segal 1966, van Wirdum 1991, Den Held *et al.* 1992, Wheeler 1993) especially where the vegetation has developed as a raft. The Scottish Borders fens support a wide range of raft-forming vegetation types, many of which are regarded as notable plant communities in the U.K. and Europe. Areas of bog vegetation are also present on some sites and these areas are of particular interest as they represent what is often considered to be a characteristic successional "climax" plant community (Walker 1970) where the vegetation surface is isolated from the groundwater and receives nourishment solely from rainwater. Intact peat areas may represent a continuous sequence of mire formation during the current postglacial (Webb & Moore 1982) to the present. However raised bog vegetation also occurs on vegetation rafts, sometimes over peat-cuttings (Walker 1966).

It seems likely that some post-glacial peat has been removed from most of the fens in the central Scottish Borders. The template for post-disturbance site and vegetation development is therefore determined by the history of peat and marl extraction at each particular site, but the occurrence of past peat cutting is sometimes difficult to establish. Peat stratigraphy might be expected to indicate this, but there are some difficulties:

- Stratigraphical discontinuities can be difficult to detect sometimes, especially in situations when the entire site has been uniformly, or completely, stripped;
- Stratigraphical discontinuities can be difficult to interpret (e.g. peat cutting *versus* sudden flooding);
- It is often not known in advance whether any site has been stripped to some extent, so the characteristics of reference material *versus* disturbed material are often uncertain and cannot be assumed *a priori*.

In the field the interface between peat which has accumulated since the cessation of peat and marl operations (post-disturbance peat) and un -modified post-glacial peat (residual peat) can be detected in a peat core with varying degrees of difficulty. It often occurs as a hiatus or fairly definite junction between peat types as at Beanrig Moss (Webb & Moore 1982) where the pale post-glacial muds and clay meet dark, oxidised monocot peat. The interface can also be distinguished by a junction of very solid peat and more detrital loose peat above it (as in the turf ponds of the Norfolk Broads (Giller & Wheeler 1986) and at Kingside Loch in the Scottish Borders (Tight 1987)).

The Scottish Borders Fens are exceptional in having good documentary evidence for disturbance in at least some sites (Robson 1985). This allows the examination of relationships between recent mire stratigraphy and documented disturbance, possibly the best known opportunity in the U.K. The documents describe in detail the drainage and peat and marl extraction operations at some sites. Sometimes these operations were not entirely successful as at Kingside Loch where the site could not be completely drained, so was re-flooded after some peat removal leaving substantial quantities of residual peat (Robson 1985, Tight 1987). Many of the sites where the drainage was very successful were almost completely stripped leaving little but the clay and rock base (Robson 1985). The comparison of the peat stratigraphy together with documentary and visual evidence for past peat cutting at a number of sites permit a co-ordinated reconstruction of the developmental history of the site.

The aims of this part of the study were to compare the peat stratigraphy of sites in conjunction with other evidence for disturbance with a view to:

1. Identifying uncut *versus* cutover sites and the stratigraphical features of cutover and intact peat surfaces;
2. Examining the role of peat and marl extraction in the development of the present vegetation.

3.2 Methods

3.2.1 EVIDENCE OF RECENT SITE HISTORY

Documentary evidence of peat and marl extraction and the past state of sites was investigated using:

- 1st Edition Ordnance Survey maps (c. 1860). These provided crude evidence of the status of sites in the 1860's and the presence or absence of drains;
- Estate records. Some of these are very detailed (for sources see Robson 1985).

The presence of characteristic drainage structures including surface drains, open outflows ('cundys') and stone-built subterranean culverts ('rumbling cundys') (some of which are so deep they have stone lined 'chimneys' as access points for maintenance) was recorded at each site as visual evidence of past disturbance.

3.2.2 PEAT STRATIGRAPHY

3.2.2.1 Reference cores and Uncut peat

Sites, or parts of sites, with well developed raised bog vegetation and lacking any obvious sign of past disturbance were assumed to be intact (i.e. uncut) peat surfaces and peat cores were extracted from these (table 3.1) to provide a reference for un-modified postglacial site development against cores from cutover sites. Comparison of the reference cores with the cores from cutover sites enabled an accurate location of the interface between post-disturbance and residual peat deposits. It is possible that such profiles show a bias towards sites, or part of sites which have a propensity for raised bog development and may therefore not be typical. Equally, however, it seems likely that many of these basins supported some sort of bog before peat extraction.

Table 3.1. Location of reference cores from uncut peat. Locations of cores are presented in Appendix 2 and figure 3.3

Site (Sample site code)	*Suspected status*	*Evidence for suspected status*	*Vegetation type*
Brown Moor Heights (BMH2 & (BMH3)	Uncut	Vegetation	Bog
Blind Moss (BL2)	Uncut	Vegetation	Bog
Wester Branxholm Loch (WBL1 & WBL2)	Uncut	Vegetation	Bog
Long Moss (LM1)	Uncut	Vegetation	Bog

3.2.2.2 Individual Site Development

General Survey

The gross peat stratigraphy of all sites was recorded up to a depth of 3m from at least one core at each site included in the general survey. In total 68 sites were included in this study.

Detailed Investigations

A subset of 9 sites (table 3.2) was selected for more detailed stratigraphical investigations, to include a range of site types, quaking and solid vegetation, and to include areas suspected of being cutover and uncut on the basis of visual and documentary evidence. Peat cores were extracted with a Hiller borer along transects across sites. Samples of characteristic post-glacial peat types from uncut areas and from residual peat were analysed for macrofossil remains to provide a basis for stratigraphical comparison (for analytical procedure see section 3.2.2.3).
Where sites were drained by a deep drain the height of the lip of the drain above the current fen surface was estimated (by levelling) to provide a crude measure of the original surface height of the site.

Table 3.2. Sites selected for detailed stratigraphic investigation.

Site	*Suspected status*	*Evidence for suspected status*	*Vegetation type*
Brown Moor Heights	Uncut	Vegetation	Bog
Blind Moss	Uncut	Vegetation	Bog
Wester Branxholm Loch	Uncut	Vegetation	Bog
Long Moss	Uncut	Vegetation	Bog
Long Moss	Cutover	Documented history	Quaking fen
Nether Whitlaw Moss	Cutover	Drainage	Poor fen
Muirfield Moss	Cutover	Drainage	Rich fen
St. Leonards Moss	Cutover	Drainage	Rich fen
Blackpool Moss	Cutover	Documented history	Rich fen and Fen carr
Groundistone Moss	Cutover	Documented history	Poor fen and Bog

Specific study: Long Moss

The general survey indicated a wide range of peat stratigraphic sequences at different sites and within sites. Long Moss was selected in the light of the general survey to investigate the stratigraphy of:

1. A site which has documentary evidence for peat removal but which was almost certainly not entirely cutover;
2. A site which apparently provides a particularly good reference section of uncut peat.

3.2.2.3 Macrofossil analysis

Macrofossil analysis involves the extraction of identifiable fragments of plants (shoots, leaves, stems, rhizomes, wood, seeds, scales) from peat samples. Samples of peat were collected from cores in the field, stored at 5°C and used for macrofossil analysis.

Analytical procedure

A sample of peat of known volume ($50cm^3$) was mixed with warm water for a few hours to disperse the sediments. This mixture was then washed through a fine sieve (0.2mm) until the washings were clear. The remains were then examined under a low power dissecting microscope, and all seeds and identifiable remains were removed, identified and quantified with reference to Wells (1988), Beggren (1969, 1981), Katz *et al.* (1965). Seeds, scales and oospores and other fragments of plant material were identified as accurately as possible and scored semi-quantitatively as follows:

xxxx	Abundant
xxx	Frequently recorded
xx	Occasionally recorded
x	Present

Although the composition of the plant communities at any time cannot be *completely* reconstructed, and although seeds are produced in varying quantities by plants and decay at different rates, macrofossil analysis nonetheless provides many useful insights into the general composition of past vegetation.

3.3 Results and discussion

3.3.1 REFERENCE CORES FROM UNCUT PEAT SURFACES

Several peat cores from areas believed to represent uncut peat surfaces were examined to establish the un-modified stratigraphic sequences of post-glacial peat deposits. Some cores at Blind Moss and Branxholm Wester Loch contained deep marl deposits whereas Long Moss and Brown Moor Heights did not. Generally a common sequence was recognised with many distinctive peat types.

The stratigraphy of peat cores obtained from areas of bog vegetation on solid peat deposits are summarised in table 3.3.

Table 3.3. Peat stratigraphy of areas representing uncut peat surfaces.

	Blind Moss BL2	*Branxholm Wester Loch 1*	*Branxholm Wester Loch 2*	*Brown Moor Heights BMH2*	*Long Moss LM1*
Peat type	*Depth below vegetation surface (cms)*				
Loose *Sphagnum - Eriophorum* peat	0-40	0-80	0-125	0-190	0-75
Brown monocot peat	40-80				
Golden-brown or red-brown hypnoid moss peat	80-300	80-630	125-300	190-260	75-410
Monocot peat		630-700			
Brown mud with *Potamogeton* fruitstones			300-335	260-290	410-470
Marl	300-350 (shell marl)	700-750 (khaki marl)	355-450 (bands of shell marl and mud)		
Blue-grey clay				290-450	470-

Generally a thin layer of *Sphagnum* and *Eriophorum* peat was found overlying fen peat, often very distinctive golden-brown fresh bryophyte peat containing abundant shoots of *Paludella squarrosa* (a species which is now extinct in Britain but which still occurs in basin mires in continental Europe) and other distinctive bryophyte macrofossils (table 3.4). A layer of peat containing prominent monocot remains sometimes with wood fragments was sometimes found between these layers. Red-brown moss peat with abundant *Scorpidium scorpioides* was sometimes found in deeper layers (table 3.4). Beneath the hypnoid moss peat there were usually layers of muds and / or marl often containing *Potamogeton* fruitstones and beneath this blue-grey clay.

Table 3.4. Macrofossils present in samples of hypnoid moss peat from reference cores.(Main peat builders in ***bold*** type).

Core	*depth*	*Bryophyte species*	*Vascular species*
Branxholm Wester Loch 1	200-250	***Paludella squarrosa,*** *Homalothecium nitens, Calliergon giganteum, Sphagnum sp.*	*Menyanthes trifoliata, Carex sp., Lychnis flos-cuculi, Calluna vulgaris, Wood*
	400-450	***Calliergon giganteum, Scorpidium scorpioides,*** *Paludella squarrosa*	*Carex sp., Equisetum , Lychnis flos-cuculi*
Branxholm Wester Loch 2	225-250	***Paludella squarrosa,*** *Homalothecium nitens, Sphagnum sp.*	*Menyanthes trifoliata, Carex diandra/paniculata, Lychnis flos-cuculi, Caltha palustris, Juncus sp., Wood*
Long Moss	130-150	***Paludella squarrosa,*** *Homalothecium nitens, Calliergon giganteum,*	*Wood, Betula sp., Carex rostrata, Potentilla erecta,*
Blind Moss	200-250	***Scorpidium scorpioides,*** *Paludella squarrosa, Calliergon giganteum*	*Carex sp., Betula sp., Carex diandra/paniculata, Potamogeton sp.*
Brown Moor Heights	200-250	***Sphagnum sp., Calliergon cf. giganteum,*** *Paludella squarrosa, Homalothecium nitens*	*Carex diandra/paniculata, Equisetum sp., Menyanthes trifoliata, Lychnis flos-cuculi, Potamogeton sp.*

3.3.2 DESCRIPTION OF PEAT TYPES

Samples of peat types corresponding to those found in the reference cores were also collected from sites believed to contain deposits of residual peat (remaining at the base of the peat cutting) as well as from uncut peat surfaces. These were included in the macrofossil analyses of peat types. The main peat types found in reference peat cores (from uncut peat surfaces) and residual peat (from cutover peat surfaces) are described below.

3.3.2.1 Sphagnum - Eriophorum bog peat (table 3.5)

Usually a thin layer of fresh and often rather loose peat directly beneath the vegetation surface. Mainly found on uncut peat surfaces.

Table 3.5. Macrofossils found in samples of *Sphagnum* - *Eriophorum* bog peat.
LM (Long Moss), BMH (Brown Moor Heights). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample site and depth below vegetation surface (cms)				
Macrofossils	*LM13 30-50*	*LM 1 0-20*	*LM 1 20-35*	*BMH 2 150-190*	*BMH 3 150-200*
Eriophorum remains	xx	xx	xxxx	x	x
Eriophorum fruits		x		x	x
Calluna leaves/shoots	x	xxx		x	
Sphagnum sect acutifolia	xx	x	x	xxxx	xxxx
Sphagnum sect. palustre	xxxx	xxxx	xxx		
Wood fragments	xxx	x	x		
Monocot remains	xxx			x	xx
Erica tetralix leaves		x			
Carex diandra nutlets	x		x		
Carex lasiocarpa nutlets			x		
Lychnis flos-cuculi seeds			x		
Carex nutlets			x		x
Betula fruits			x		x
Homalothecium nitens			x		
Potamogeton fruitstones	x				
Paludella squarrosa	x				
Juncus seeds	x				x
Calliergon spp.		x		xxx	
Scorpidium scorpioides	xxx				
Equisetum remains				x	
Aulacomnium palustre					x

3.3.2.2 Golden hypnoid moss peat (table 3.6)

Very distinctive golden-brown moss peat usually very fresh with well preserved moss remains dominated by shoots of *Paludella squarrosa* accompanied by often abundant *Homalothecium nitens*, *Calliergon giganteum* and *Sphagnum* sect. *Acutifolia* leaves. Remains of vascular species include *Carex diandra* nutlets, *Carex* cf. *rostrata* nutlets and utricles, *Carex* sp. nutlets, *Menyanthes trifoliata* seeds, *Lychnis flos-cuculi* seeds, *Betula* fruits, *Equisetum* fragments, *Calluna* twigs and wood fragments cf. *Betula*.

Table 3.6. Macrofossils found in samples of golden hypnoid moss peat.
LM (Long Moss), AL (Ashkirk Loch), WBL (Branxholm Wester Loch), BMH (Brown Moor Heights), SL (St. Leonards Moss). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample site and depth below vegetation surface (cms)								
Macrofossils	*LM 1 35-50*	*LM 1 130-150*	*LM 16 120-150*	*AL 8*	*WBL 1 150-200*	*WBL 1 200-250*	*WBL 2 225-250*	*BMH 2 200-250*	*SL 5* 235-*
Paludella squarrosa	xxxx	xxxx	xxxx	xx	xxx	xxx	xxx	xx	xxxx
Homalothecium nitens	xxx	xxx	xx		xxx		xxx	xx	x
Calliergon giganteum		xx	xx		xx		xx	xxx	
Betula fruits	x	x	x	x					x
Potentilla seeds		x		x					
Carex rostrata fruits	x	xx							
Carex diandra nutlets	x	x	xx				xx	xx	
Wood fragments	x	x	xx	xxx	x	x	x		
Monocot remains	xxx	xx	xxx	xx	xxx	xxxx	xxx		xx
Bryophyte capsules	xx	xx				x	x		
Sphagnum sect palustre	xx								
Calluna roots	xxx								
Eriophorum fruits	x								
Carex nutlets	x		x		xx				x
Alnus fruits			x						
Menyanthes trifoliata seeds				x	x		x	x	
Sphagnum sect Acutifolia leaves				xxx	x		xxx	xxx	xx
Lychnis flos-cuculi seeds				x	x	x	x	x	x
Equisetum remains				x				xx	xx
Chara oospores				x					
Calluna shoots					x	x			
Juncus seeds						x	x		
Caltha palustris seeds							x		
Potamogeton fruitstones								x	

3.3.2.3 Red-brown hypnoid moss peat (table 3.7)

Rather loose red-brown moss peat dominated by leaves of *Scorpidium scorpioides*. Often accompanied by *Calliergon giganteum* and *Paludella squarrosa*. Vascular remains include *Menyanthes trifoliata* seeds, *Potamogeton* sp. fruitstones, *Carex* sp. nutlets, *Carex* cf. *diandra* fruits, *Carex lasiocarpa* fruits, *Betula* sp. fruits, *Equisetum* fragments and occasional *Lychnis flos-cuculi* seeds.

Table 3.7. Macrofossils found in samples of red-brown hypnoid moss peat.
LM (Long Moss), MU (Murder Moss), WBL (Branxholm Wester Loch), SL (St. Leonard's Moss). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample sites and depth below vegetation surface (cms)					
Macrofossils	*LM 14 25-50*	*LM 14 150-200*	*MU 8**	*WBL 1 400-450*	*Blind 150-200*	*SL 5* 170-*
Scorpidium scorpioides	xxx	xxxx	xxx	xxxx	xxxx	xx
Calliergon?	xxx	xx				
Calliergon giganteum				xxxx		xxxx
Carex diandra	xx	x			x	
Carex lasiocarpa fruits		x				
Carex nutets		x			x	
Menyanthes trifoliata seeds	x				x	
Homalothecium nitens	x					xx
Paludella squarrosa	x			x		xx
Potamogeton fruitstones	x					
Carex rostrata fruits	x					
Betula fruits	x	x	x		x	
wood fragments	x	xx	xxx		x	
Rhizomnium/Cinclidium	x	x				
Monocot remains		xx	xxxx	xx	xxx	x
Equisetum remains		xx	xxx	x		
Potentilla palustris		x				
Lychnis flos-cuculi seeds		x	x	x		x
Chara oospores			x			
Alnus fruits			xxx			
Juncus seeds					x	x

3.3.2.4 Sedge peat (table 3.8)

Dark brown, often dry and humified peat containing abundant monocot remains and sedge stem bases sometimes accompanied by plentiful wood fragments.

Table 3.8. Macrofossils found in samples of monocot peat.
LM (Long Moss), BPM (Blackpool Moss). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample site and depth below vegetation surface (cms)			
Macrofossils	*LM 3 0-50*	*BPM 6 100-150*	*BPM 7 50-100*	*Blind 130-150*
Carex diandra/paniculata	xxxx		x	
Sedge remains	xxxx	xxxx	xxx	xxxx
Wood fragments	xxxx	xxx		
Equisetum remains	x	xxx	xxxx	
Betula fruits	x	xx	xxx	
Lychnis flos-cuculi	x	x	x	
Potentilla erecta seeds	xx	x		
Carex rostrata		x	x	
Carex nutlets		x	x	xx
Moss stems		x		
Chironomid heads		x		
Calliergon giganteum			xxx	
Scorpidium scorpioides?				xxx
Potamogeton fruitstones			x	
Menyanthes trifoliata seeds			x	
Mentha seeds		x	x	
Potentilla palustris seeds				
Angelica sylvestris mericarps			x	
Caltha palustris seeds			x	

3.3.2.5 Woody peat (table 3.9)

Humified dark crumbly peat dominated by wood and twigs with sedge rhizomes, *Carex* sp. nutlets, *Betula* fruits, *Potentilla palustris* seeds, *Cirsium palustre* seeds and a few bryophyte stems.

Table 3.9. Macrofossils from samples of woody peat.
LM (Long Moss). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample site and depth below vegetation surface (cms)			
Macrofossils	*LM 5 30-50*	*LM 15 25-50*	*LM 14 125-150*	*LM 3 0-50*
Wood fragments	xxxx	xxx	xxxx	xxxx
Sedge remains	xxxx	xxx	xx	xxxx
Equisetum remains	x	xx	x	x
Calluna roots/shoots	x	xx		
Carex diandra / paniculata fruits	x	xxx		xxx
Carex nigra fruits	x			
Carex rostrata fruits	x	xx		
Carex nutlets	xx	x	x	x
Potentilla erecta seeds	x	x		x
Cirsium palustre seeds	x			
Betula fruits		xx	xx	
Juncus seeds		x		x
Potamogeton fruitstones		x		
Lychnis flos-cuculi seeds				x
Potentilla palustris seeds			x	
Moss	x	x	x	x

3.3.2.6 Black and brown aquatic muds (table 3.10)

Very fine textured smooth muds containing few identifiable macrofossils. Occasional *Potamogeton* fruitstones are found along with *Nymphaea* and *Nuphar* seeds. Chironomid head parts and insect wing cases are found frequently. Shell fragments sometimes occur. These mud layers can sometimes be several metres deep as at Ashkirk Loch, Wester Branxholm Loch, Blackpool Moss and Whitmuirhall Loch.

Table 3.10. Macrofossils found in samples of aquatic mud.
BPM (Blackpool Moss);AL (Ashkirk Loch), MU (Murder Moss), BE (Beanrig Moss). The abundance of macrofossils in each sample is indicated as follows: xxxx - abundant; xxx - frequently recorded; xx - occasionally recorded; x - present.

	Sample site and depth below vegetation surface (cms)								
Macrofossils	*BPM 6 550-600*	*AL 6 450*	*AL 7* 250-300*	*AL 7** 80*	*AL 7** 325*	*Green side 3 280*	*MU 8*	*Blind 200-250*	*BE 130-140*
Sphagnum sect. acutifolia leaves	xx	xx	x	xx	x				xx
Nymphaea alba seeds	x				x		xxx		
Nuphar lutea seeds			x	xx	x				
Chironomid heads	x	x				x			
Insect remains	x	xx				xx			
Moss fragments	x	xx			x	x			
shell fragments	x								
Equisetum remains	x	x		x	x	xxxx	xx		x
Carex spp. nutlets	x			x		x	x	x	x
Chara oospores	x	x			xx		xxx		xxx
Betula fruits	x					x		x	
Monocot remains		x				xx	x		x
Calliergon giganteum						xx		xx	
Potamogeton fruitstones			x		x	xxxx	x	x	
Scorpidium scorpioides								xx	
Ranunculus flammula seeds				x					x

3.3.2.7 Pale, marly aquatic muds

Pale brown fine textured muds containing *Potamogeton* fruitstones and some vascular remains and abundant *Chara* oospores.

3.3.2.8 Shell marl

Very white sticky deposit containing calcified *Chara* oospores and abundant shells of aquatic crustacean species and sometimes remains of aquatic plant species.

3.3.2.9 Blue-grey clay

Very distinctive smooth blue-grey clay found at the base of postglacial peat and marl deposits. Sometimes quite a thick layer, occasionally found between peat layers, sometimes overlies deposits from the Allerød interstadial (Late Devensian) (Webb & Moore 1982).

3.3.3 CHARACTERISTICS AND DEVELOPMENT OF UNCUT SURFACES

The peat stratigraphic sequences commonly found in residual and un-modified peat deposits in the Scottish Borders fens are summarised in figure 3.1. In most sites the peat deposits are underlain by a thick blue-grey clay. Within this layer there are some peaty bands which represent the interstadial periods in the last glaciation (Webb & Moore 1982, Tight 1987). These clays are generally overlain by shell marl and/or fine textured pale brown, mid-brown or dark brown and black aquatic muds with *Potamogeton* fruitstones, *Nuphar lutea* seeds, *Nymphaea alba* seeds and wing cases of insects. This is overlain by hypnoid moss peat or monocot peat, sometimes in alternating layers (as at Blind Moss - this could represent a mosaic of raft vegetation as is seen currently at sites with well developed moss cushions surrounded by sedge-dominated vegetation). In many cases the moss peat is strikingly well preserved and it can be dominated by *Calliergon giganteum*, *Scorpidium scorpioides*, or *Paludella squarrosa*. Vascular plant species include *Menyanthes trifoliata, Caltha palustris*, *Lychnis flos-cuculi* and *Carex cf. diandra* suggesting that these communities were similar to those which presently occur on some of the Scottish Borders fens. The *Paludella squarrosa* peat is golden-brown in colour and often contains shoots of *Homalothecium nitens* and *Sphagnum* species. Wood fragments and sedge rhizomes are common in these deposits and they can become more prominent, changing the character of the peat. In a few cases the moss layer is poorly defined and the overlying peat is dominated by sedges and wood. This peat type also sometimes overlies the moss peat supporting the supposition that in other sites the peat extracted as a fuel source was this upper, solid, woody peat. However, in most extant examples of uncut peat the peat overlying the moss peat is *Sphagnum* peat though often only a thin layer, upto one metre in depth, and the present peat surface is embryonic raised bog. Similar stratigraphic sequences have been described by Bellamy *et al.* (1966) from two sites in the Tees basin.

3.3.3.1 Marl formation

Shell marl is formed by the deposition of calcium carbonate encrusted aquatic plants, in particular charophyte species, and faunal species with calcareous skeletons: Ostracods, Gastropods, Bivalves (Wetzel, 1960; Kelts & Hsu, 1978). Calcium ions are mainly derived from

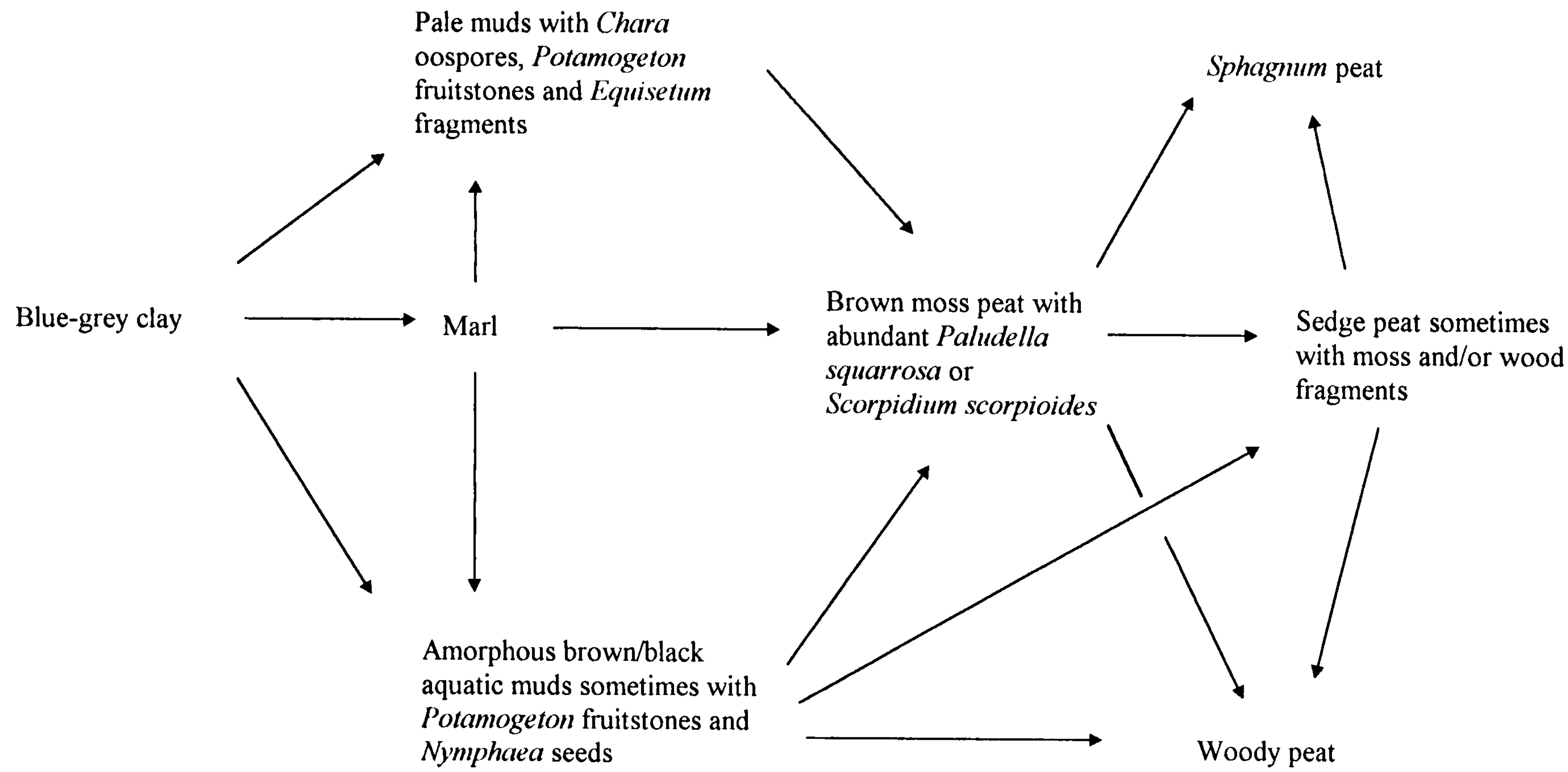


Figure 3.1. Summary of post-glacial successional sequences from the Scottish Borders fens.

groundwater input and carbonate ions may be derived from direct atmospheric equilibria, respiration and bacterial reduction of organic matter (Kelts & Hsu, 1978). The conditions required for the formation of marl are: sufficient quantities of assimilable organic matter, maximum light conditions (for photosynthesis), and high temperatures (for supersaturation of dissolved carbon dioxide and precipitation of carbonates/calcite). These are most likely to occur in very shallow littoral zones, calm and seldom renewed waters where base cations (calcium and magnesium) are likely to be more abundant due to runoff from surrounding soils, peripheral springs are more likely to discharge and submerged aquatic plants and their associated fauna are likely to thrive. (Some macrophytes become encrusted with calcium carbonate amounting to more than their own weight per growth season, and can lead to sedimentation rates in the order of metres per hundreds of years (Kelts & Hsu 1978).) *Chara* species almost always contain more calcite than other plants probably because they more efficiently utilise bicarbonate in photosynthesis (Wetzel 1975). The deepest and whitest deposits of marl are therefore most likely to occur within sites which, during the period of marl formation (generally around the early post-glacial), were relatively shallow lakes or edges of lakes influenced by strong base-rich springs, or which were surrounded by base-rich soil leaching calcium. Where the springs were less base-rich or the run-off catchment smaller or the water depth greater, the aquatic sediments become progressively darker, with a continuum from grey marl to coarse textured pale muds to brown muds and to fine-textured dark brown and black muds in the deepest regions.

3.3.4 BOG DEVELOPMENT

The reference cores extracted from areas of solid peat (assumed to be representative of un-modified postglacial peat development) show strikingly similar patterns of development (figure 3.2). These sites appear to have developed hydroserally through an aquatic phase where muds, sometimes calcareous, were deposited, through a phase dominated by rich-fen bryophytes (*Scorpidium scorpioides* and *Calliergon giganteum*) with sparse monocots, to a vegetation dominated by *Paludella squarrosa*, *Homalothecium nitens* and *Sphagnum* with sedges and dicots and small trees. After this the vegetation would either become dominated by sedge fen or fen carr, or the vegetation may be invaded by bog species, notably *Sphagnum* species typical of ombrogenous bogs (table 3.11).Where bog vegetation does occur it is generally over the deepest peat deposits at a site, which are usually the areas furthest from the influence of groundwater inputs.

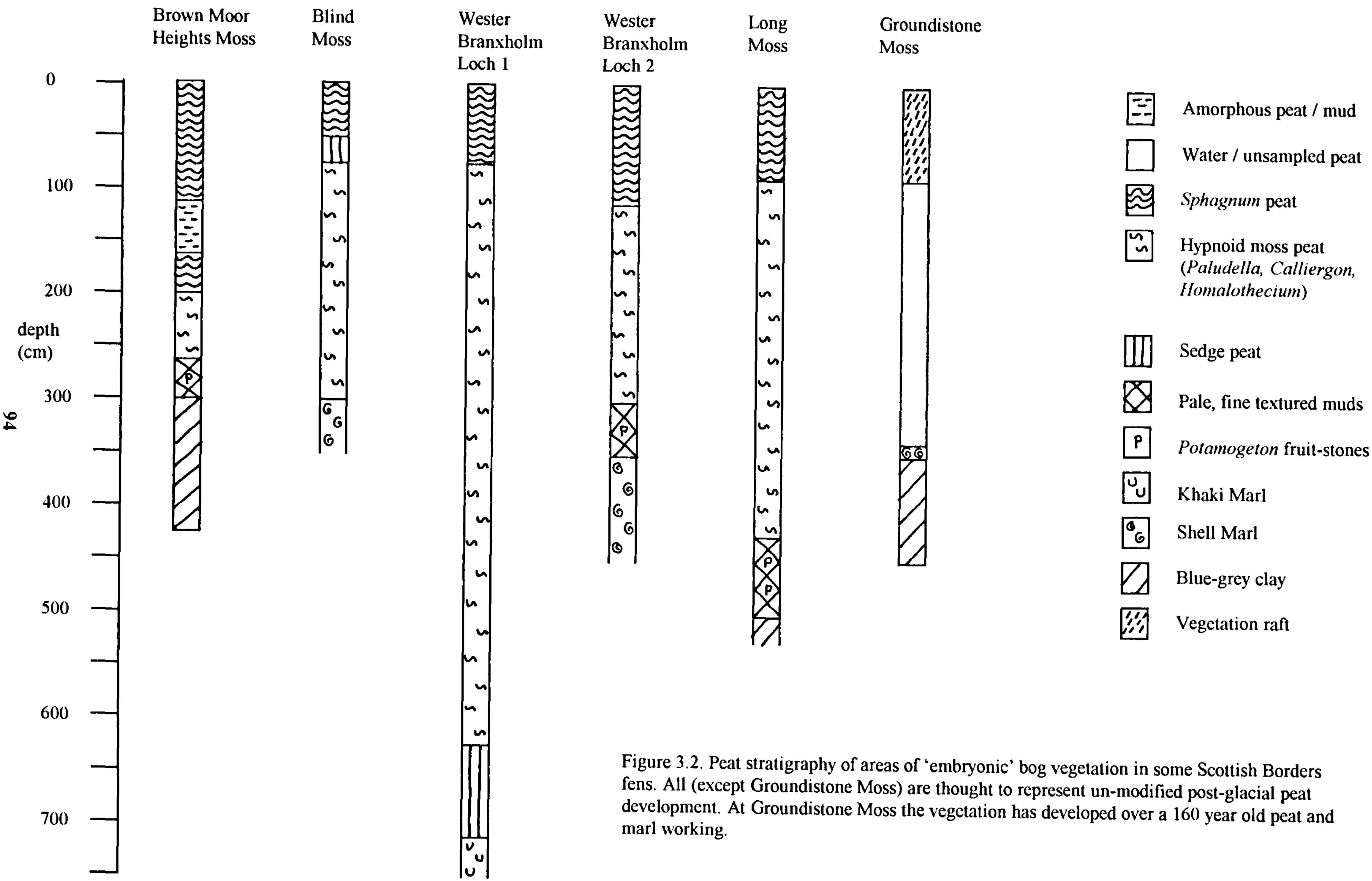


Figure 3.2. Peat stratigraphy of areas of 'embryonic' bog vegetation in some Scottish Borders fens. All (except Groundistone Moss) are thought to represent un-modified post-glacial peat development. At Groundistone Moss the vegetation has developed over a 160 year old peat and marl working.

Table 3.11. Un-modified postglacial succession at reference sites.

Successional phase		*Deposit*
1	Aquatic phase	marl, muds containing *Potamogeton*, *Nuphar*, *Nymphaea*
2	Bryophyte dominated floating raft	*Scorpidium scorpioides*, *Calliergon giganteum*
3	Thicker floating raft dominated by Paludella with Sphagnum , sedges, dicots and scrub	*Paludella squarrosa*, *Homalothecium nitens*, *Sphagnum* leaves, *Betula* twigs, *Lychnis flos-cuculi*, *Carex diandra*, *Carex rostrata*, other sedges
3a	Grounded raft with more dominant monocots and more extensive scrub development	Woody peat, monocot remains, more oxidised
4	Isolation of vegetation surface from groundwater input, development of ombrogenous bog	*Sphagnum papillosum*, *Sphagnum* spp., *Eriophorum angustifolium*, *E. vaginatum*, *Betula*, *Calluna*.

Peat dominated by *Paludella squarrosa* is frequently found beneath *Sphagnum* peat at bog sites in the British Isles (table 3.12), especially in northern Britain (Hammond 1968, Dickson 1973, Jones 1977) and in most cases dates to the early part of the Flandrian period. Extensive development of bog in the British Isles occurred in zones VII and VIII of the Flandrian. Zone VIIa coincides with the Boreal-Atlantic transition which occurred 7000-7500 years ago and where Dickson (1973) recognised a marked reduction in rich-fen bryophyte species. In most cases the rich-fen bryophyte peat has been succeeded by bog, sometimes via fen woodland. *Sphagnum* leaves are often found as a conspicuous component of the *Paludella squarrosa* peat; however *Sphagnum* did not become dominant in the peat until zone VIIa in the Flandrian when ombrogenous bogs became widespread. This change was thought to be due to the increased oceanicity of the climate, making conditions more favourable for *Sphagnum* species but causing the decline of northern continental bryophyte species such as *Paludella squarrosa* by the reduction of available habitats (Dickson 1973). *Paludella squarrosa* is now extinct in the UK but its habitat has been described from Fennoscandia where it is common in subalpine zones in fens accompanied by *Drepanocladus revolvens*, *Sphagnum warnstorfii* and *Homalothecium nitens* (Martensson, cited in Dickson 1973). *Homalothecium nitens* still occurs in fens in the Borders amongst rich-fen vegetation often as cushions on a "grounded" raft of vegetation accompanied by *Drepanocladus revolvens*, *Scorpidium scorpioides*, *Sphagnum contortum* and *Sphagnum warnstorfii*.

There is only one case where recent hydroseral development of bog in the Scottish Borders fens is certain although plenty of cutover sites show development of poor fen. At Groundistone Moss an embryonic raised bog plant community has developed since the cessation of peat and marl operations in the 1830's (figure 3.2). *Sphagnum capillifolium*, *Sphagnum magellanicum*, *Sphagnum papillosum* and *Eriophorum vaginatum* all occur in a small area as a quaking raft

Table 3.12. Summary of the occurrence of hypnoid moss fen peat in peat cores from British fens. Modified from Dickson, J.H, Bryophytes of the Pleistocene: The British record and its chronological and ecological implications (1973).

Site	*Zone*	*Deposit below*	*Deposit above*	*Thickness of hypnoid moss peat*	*Moss macrofossils*
Kirkmichael	LDe	Sand and gravel	Sand and gravel	At interface	*Calliergon trifarium, Helodium blandowii, Sphagnum, Homalothecium nitens, Meesia trichista, Scorpidium scorpioides*
Burtree Lane	IV-V	Detrital mud/marl	Wood peat	~100cm	*Paludella squarrosa, Helodium blandowii, Homalothecium nitens, Sphagnum teres*
Midgeholme Moss	V-VI	*Carex, Cladium, Phragmites* fen peat	*Sphagnum / Eriophorum* peat	100cm	*Paludella squarrosa, Homalothecium nitens*
Malham Tarn	VI-VIIa	Marl	*Sphagnum / Eriophorum* peat	50cm	*Calliergon giganteum, Paludella squarrosa, Homalothecium nitens, Sphagnum subsecundum*
Fallhogy	VIIa-VI	Detrital fen peat	*Sphagnum / Eriophorum* peat	50cm	*Drepanocladus fluitans, Paludella squarrosa, Homalothecium nitens*
Buckenham Broad	VI-VIII	Wood peat	Clay and fen peat	150cm	*Homalothecium nitens, Meesia trichista, Calliergon giganteum, Paludella squarrosa, Sphagnum teres*
Bradford Kaims	LDe	Late Devensian clay	Detrital mud	At interface	*Scorpidium scorpioides, Paludella squarrosa, Calliergon giganteum, Cratoneuron commutatum,*
	VIIa-VIIb	Detrital mud	*Sphagnum* and wood peat	50cm	*Paludella squarrosa, Calliergon giganteum*
Holme Fen	VIIb	Fen peat and wood	*Sphagnum* peat	<50cm	*Calliergon giganteum, Drepanocladus revolvens, Meesia longiseta*
Amberly Wild Brooks	VIII	Fen peat and wood	*Molinia* peat	<50cm	*Homalothecium nitens, Meesia trichista*
	VIII	Clay	Fen peat and wood	<50cm	*Homalothecium nitens, Sphagnum spp.*

over 3.6m of fen water. This is one of the deepest parts of the site and is an example of the very fast development of bog vegetation over a 160 year old base-rich peat cutting.

3.3.5 SPECIFIC STUDY: LONG MOSS

The stratigraphy of the peat at Long Moss was investigated along a transect from the area of solid peat supporting raised bog vegetation into the area of quaking fen vegetation (figure3.3). The results are presented in figure 3.4.

At Long Moss the deepest part of the basin is at the southern end, beneath an area of *Eriophorum vaginatum - Sphagnum papillosum* bog vegetation. The basin becomes shallower towards the outflow in the north. There is a shelf of peat where the solid peat adjoins a strongly quaking vegetation raft, supporting rich-fen plant communities. This is a striking change which can be clearly seen in the junction of vegetation types and on aerial photographs.

The peat at Long Moss is solid and greater than 5m deep in the central bog area. The *Sphagnum - Eriophorum* bog peat forms a superficial layer less than 1m deep. Beneath this there is a deep deposit of very fresh golden-brown hypnoid moss peat which is mainly composed of *Paludella squarrosa*. This is accompanied by *Homalothecium nitens* and *Scorpidium scorpioides*. Among the vascular species represented are *Carex rostrata* and *Menyanthes trifoliata*. Deeper in this deposit *Chara* oospores become increasingly frequent. Beneath the hypnoid moss peat there is a layer of pale aquatic mud which contains abundant *Potamogeton* fruitstones and *Chara* oospores. The basal deposits are blue grey clays and clayey peats which are believed to be of late-glacial origin (Webb & Moore 1982, Tight 1987). The surface peat becomes more humified and woody nearer to the area of quaking fen. In the quaking fen the raft is developed over upto 1m of watery peat. Beneath this the peat is solid and identical to the golden-brown *Paludella squarrosa* dominated peat found beneath the bog area.

Long Moss was allocated as a 'common' moss to the parishioners of Wilton (Hawick) as a source of peat for domestic fuel. The most suitable peat for this purpose is that with a high calorific value so woody peat would be particularly suitable. The peats were firstly cut from the most accessible and most easily drained parts of a site (Robson 1985) which at Long Moss would probably have been the shallower north end and maybe around the edges of the north end, leaving the more inaccessible central area intact.

The upper surface of the golden *Paludella squarrosa* peat beneath the vegetation raft appears to represent the base of a peat cutting and the template for post-disturbance vegetation development. Had the peat not been removed the layers of very woody peat encountered at the edge of the peat

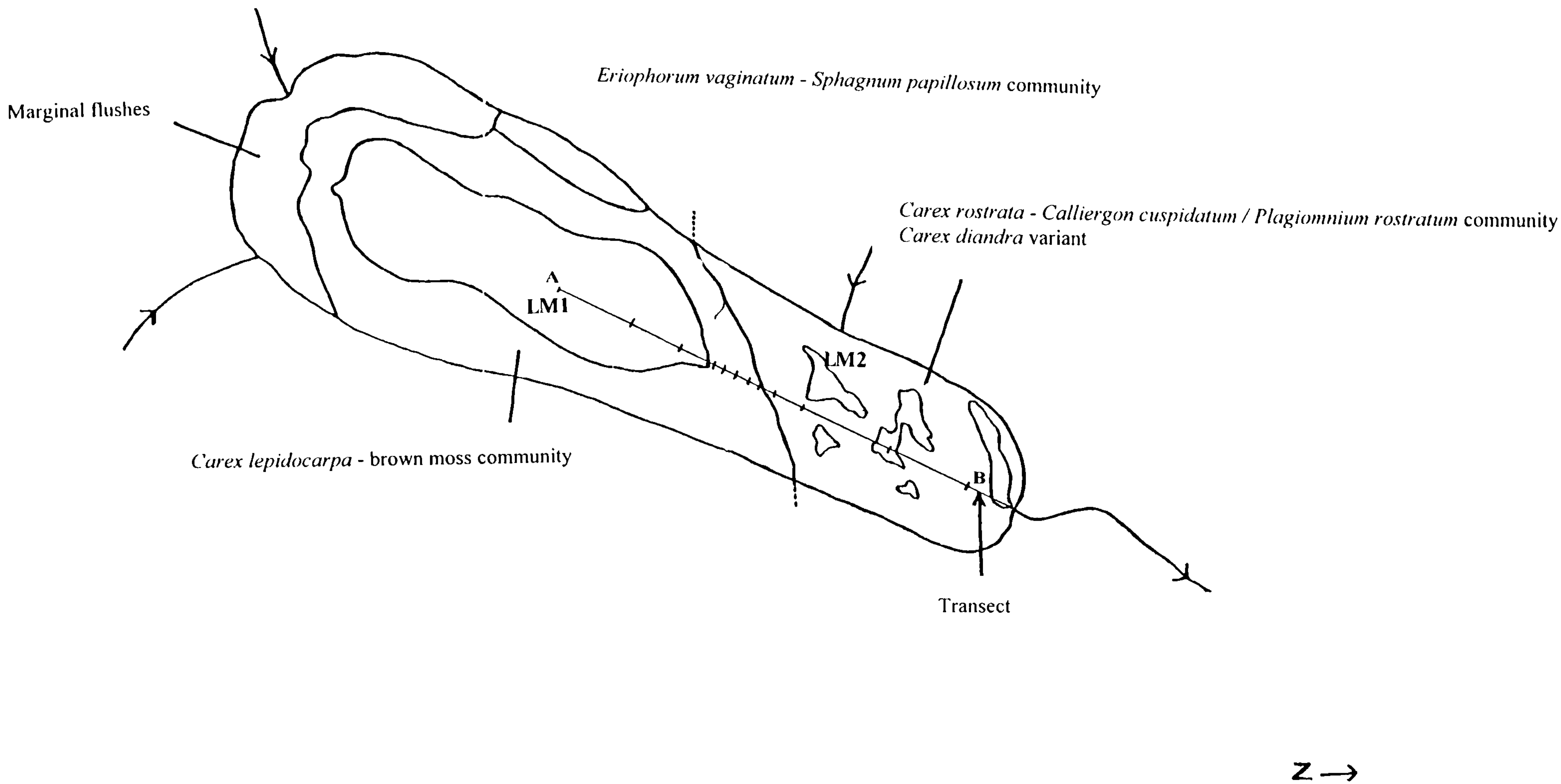


Figure 3.3. Sketch map of Long Moss (Wilton Common) showing the locations of peat cores along a transect from the central bog area (solid peat) into the fen (quaking vegetation raft). Scale 1:2500 (1cm = 25m)

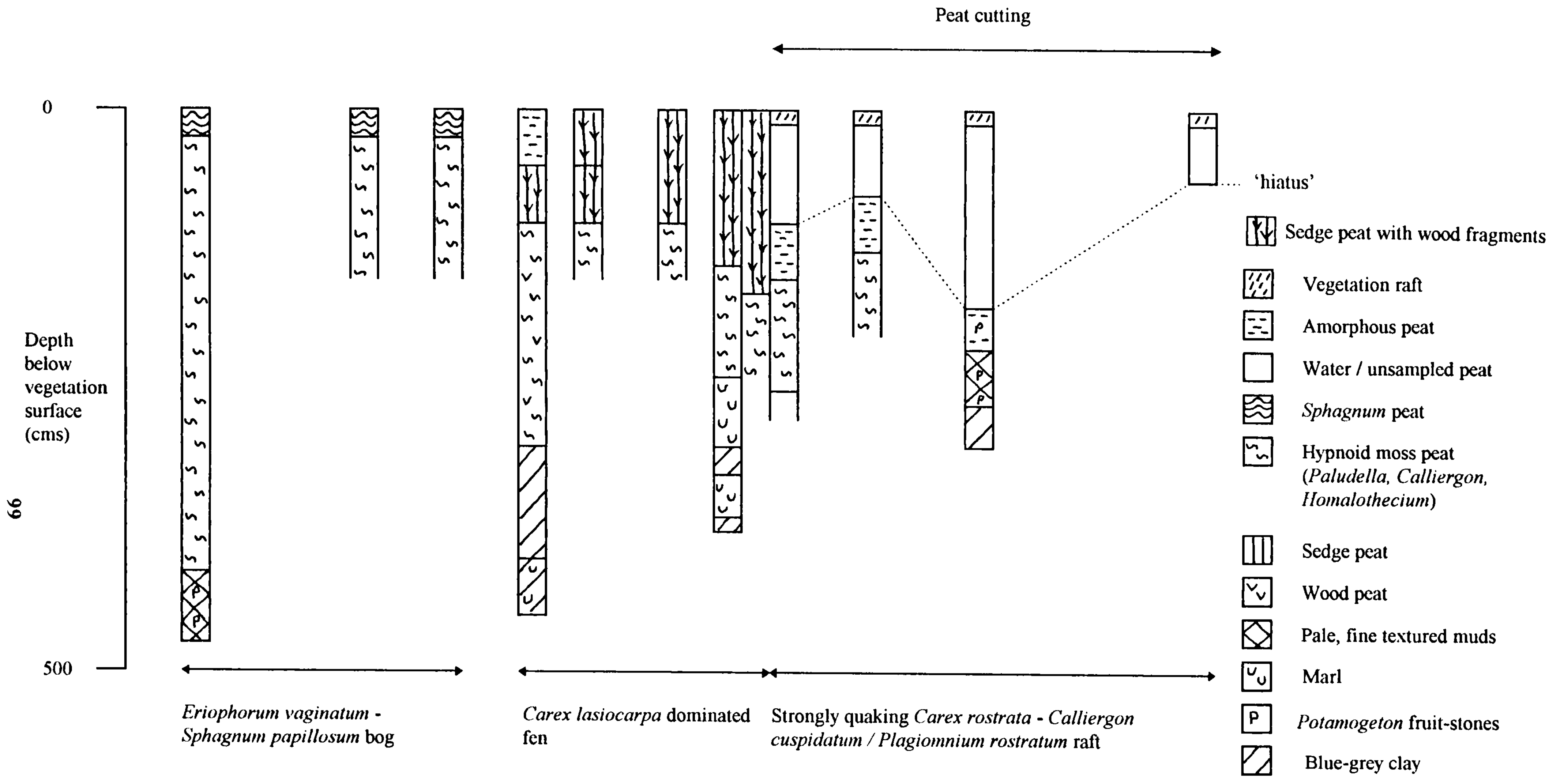


Figure 3.4. Peat stratigraphy of Long Moss along trasect A-B. Peat type symbols are modified from Tröels-Smith (1955) For transect location see figure 3.3.

cutting probably would have extended over the peat cutting area. It seems likely that the residual peat was not removed because:

- It was too difficult to remove;
- Drainage was ineffective;
- It was of poor quality and therefore not worth the effort;
- It did not overly shell marl deposits.

The peat stratigraphy at other sites is comparable to that at Long Moss, with some variation in the depth and actual content of the deposits. Deeper uncut sites (e.g. Branxholm Wester Loch) contain a considerable quantity of fine textured brown aquatic muds beneath the hypnoid moss peat and in some areas there are deposits of white shell marl. The example from Long Moss illustrates how stratigraphic sequences from uncut sites can be extrapolated to other sites which are known or believed to have been used for peat and marl extraction to determine the extent of peat and marl removal at sites, the depth of residual deposits which remain. This can then be related to the development of the present vegetation.

3.3.6 POST-DISTURBANCE PEAT TYPES

The junction of residual peat and post-disturbance peat is referred to as a hiatus in the peat stratigraphy. After the cessation of peat cutting a number of different peat types developed in the Scottish Borders fens (table 3.13). Generally these peat types are less compact than the residual peat types and are often difficult to sample with a peat borer. In many sites the post-disturbance peat is fluid detrital peat which has been formed in and beneath quaking vegetation rafts. The vegetation rafts contain a network of rhizomes and moss fragments and can be up to 1m thick.

Table 3.13. Post-disturbance peat types found in the Scottish Borders fens.

Post-disturbance peat type	*Situation*
Watery peat	Formed beneath a quaking vegetation raft
Detrital amorphous peat	A thin layer formed beneath a quaking vegetation raft or in the rooting zone of the present vegetation.
Amorphous peat with inwashed wood fragments	Can occur beneath rafts or where the vegetation is rooted into the substratum.
Inwashed silt (can be mixed in with amorphous peat)	Forming the rooting zone of the present vegetation or beneath a raft
Sedge - *Equisetum* peat	Loose peat formed in swampy areas
Oxidised / humified monocot peat	Formed in areas where the drainage has remained effective. Usually < 50cms thick and the rooting zone of the present vegetation.

3.3.7 INDIVIDUAL SITE DEVELOPMENT

A summary of the past and present conditions at all sites included in the survey is presented in table 3.14.

Thirty-one out of 68 sites have some documentary evidence of past disturbance. Of these 31 have visual evidence of extensive drainage, 21 show a distinct hiatus in the peat stratigraphy and 15 have quaking vegetation rafts (table 3.15). Rather surprisingly two sites which present apparently uncut peat also have documentary evidence of some peat removal. This suggests that not all sites where peat removal took place were stripped uniformly. The occurrence of vegetation rafts cannot be relied upon as an indicator of past peat cutting as only 50% of sites with documentary evidence of peat removal actually support vegetation rafts. A marked hiatus in the peat stratigraphy is a more reliable indicator of past disturbance as is the presence of deep drains and culverts.

Table 3.15. Numbers of sites with features related to past disturbance.

Documentary evidence	31					
Uncut peat	2	5				
Visual evidence	21	0	41			
Hiatus	17	0	31	41		
Recently modified	4	0	4	2	9	
Vegetation raft	15	5	18	19	1	33
	Documentary evidence	*sites with intact peat*	*Visual evidence*	*Hiatus in peat stratigraphy*	*Recently modified*	*Vegetation raft*

A summary of the peat stratigraphic sequences from the Scottish Borders fens is presented in table 3.16. The deposits at many sites are uneven in depth and contain several of these sequences indicating the differential removal of peat from different areas within sites and possibly the occurrence of different peat types prior to disturbance.

Some cutover sites do not have a distinct hiatus in the peat stratigraphy because:

1. They have been recently modified in pond creation schemes (Borthwickshiels Loch, Cavers Long Moss, Hare Moss, Huntley Moss, Newhouse Moss, Tocher Lodge Moss, Lionfield Moss, Synton Loch);
2. They are largely open water (Pickmaw Moss, Selkirk Pot Loch);
3. They have a clay base overlain by a thin layer of recent peat with rooted vegetation (Curdyhaugh Moss, Little Moss, Threephead Moss);

Table 3.14. Evidence for past peat and marl extraction at Scottish Borders fen sites.
* In the substratum category *quaking* refers to areas with 'grounded' vegetation rafts where the peat beneath the raft is soft but not watery, *floating* refers to areas where the vegetation raft is floating over deposits which are watery and which cannot be sampled by a Hiller peat borer, *solid* refers to areas where the peat immediately beneath the surface is solid.

	PAST CONDITION		**PRESENT CONDITION**			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Adderstonelee Moss		Rough land with drains	Central fen carr area with *Betula* and *Salix* scrub. Flushes along western edge and wet sedge swamp to the south. Deep open peripheral drain and outflow to the north	Drain	Quaking and solid areas	
Ashkirk Loch		Open water surrounded by marsh with a nearby track and subterranean culvert	Small Loch surrounded by quaking rich-fen vegetation and more extensive fen to the west. Flushes along the north western boundary. Drained by a stone lined subterranean culvert	Culvert	Quaking and solid areas	✓
Beanrig Moss		Rough land with an outflow drain	Fen carr, rich fen flushes, grounded raft with base tolerant *Sphagnum* species.	Drain	Quaking and solid areas	
Bees Wood Moss		Marsh	'grounded' raft of small sedge fen	Stream	Quaking	
Berry Moss		Open water surrounded by marsh with a drain	Fen carr and species poor sedge fen. Open drain to the west	Drain	Solid	
Bitchlaw Moss		Rough land with a drain	Open water with floating raft of *Carex rostrata* fen to the north. Open outflow drain to the south	Drain	Floating raft and open water	
Blackcraig Moss		Rough land with a drain	Degraded sedge fen and rush pasture. Surface drains	Stream	Solid	
Blackpool moss	Drained in 1780s;peat and marl removed. Fewers of Midlem had rights to cut peat from the south edge.	Marsh with open drains at the west end and a subterranean culvert at the eastern end	Extensive fen carr, species poor Phragmites reed bed and sedge fen, wet grassland. Subterranean culvert.	Culvert	Quaking and solid areas	✓
Blind Moss	Marked as the "Far Moss" on a plan of Burnfoot Farm from the early 1800's	marsh at the north-eastern end	Pool at north eastern end with floating islands of rich fen and poor fen vegetation. Abrupt junction with areas of solid peat supporting shallow raised bog vegetation. Quaking 'grounded' rafts of rich fen vegetation	Drain	Quaking and solid areas	
Boghall Moss		Marsh with a drain and a nearby track	Tall herb fen and species poor sedge fen. One upwelling spring at western edge. Large subterranean drain.	Culvert	Solid	✓

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Boosmill Hill Moss		Rough land	Partly excavated to form a pond. Areas of quaking rich-fen surrounded by species poor swamp		Quaking and solid areas	
Borthwickshiels Loch	Formerly known as the Roberton Moss	Marsh	Modified to create fishing Loch. Blocked stone-lined subterranean culvert with stone lined access chimneys	Culvert	Solid	✓
Branxholm Wester Loch		Open water surrounded by marsh with rough land to thesouth-west	Loch surrounded by quaking rich fen with extensive fen development to south west surrounding an area of raised bog vegetation. Upwelling springs and flushes.	Drain	Quaking and solid areas and open water	✓
Brown Moor Heights		Marsh with a small drain	Shallow raised bog vegetation surrounded by quaking poor fen and peripheral spring fed areas with base-tolerant *Sphagnum* species	Drain	Quaking	
Buckstruther Moss		Open water	Open water at north and south ends with a mosaic of pools and poor fen floating rafts with some birch scrub in between. Dammed at northern end	Drain	Floating raft and open water	
Cavers Long Moss		Open water	Open water with fringing species poor swamp	Stream	Solid and open water	
Clerklands moss		Rough land with a drain	Wet grassland and species poor fen/rush pasture. Peripheral open drain	Drain	Solid	
Curdyhaugh Moss	The shepherd at Clarilawmuir cut peats at this site.	Marsh with a drain	Wet grassland and small sedge fen with reeds.	Drain	Solid	
Dry Loch	Part of Selkirk Common. (marked as open water on a 1840s map)	Peripheral drain	Species poor sedge fen and scrub. Peripheral deep open drain	Drain	Solid	
Dunhog Moss		Marsh with a subterranean culvert with a nearby track	Central poor fen surrounded by quaking rich fen. Flushes at eastern end. Blocked sluice at western end	Culvert	Quaking and solid areas	
Fluther Moss		No symbols	Species poor sedge fen, rush pasture	Stream	Solid	
Greenside Moss		Open water with a nearby track	Floating poor fen vegetation surrounded by floating raft of nutrient enriched rich-fen vegetation.	Drain	Floating raft and open water	

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Groundistone Moss	Important commercial marl pit run by the Buccleuch Estate. Large quantities of marl were removed over a 20 year period 1813-1833	Marsh with a drain	Floating poor fen vegetation with embryonic raised bog vegetation and *Betula* scrub. Surrounded by species poor reedbeds and pools of open water. Blocked outflow.	Culvert	Floating raft	
Haining Moss		Rough land with scrub and a nearby track	Fen carr. Pool fringed with *Typha*	Drain	Solid and open water	
Hall Moss	One of the four Synton marl mosses	No symbols, a nearby track	Species-rich small sedge fen. Stone-lined subterranean culvert with stone-lined access chimneys	Culvert	Quaking and solid areas	✓
Harden Moss	Formerly named Todshaw Moss. Part of Wilton Common and declared a common Moss at the division of Wilton Common in 1764 with allocated spreading ground.	Rough land with a drain and a nearby track	Species poor sedge fen. Surface drains	Drain	Solid	
Hare Moss		Open water and marsh with a drain and a nearby track	Modified to create a pond. Fringing *Phragmites* and *Equisetum/Carex rostrata* swamp	dammed	Solid and open water	
Hartwoodburn Moss		No symbols, a nearby track	Duck pond with fringing Phalaris/*Sonchus* tall herb fen	Shallow Drains	Solid and open water	
Highchesters Moss		Rough land with a nearby track	Species poor sedge fen, open outflow	Drain	Solid	
Hummelknowes Moss		Marsh and rough land with a drain and a nearby track	Species-rich small sedge fen, species poor sedge fen, *Phragmites* reedbed, upwelling springs, rush pasture and wet grassland. Central drain leading to deep open outflow drain	Drain	Quaking and solid areas	
Huntley Moss	A marl pit.	No symbols	Modified. Species poor swamp vegetation. No peat. Concrete sluice to control drainage	Culvert	Solid	
Hutlerburn Loch		Open Water surrounded by marsh with rough land to the west	Open water at eastern end surrounded by quaking poor fen. Peripheral flushes surrounding shallow raised bog vegetation. Shallow surface drain along northern edge	Drain	Quaking and solid areas and open water	

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Kippilaw Moss		Open water with a nearby track	Central pools surrounded by nutrient enriched quaking rich fen vegetation. Partly blocked stone lined subterranean culvert	Culvert	Floating raft and quaking areas	✓
Ladywoodedge Moss	Part of Selkirk Common	Marsh and rough land with a nearby track	Tall herb fen and small sedge rich fen. Open drain along north western edge	Drain	Solid	✓
Lilliesleaf Moss		Marsh and scrub	Species poor tall herb fen and *Phragmites* reedbed with dense *Salix* scrub	Drain	Solid	
Lionfield Moss		Rough land with a drain	Open water	Drain	Solid	
Little Moss		Marsh	Dense *Phragmites* and *Typha* reedbed surrounded by Salix scrub		Solid	
Long Moss	Part of Wilton Common and declared a common moss at the division of Wilton Common in 1764 with allocated spreading ground.	Rough land with a drain	Pool with strongly quaking raft of sedge rich-fen vegetation with some development of poor fen. Abrupt junction with solid peat supporting shallow raised bog vegetation surrounded by small sedge rich fen. Open outflow drain	Drain	Quaking and solid areas and floating rafts	
Mabonlaw Moss	Part of Wilton Common	Central drain, no symbols	Mosaic of bog/wet heath hummocks and rich fen runnels at northern end with sedge fen at the south end. Central drain leading to a partly blocked stone-lined subterranean culvert at the south end	Culvert	Solid	
Muirfield Moss		Curving central drain and a nearby track	Quaking rich fen, rich-fen flushes, wet grassland and rush pasture with a curving central drain leading to a stone-lined subterranean conduit at the eastern end	Culvert	Quaking and solid areas	✓
Murder Moss	Fewers of Midlem had rights to cut peats from the edge. Drain constructed and deposits removed along the south side but large areas too wet to remove large quantities of peat and marl	Marsh with a drain and subterranean culvert	Peripheral rich fen flushes, Small sedge rich fen, sedge swamp and fen carr. Upwelling springs. Stone lined subterranean outflow drain.	Culvert	Quaking and solid areas and floating rafts	✓
Nether Whitlaw Moss	Known as the Easter Long Moss	Marsh with a nearby track	Quaking raft of peripheral sedge fen and central poor fen. Blocked outflow	Drain	Floating raft	

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Newhouse Moss		Open water, rough land and a drain	Modified under pond creation scheme. Open water and tall herb fen	Culvert	Solid and open water	
Pickmaw Moss		Open water with a drain to Murder Moss	Open water with fringing species-poor sedge swamp	Drain	Quaking and solid areas and open water	
Riddellshiel Loch		Open water with a drain	Open water surrounded by species poor sedge swamp	Culvert	Solid and open water	
Rotten Moss	Part of Wilton Common	Marsh	Sedge fen and fen carr. Peripheral upwelling spring. Central drain leading to open outflow	Drain	Solid	
Seacroft Moss		Open water with a drain and a nearby track	Species poor sedge swamp, species-rich small sedge fen rush pasture and flushed grassland. Open drain at edge	Drain	Quaking and solid areas	
Selkirk Hill Moss		Drain, no symbols	Species poor sedge swamp, drain recently dammed in pond creation scheme	Drain	Solid	
Selkirk Pot Loch	Selkirk Common and Greenhead Estate marl moss	Marsh surrounding open water with a nearby track	Open water surrounded by species-poor *Phragmites* and sedge swamp	Shallow drain	Solid and open water	
Selkirk Racecourse Moss	Part of Selkirk Common	Marsh with a drain	Peripheral rich fen flushes, pool with quaking sedge raft and quaking island with rich fen and fen carr. Partly blocked outflow	Drain	Quaking and solid areas and floating	✓
Shielswood Loch		Open water with fringing marsh	Open water with fringing *Phragmites* reedbed and Carex diandra rich-fen to the south	Drain	Quaking and solid areas and a floating raft	
St Leonards Moss		Small area of open water, central drain and subterranean culvert	Sedge swamp, sedge fen, small sedge rich-fen and peripheral rich-fen flushes with a central drain leading to a stone-lined subterranean conduit which had been partly blocked with a concrete sluice	Culvert	Quaking and solid areas	
Stoneyford Moss	One of the four Synton marl Mosses	Drains, no symbols	Species poor sedge swamp, Flushed wet grassland. Surface drains	Drain	Solid	✓
Stouslie Pool		Open water	Small sedge fen and *Carex paniculata* swamp	Drain	Quaking	

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Synton Courses Loch	One of the four Synton marl mosses	Open water with a subterranean culvert	Open water with fringing quaking species poor sedge swamp. Blocked stone-lined subterranean conduit outflow to the south	Culvert	Quaking and open water	✓
Synton Loch	Formerly part of Stoneyford Moss	Drain, no symbols	Dammed to create Loch for fishing	Culvert	Solid and open water	✓
Tandlaw Moss		Open water, scrub, drain	Open water with scrub and species poor *Phalaris* and *Phragmites* reed bed to the east	Drain	Solid and open water	
Tathyhole Moss	One of the four Synton marl mosses	Marsh with a drain	Species poor rush pasture and swamp. Central drain leading to deep open outflow	Drain	Solid	✓
Threephead Moss	Part of Wilton Common and declared a common moss at the division of Wilton Common in 1764 with allocated spreading ground	Rough land	Hummocks of Bog/wet heath vegetation forming a mosaic with rich-fen runnels at the east. Species rich small sedge rich-fen to the west. Surface drains and an open outflow drain	Drain	Solid	
Tocher Lodge Moss		No symbols	Dammed and flooded. peripheral spring and flushes	Culvert	Solid and open water	
Todshawhill Moss	A commercially run peat pit.	Rough land	Tall herb fen and species poor swamp. Shallow pool. Surface drains	Drain	Solid	
Whitehaughmoor Moss East basin	Part of Wilton Common	Open water	'Grounded' raft of rich-fen vegetation with cushions of base-tolerant Sphagnum species and nationally scarce rich-fen bryophytes	Shallow drain	Quaking	✓
Whitehaughmoor Moss Middle basin	Part of Wilton Common	Open water	'Grounded' raft of small sedge, bryophyte rich rich-fen vegetation	water supply to farm	Quaking	✓
Whitehaughmoor Moss West basin	Part of Wilton Common	Open water	'Grounded' raft of vegetation, species-rich fen vegetation to the north and wetter sedge fen to the south. Open outflow drain to the south	Drain	Quaking	
Whitmuir Moss		Marsh and scrub	Fen carr	Drain	Solid	

table 3.14 cont.

	PAST CONDITION		PRESENT CONDITION			
Site Name	*Documented History*	*1st Edition OS (1860's)*	*Description 1990's*	*Outflow*	*Substratum**	*Marl*
Whitmuirhall Loch	An important commercial marl pit. The western end was part of Selkirk Common	Marsh, open water at the eastern end, drain and a nearby track	Loch to the east surrounded by 'grounded' rafts of nutrient enriched species poor sedge swamp and *Phragmites* reedbed. Deep blocked stone lined outflow	Culvert	Quaking and solid areas and open water	✓
Woolaw Loch	Part of Wilton Common	Open water	Quaking raft. Mosaic of small sedge rich-fen and bryophyte-rich poor-fen. Also small areas with base-tolerant *Sphagnum* species. Partly blocked open outflow to the north	Drain	Floating raft	
Woolaw Moss	Part of Wilton Common. An important source of peat for commoners which was "exhausted" in places by the division of Wilton Common in 1764	Rough land with drains	Rush pasture and wet grassland. Surface drains and stone-lined subterranean conduit. The western end has been excavated to form a pond	Culvert	Solid	✓

Table 3.16. Peat stratigraphic sequences found in the Scottish Borders fens. The hiatus is a marked discontinuity in the peat. Where the peat is solid the hiatus often occurs near the vegetation surface in the rooting zone of the present vegetation as noted at Beanrig Moss by Webb and Moore (1982).

Substratum beneath hiatus	*Above hiatus*	*sites*
clay (blue-grey)	Fluid, watery peat, unsampled by a Hiller borer	Bees Wood Moss Groundistone Moss Bitchlaw Moss Buckstruther Moss Greenside Moss Selkirk Pot Loch Synton Courses Loch Tathyhole Moss Threephead Moss Whitehaughmoor Moss West basin Whitehaughmoor Moss Middle basin Woolaw Loch
	Rooting zone of present vegetation	Huntley Moss Curdyhaugh Moss Hartwoodburn Moss Little Moss
clay (blue-grey) → marl	Sedge peat W oody peat Detrital peat	Blackpool Moss Berry Moss Groundistone Moss Murder Moss Selkirk Racecourse Moss Shielswood Loch Stoneyford Moss Stouslie Pool Tandlaw Moss
	Rooting zone of present vegetation	Whitehaughmoor Moss East basin Whitmuirhall Loch Riddelshiel Moss Boghall Moss Muirfield Moss

table 3.16 cont.

Substratum beneath hiatus	*Above hiatus*	*sites*
clay (blue-grey) → brown muds with *Potamogeton* fruitstones and *Menyanthes* seeds and shell fragments → woody monocot peat (occasionally with *Scorpidium* moss fragments)	Sedge peat Detrital peat Silt	Murder Moss Rotten Moss Seacroft Moss Whitmuirhall Loch Hummelknowes Moss
clay (blue-grey) →marl →woody sedge peat	Detrital peat	Clerklands Moss Dry Moss Kippilaw Moss Ladywoodedge Moss Murder Moss Todshawhill Moss
clay (blue-grey) → Woody peat with shell fragments	Woody sedge peat Silt	Blackcraig Moss Dry Moss Haining Moss Kippilaw Moss Lilliesleaf Moss Whitmuir Moss Whitmuirhall Loch
clay (blue-grey) → pale brown muds with *Potamogeton* fruitstones, moss and shell fragments	Sedge and *Equisetum* peat	Beanrig Moss Nether Whitlaw Moss St Leonard's Moss
clay (blue-grey) → dark brown to black muds with *Potamogeton* fruitstones and *Menyanthes* seeds (occasionally with shell fragments)	Sedge and *Equisetum* peat Detrital peat	Ashkirk Loch Blackpool Moss Dunhog Moss Greenside Moss Highchesters Moss

table 3.16 cont.

Substratum beneath hiatus	*Above hiatus*	*sites*
clay (blue-grey) → brown muds with *Potamogeton* fruitstones → hypnoid moss peat (*Paludella squarrosa*) sometimes with wood fragments	Sedge and *Equisetum* peat (occasionally containing wood fragments)	Adderstonelee Moss Long Moss Blind Moss Fluther Moss Harden Moss Mabonlaw Moss Muirfield Moss St Leonard's Moss
clay (blue-grey) →pale muds with *Potamogeton* fruitstones and shell fragments → sedge / hypnoid moss peat	Sedge and *Equisetum* peat	Ashkirk Loch
clay (blue-grey) → marl → brown muds with *Potamogeton* fruitstones → hypnoid moss peat (*Paludella squarrosa* or *Scorpidium scorpioides* dominant) → monocot peat (with wood fragments)	No hiatus (Blind Moss and Branxholm Wester Loch) Rooting zone of present vegetation	Blind Moss Branxholm Wester Loch Long Moss Hummelknowes Moss
clay (blue-grey) → pale muds with *Potamogeton* fruitstones and *Equisetum* → hypnoid moss peat (*Paludella squarrosa* often dominant) occasionally with sedge and wood fragments → *Sphagnum* moss peat	No hiatus	Long Moss Brown Moor Heights Hutlerburn Loch
clay (blue-grey) → marl → brown muds with *Potamogeton* fruitstones → hypnoid moss peat (*Paludella squarrosa* often dominant) → *Sphagnum* moss peat	No hiatus	Blind Moss Branxholm Wester Loch

4. They have a clay base overlain by watery detrital peat and a raft of vegetation (Bitchlaw Moss, Buckstruther Moss, Selkirk Racecourse Moss, Groundistone Moss, Synton Courses Loch, Woolaw Loch, Whitehaughmoor Mosses).

It is possible that these sites were easily drained or contained evenly distributed peat types and that all the deposits overlying the basal clays were removed, stripping the entire site.This practice has been reported from valley fen sites in Norfolk (Wheeler & Shaw 1995a). The stripping of all deposits would be more likely to have occurred in sites with substantial marl deposits as these were typically found between the peat and the basal clay although they did not always occur over the entire site and often occurred in varying thicknesses (Robson 1985, Tight 1987).

Some sites also lack a hiatus in the peat stratigraphy because they are apparently uncut. These include Branxholm Wester Loch, Brown Moor Heights, Hutlerburn Loch, part of Long Moss and part of Blind Moss.

3.3.8 STATUS OF INDIVIDUAL SITES

Most fen sites in the Scottish Borders show some evidence for the removal of peat and /or marl deposits and few areas of uncut peat remain. The status of each site, whether it has been cut-over, partly cut-over or uncut, based on the evidence presented is summarised in table 3.17.

The status of a site is sometimes not clear cut and often several pieces of evidence are required to reconstruct the history of a site, its status and the relationship between the present vegetation and the site history. For example, Long Moss and Blind Moss both contain areas of shallow raised bog vegetation developed over apparently uncut peat. However both these sites have documentary evidence for past peat cutting, Blind Moss was the "far moss" used by Burnfoot Farm and Long Moss was allocated as a common moss to the parishioners of Wilton, Hawick at the division of Wilton Common in 1764. Peat stratigraphy at both sites indicates that peat was removed from part of the site (near the outflow drain) leaving a substantial portion uncut (figure 3.5 a,b). Certain sites have been modified recently, mainly by pond and lake creation schemes and in these cases the impact of the past disturbance can only be assessed partially as the more recent disturbance has removed much of the stratigraphic evidence. Many sites with a well documented history of peat and/or marl extraction contain no residual deposits (Groundistone Moss, Huntley Moss, Stoneyford Moss, Synton Courses Moss, Hall Moss) probably because the peat and marl was entirely stripped from the site (figure 3.5 c). At Groundistone Moss there is, nowadays, a small but distinct area of raised bog vegetation. Although this is indicative of uncut peat surfaces, in this case no residual peat remains beneath the surface. Along with strikingly detailed documentary evidence this indicates that the post-glacial deposits were entirely stripped; hence the regeneration of bog must have occurred since the cessation of peat and marl operations at the

Table 3.17. Status of individual Scottish Borders fen sites based on evidence for past peat and marl extraction.

	Peat/marl extraction		*Summary description*	*Hiatus in peat stratigraphy*	*Visual evidence for disturbance*	*Documentary evidence for disturbance*
Site Name	*Peat*	*Marl*				
Adderstonelee Moss	✓		Uneven peat removal; substantial depth of residual peat.	✓		
Ashkirk Loch	✓		Even removal of peat, deep deposits (>4.5m) of aquatic muds; 'grounded' vegetation raft.	✓	✓	
Beanrig Moss	✓		Even removal of peat, little residual peat, grounded vegetation raft, flushes and fen meadow.	✓	✓	✓
Bees Wood Moss	?		Grounded vegetation raft, no peat deposits.			
Berry Moss	✓		Even removal of peat and possibly some marl, little residual peat.	✓	✓	
Bitchlaw Moss	?		Floating vegetation raft and open water, no peat deposits.			
Blackcraig Moss	✓		Vegetation rooted into solid peat, some residual peat.	✓	✓	
Blackpool moss	✓	✓	Uneven peat and marl removal. Marl and peat near the edges and at the western end has been stripped. Deep deposits of aquatic muds (>7m) in the central area. This is likely to be the "poor quality" peat described in a survey undertaken in the 1870's (Robson 1985).	✓	✓	✓
Blind Moss	part cut-over		Some peat removed at the northern end where a floating vegetation raft abruptly adjoins deep solid peat supporting shallow raised bog vegetation.	✓		✓
Boghall Moss	✓		Little residual peat and marl. Species poor tall herb fen and sedge fen rooted into the solid peat.	✓	✓	
Boosmill Hill Moss	✓		Floating raft over substantial deposits of residual hypnoid moss peat.	✓	✓	
Borthwickshiels Loch	✓		Recently modified to create a lake, no peat deposits but documentary and visual evidence for removal of peat.		✓	✓
Branxholm Wester Loch	Uncut		Well developed shallow raised bog vegetation over deep (>7m) deposits of solid peat and marl.			
Brown Moor Heights	Uncut		Well developed shallow raised bog vegetation over deposits of soft but solid peat.			
Buckstruther Moss	?		No peat deposits. Open water and floating poor-fen vegetation.			
Cavers Long Moss	?		Recently modified site, no peat deposits.			
Clerklands moss	✓		Some residual peat and marl beneath recent detrital peat. Species-poor fen rooted into solid peat.	✓	✓	

table 3.17 cont.

	Peat/marl extraction		*Summary description*	*Hiatus in peat stratigraphy*	*Visual evidence for disturbance*	*Documentary evidence for disturbance*
Curdyhaugh Moss	✓		No residual peat, completely stripped. but recorded as the main source of peat for the shepherd at Clarilaw farm. Fen meadow vegetation rooted into the solid substratum.			✓
Dry Loch	✓		Some residual deposits of peat and marl. Fen meadow and species-poor sedge fen rooted into solid substratum.	✓	✓	
Dunhog Moss	✓		Residual deposits of brown aquatic muds. 'Grounded' vegetation raft with scrub development and flush vegetation.	✓	✓	
Fluther Moss	✓		Residual deposits of hypnoid moss peat. Species poor fen vegetation rooted into the solid substratum.	✓		
Greenside Moss	✓		Floating vegetation raft. Deep (>3m) residual deposits of brown aquatic muds.	✓		
Groundistone Moss	✓	✓	No residual peat, site entirely stripped of peat and marl deposits. Floating raft of poor-fen vegetation with local development of bog vegetation.	✓	✓	✓
Haining Moss	✓		Residual woody peat overlain by sedge peat.	✓		
Hall Moss	✓	✓	No residual peat, site entirely stripped of peat and marl. Grounded raft of rich-fen vegetation	✓	✓	✓
Harden Moss	✓		Uneven removal of peat, baulk in the centre with residual deposits of hypnoid moss peat, little residual peat around the edges. Species-poor sedge swamp	✓	✓	✓
Hare Moss	?		Recently modified to create a lake. No peat or marl deposits.			
Hartwoodburn Moss	?		Recently modified to create a pond. No peat or marl deposits.			
Highchesters Moss	✓		Residual deposits of dark brown muds overlain by recent detrital peat. Species poor sedge fen and swamp rooted into the solid substratum	✓	✓	
Hummelknowes Moss	✓		Residual deposits of marl brown muds and hypnoid moss peat. Silt inwash, uneven stripping of peat leading to areas of vegetation developed on solid peat and as vegetation rafts.	✓	✓	
Huntley Moss	✓	✓	No residual peat, site entirely stripped of peat and marl.		✓	✓
Hutlerburn Loch	Uncut		Well developed shallow raised bog vegetation overlying deep (>4m) solid peat.			
Kippilaw Moss	✓		Deep (>4.5m) deposits of fluid detrital peat overlying residual marl and woody peat. Blocked drain. Floating vegetation raft and open water.	✓	✓	
Ladywoodedge Moss	✓		Some residual peat and marl. Rich-fen and tall herb fen vegetation rooted into solid peat.	✓	✓	

table 3.17 cont.

	Peat/marl extraction		*Summary description*	*Hiatus in peat stratigraphy*	*Visual evidence for disturbance*	*Documentary evidence for disturbance*
Lilliesleaf Moss	✓		Some residual peat, no marl. Phragmites reedbed and Salix carr over solid substratum.	✓	✓	
Lionfield Moss	?		No peat deposits. Open water.			
Little Moss	?		No peat deposits. Phragmites reedbed and Salix scrub over solid substratum.			
Long Moss	part cut-over		Some peat removed at the northern end where a floating vegetation raft abruptly adjoins deep solid peat supporting shallow raised bog vegetation.	✓		✓
Mabonlaw Moss	✓		Varying quantities of residual peat, deepest at northern end. Range of vegetation rooted into the solid substratum.	✓	✓	✓
Muirfield Moss	✓		Peat and marl deposits almost entirely stripped and supporting species-rich flush vegetation rooted into the solid substratum except at the western end where there are some residual deposits of peat and a vegetation raft.	✓	✓	
Murder Moss	✓		Peat unevenly stripped. Residual peat and marl deposits over much of the site. More peat has been removed along the southern edge and around the "island". Present vegetation a mixture of vegetation rafts and areas rooted into the solid peat.	✓	✓	✓
Nether Whitlaw Moss	✓		Little residual peat, site virtually stripped of peat. Present vegetation developed as a floating raft.	✓		✓
Newhouse Moss	✓		Recently modified. No residual peat or marl.		✓	
Pickmaw Moss	✓		No residual peat or marl, mainly open water.		✓	✓
Riddellshiel Loch	✓		Some residual marl, no peat, mainly open water.	✓	✓	
Rotten Moss	✓		Residual muds and monocot peat. Present vegetation rooted into the solid substratum.	✓	✓	✓
Seacroft Moss	✓		Residual muds and monocot peat. Present vegetation rooted into the solid substratum with area developed as a 'grounded' vegetation raft.	✓		
Selkirk Hill Moss	✓		Recently modified. No peat deposits.	✓	✓	✓
Selkirk Pot Loch	✓	✓	No peat deposits, mainly open water.			✓
Selkirk Racecourse Moss	✓		Little residual peat or marl, site almost entirely stripped. Present vegetation rooted into the solid substratum, floating vegetation rafts with scrub development and grounded vegetation rafts.		✓	✓

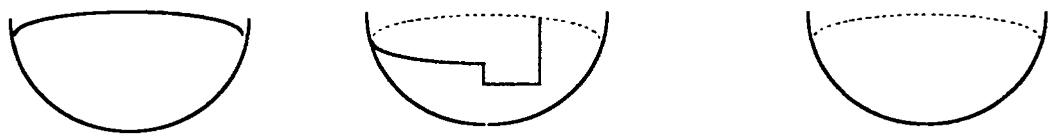
table 3.17 cont.

	Peat/marl extraction		*Summary description*	*Hiatus in peat stratigraphy*	*Visual evidence for disturbance*	*Documentary evidence for disturbance*
Shielswood Loch	?		Some marl deposits, mainly open water.			
St Leonards Moss	✓		Residual deposits of hypnoid moss peat. Unevenly stripped alternate quaking and solid areas near central drain.	✓	✓	
Stoneyford Moss	✓		No residual peat, a little marl, rank species-poor fen rooted into the solid substratum.	✓	✓	✓
Stouslie Pool	✓		Little residual peat or marl. Traces of marl above the basal clay.	✓	✓	
Synton Courses Loch	✓	✓	No residual peat or marl. Site entirely stripped. Floating species-poor sedge fen vegetation		✓	✓
Synton Loch	✓	✓	Recently modified, no peat deposits.		✓	✓
Tandlaw Moss	✓		Recent sedge peat over thin residual marl deposits.	✓	✓	
Tathyhole Moss	✓	✓	No residual peat or marl. Site entirely stripped. Present species-poor fen vegetation rooted into the solid substratum.	✓	✓	✓
Threephead Moss	✓		No residual peat. Site entirely stripped. Present wet heath and rich-fen vegetation rooted into the solid substratum.			✓
Tocher Lodge Moss	✓		Recently modified, no peat deposits.			✓
Todshawhill Moss	✓		Sedge and *Equisetum* peat overlies woody residual peat and a thin marl layer.	✓	✓	✓
Whitehaughmoor Moss East basin	✓		No residual peat. A little marl. Site almost entirely stripped. Present rich-fen vegetation developed as a floating raft			
Whitehaughmoor Moss Middle basin	✓		No residual peat or marl. Site entirely stripped. Present rich-fen vegetation developed as a floating raft			
Whitehaughmoor Moss West basin	✓		No residual peat or marl. Site entirely stripped. Present rich-fen vegetation developed as a floating raft No residual peat.			
Whitmuir Moss	✓		Woody peat overlies hypnoid moss peat with wood fragments. No marl.	✓		✓
Whitmuirhall Loch	✓	✓	Uneven peat and marl removal. Some residual deposits of aquatic muds and marl. Present species-poor fen vegetation developed as floating rafts, grounded rafts and over solid peat. Large area of open water.	✓	✓	✓
Woolaw Loch	✓		No residual peat or marl. Site entirely stripped. Present rich-fen and poor-fen vegetation developed as a floating raft No residual peat.		✓	
Woolaw Moss	✓	✓	Some residual peat, other areas entirely stripped. Present fen meadow and rush pasture vegetation rooted into solid substratum	✓	✓	✓

site in the 1830's. Where there is no documentary or visual evidence for past peat or marl removal and no peat or marl deposits then it is impossible to assess the status of the site (Buckstruther Moss, Cavers Long Moss, Bees Wood Moss, Bitchlaw Moss, Hare Moss, Hartwoodburn Moss, Lionfield Moss, Little Moss, Shielswood Loch) though it seems likely that peat and / or marl may have been completely stripped from at least some of these sites.

Peat and marl deposits were removed to a varying extent both within sites and between sites but it appears that, where practicable, as much as possible was removed. Many sites were partially exploited but not entirely stripped (figure 3.5 b) - for example at Murder Moss and Blackpool Moss it became uneconomic to remove any more water and peat. Murder Moss was assessed as containing good quality peat but it was often flooded so the peat could rarely be easily removed from a large area of the site (Robson 1985).

(a) Uncut/Intact	(b) Part of peat/marl deposits removed	(c) All peat/marl deposits removed



Reasons

• Inaccessible site • Difficult / expensive drainage • Poor quality peat	• Only 'good quality' peat and peat overlying marl removed • Poor drainage • No extensive or deep marl beds • Parts of the site inaccessible	• Accessible site • Effective drainage • Deep and extensive marl deposits • 'Good quality' peat

Present stratigraphy

Uncut peat	Residual post-glacial peat / marl deposits (often containing fresh moss peat or aquatic muds brown and black)	No residual peat / marl deposits

Figure 3.5 a-c. Scenarios of site development.

Many sites which have been cut-over still contain a considerable depth of residual peat deposits, most notably those which contain aquatic brown and black muds (Greenside Moss, Ashkirk Loch, Blackpool Moss, Whitmuirhall Loch). Where similar deposits occur on uncut sites they occur in the deepest areas and it is assumed that these muds would have originally been laid down in deep water conditions and that a substantial depth of peat of a different type or open water was removed from the cutover sites after drainage. Paler brown, coarser muds are reported to form in areas of intermediate depth and marl is considered to form in shallow pool areas and near the edges of sites (Tight 1987).

The evidence presented suggests that in many cases only part of the peat deposits was removed leaving a variable quantity of residual peat and, occasionally, an area of intact, uncut peat. Where the peat and marl deposits were completely stripped leaving little but the clay and rock base (Robson 1985) there is only a stratigraphic record of the recent peat and vegetation development, either as vegetation rooted in thin peat or inwashed silt (e.g. Huntley Moss) or as vegetation developed hydroserally as a raft over a flooded peat cutting (e.g. Groundistone Moss, Nether Whitlaw Moss (figure 3.6)). This situation also occurs over parts of sites, where in places the deposits were completely or almost completely stripped away but where, in other areas, there were some residual deposits left, particularly in areas of deeper peat where the drainage was probably less successful or the peat was poorer quality (e.g. Long Moss (figure 3.4), St. Leonard's Moss (figure 3.7), Muirfield Moss (figure 3.8)). This may reflect the differential occurrence of residual peat types and marl over the expanse of a site although it may also reflect different extraction techniques - records indicate that there were recognised strategies for removing the peat to avoid leaving waterlogged holes and impeding further drainage (Robson 1985). Because peat was such an important source of domestic fuel and most of the accessible peat suitable for this purpose was removed we can only guess the types of peat that were most desirable as fuel. It appears that peats with large amounts of wood would have a higher calorific value than those composed of moss or aquatic muds (which are those which most commonly occur as large residual deposits). The peat at the centre of Blackpool Moss (brown and black fine-textured aquatic muds) was described in a drainage assessment survey as poor quality (Robson 1985).

3.3.9 PEAT AND MARL EXTRACTION IN THE SCOTTISH BORDERS FENS

British fens have been important resources in the past, as a source of peat for fuel and in the Borders as a source of marl which was used as low-grade lime. Therefore the present vegetation of many fens has resulted from the re-vegetation of a peat or marl cutting. In the Borders fens most of the peat and marl extraction had ceased by the 1830's when the industrial revolution had begun and improvements in transport meant that coal and lime were more readily available (Dodgshon 1978, Robson 1985). Modification of the Scottish Borders fens has continued to the present: unprotected sites have been drained and used for economic activity including agriculture,

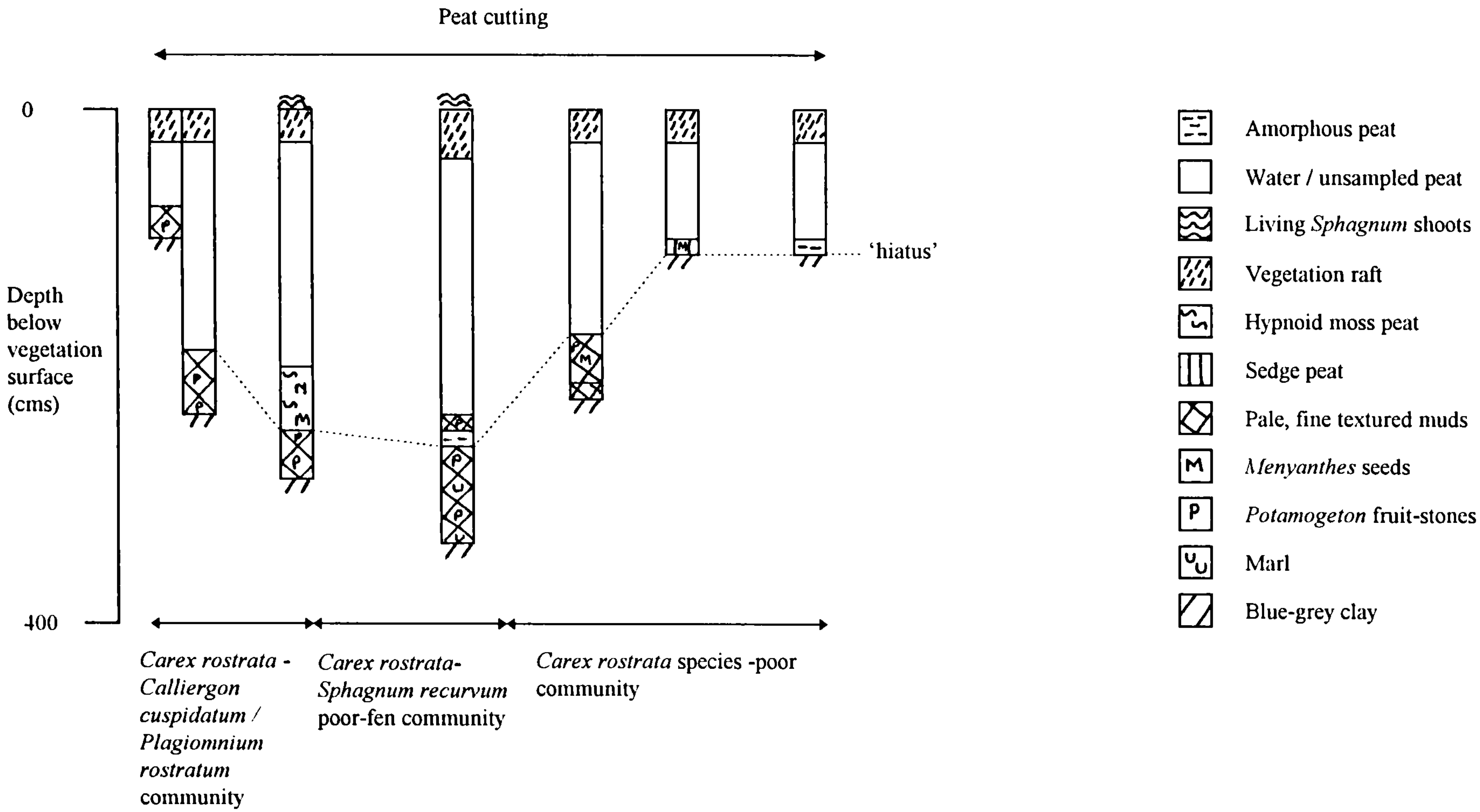


Figure 3.6. Peat Stratigraphy of Nether Whitlaw Moss along transect A-B (for transect location see figure A2.10 in Appendix 2).

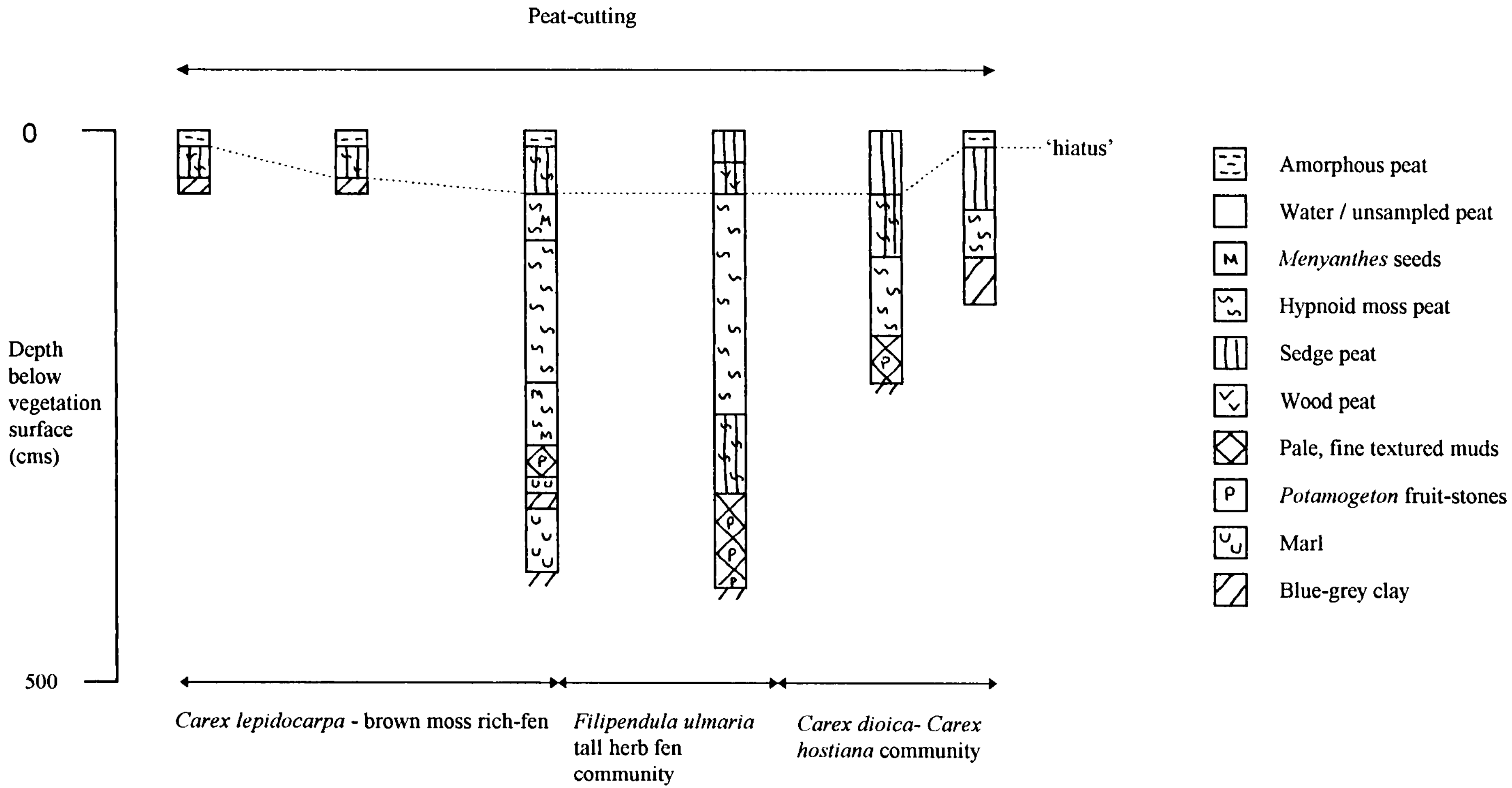


Figure 3.7. Peat Stratigraphy of St. Leonard's Moss along transect A-B (for transect location see figure A2.11 in Appendix 2).

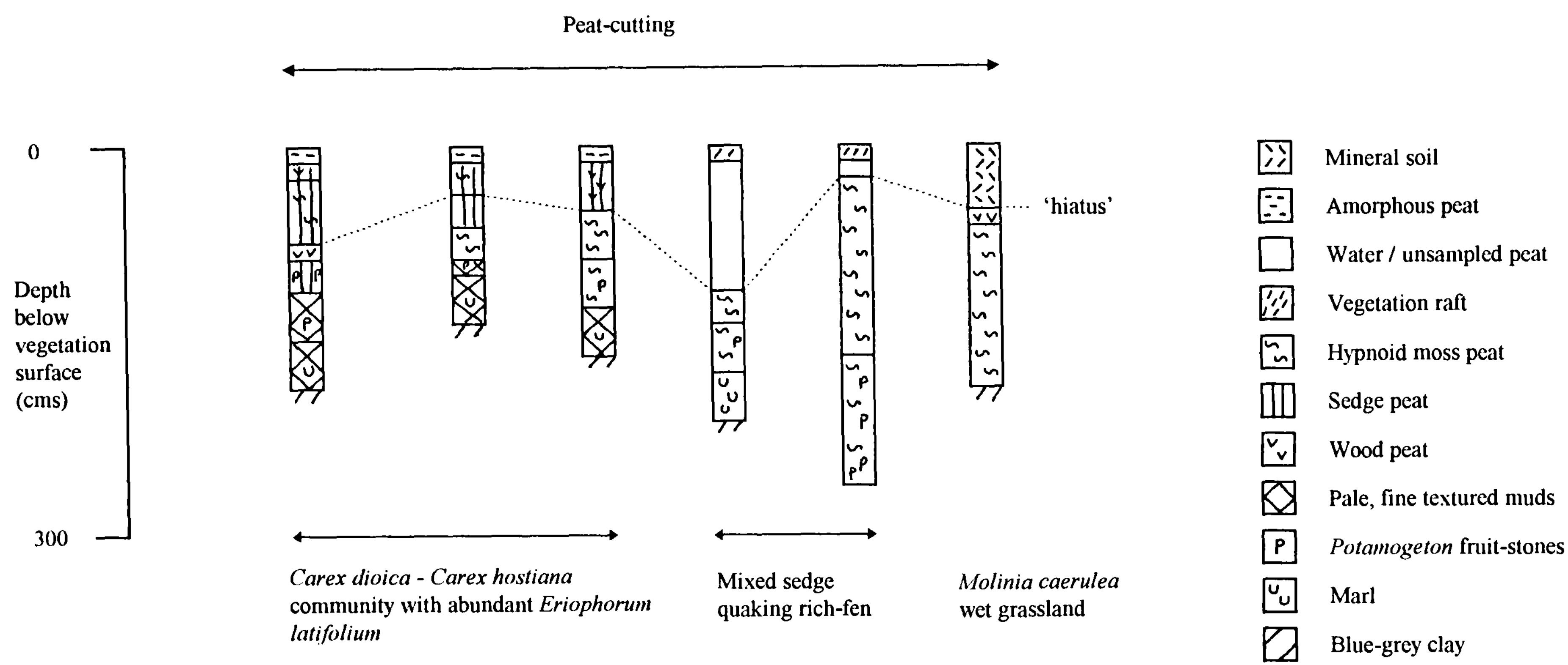


Figure 3.8. Peat stratigraphy of Muirield Moss along transect A-B (for transect location see figure A2.8 in Appendix 2).

forestry and landfill, some sites used as pasture have been fertilised; others have been dug out, re-flooded and used as lakes or ponds. Many more have simply been fenced off and forgotten.

3.3.9.1 Removal of peat and marl

Peat could be obtained from sites either by first draining the site and then cutting the peats out, or by scooping wet peat out of pits. Drainage was the most effective method and would begin with a network of surface drains on the site and at the outflow (which had to be made deeper as more peat was removed). The deeper the drains, the more difficult and expensive the drainage operation. Therefore the deeper deposits were the most difficult and costly to remove. If marl was to be removed then the peat overlying the marl had to be removed first.

Draining a fen site was often an expensive operation but many landowners and tenants were prepared to pay, particularly if they could sell the peat and marl. The cost was calculated by surveyors who would also determine how much peat and marl were present and how much water would need to be removed to yield the greatest quantity of peat and /or marl.

3.3.9.2 Benefits of drainage

The reasons for draining a site were numerous:

- create pasture / arable land;
- remove peat, if present, for use as fuel;
- remove marl, if present.

Without drainage the fen site was less useful: it could be used as pasture for livestock during dry seasons and when the ground was frozen but was also a drowning hazard for livestock. In addition the hay could be cut by hand from sites which were inaccessible to livestock.

The possible benefits of draining fens meant that most of the sites in the Scottish Borders show some signs of attempted drainage although some attempts were more successful than others. Sometimes where peat and marl deposits were removed the site has subsequently re-flooded. In other cases the drains remained effective and agricultural land has been created. After each bout of peat cutting was finished the turf of vegetation which was removed from the top peats at the start of cutting was put back onto the peat surface to produce a new vegetation surface.

3.3.9.3 Quantities of peat and marl removed from some of the Scottish Borders fens

About 40 cartloads of peat were required by each household per year. This approximates to 90 cubic metres of peat which is a similar amount to that allowed to the commoners in Norfolk (Wheeler & Shaw 1995a). The peat shrank when it was drained and as it dried on the spreading ground around sites so these figures would represent less than the equivalent volume of wet peat 'in situ'. A simple estimate of the reduction in volume of a site after drainage is presented in table 3.18.

Table 3.18. Estimation of the reduction in peat volume after drainage based on the difference in height of the lip of the drain above the present vegetation surface. (This does not account for shrinkage of peat after drainage or for deposits which would have occurred beneath the present surface before re-flooding.)

Site	*Height of drain lip above fen surface (m)*	*Area of basin (m^2)*	*Estimate of reduction in peat volume (m^3)*
Muirfield Moss	3.08	39200	120736
Whitmuihall Loch	1.13	88900	100457
Murder Moss	0.89	88800	79032
Ashkirk Loch	1.255	50200	63001
Nether Whitlaw Moss	0.53	42300	22419
St. Leonard's Moss	0.87	24200	21054
Kippilaw Moss	2.2	7600	16720
Beanrig Moss	0.375	13500	5062.5

Accounts for estates which ran 'commercial' peat and marl extraction operations provide an insight into the quantities removed during the period of operation and how profitable a successful operation could be:

- Accounts for the marl sales at Groundistone Moss during 1813 report the sale of 3500 cubic yards of marl during that year. Groundistone Moss was stripped of peat and marl between 1813-1833;
- At Blackpool Moss 900 cubic yards of marl was removed during the period of operation of the marl pit between 1789 and 1791;
- Upto 5 m of peat was removed from the eastern side of Toshawhill Moss between 1811 and 1819;
- The income from the sale of peat at Whitmuihall Loch averaged £30 per year during the 1880's and the total income from marl sales between 1772 and 1807 was calculated at £5082.19s.

3.3.10 CHARACTERISTICS AND DEVELOPMENT OF CUT-OVER SURFACES

Most of the sites investigated in the Borders contain peat and / or marl cuttings. Therefore much of the present vegetation has developed in the past 200 years (since the cessation of peat and marl extraction). There seem to be two basic mechanisms and outcomes of re-vegetation of peat-cuttings:

1. Formation of vegetation rafts;
2. Formation of vegetation rooted into the base of the peat cutting.

3.3.10.1 Formation of vegetation rafts

The presence of a vegetation raft is not a reliable indicator of a re-vegetated peat cutting. However many sites where there is evidence of peat and / or marl removal now contain vegetation rafts. These rafts can either be floating over watery, fluid peat (e.g. Groundistone Moss, Nether Whitlaw Moss), or they can be "grounded" where the raft quakes but overlies a thin layer of loose peat (e.g. Beanrig Moss). Typically vegetation rafts support a luxuriant bryophyte cover, probably because of the hydrostatic environment maintained by the raft (Green & Pearson 1968, Giller & Wheeler 1986). The mechanisms of raft formation and development will be discussed further in chapter 5.

3.3.10.2 Formation of vegetation rooted into the base of the peat cutting

Re-vegetation also occurs through the direct colonisation of the base of the peat cutting. This can occur where the drains flowing out of a site remain unblocked after the cessation of peat and marl removal. This situation occurs widely in the Scottish Borders fens and the resulting surface can support a wide range of habitats and vegetation types. These include:

- Species-rich flushes with numerous rich-fen bryophytes and small sedges over seepage areas around the edges of sites on skeletal residual marl and peat (e.g. Muirfield Moss, Beanrig Moss, Ashkirk Loch). These areas are often not as species-rich as rich-fen flush vegetation in corresponding un-modified fens (e.g., fens in Anglesey) and this may be due to their recent development (Wheeler & Shaw 1995a). As their development continues, provided there is an adequate pool of colonists, their species richness may increase. This has been observed in successional stages of colonisation of marl beds in the U.S.A. (Seichab 1984);
- Fen meadow and rush pasture. These communities are often found in re-vegetated peat cuttings where there are less obvious spring inputs and where the surface of the peat has become oxidised. These communities are often present around the margins of cut-over sites where much of the peat was completely stripped.
- Sedge swamp. These communities are often species poor and flooded for much of the year. They may represent situations where the drains have gradually become blocked, and where there are high fluctuations in the water table, favouring large sedge species and reeds.

3.3.10.3 Factors influencing the re-vegetation of peat and marl cuttings

It is unclear which factors are most important in determining the recolonisation and re-vegetation of peat and marl cuttings, and the precise mechanisms of raft formation are uncertain; however effectiveness of the drains at the cessation of peat cutting is likely to be important. Documentary evidence from Kingside Loch reports the deliberate re-flooding of this site, which in a partly drained state was a breeding ground for liver fluke and therefore a hazard to livestock (Robson 1985) so it is possible that some sites with poor drainage were deliberately dammed. Sites where the drainage was good would probably have been left and the new vegetation used as extra pasture for livestock. However some of these may also have gradually re-flooded as the drains became blocked.

A summary of factors affecting the re-vegetation of a former peat or marl cutting is presented in figure 3.9. These include:

- The morphology of the basin after the cessation of peat and marl operations and the amount of residual peat. White (1930) found that peat cuttings of different depths re-vegetated differently;
- The efficiency of the drains. Where drainage was poor, deeper sites with steeper sides would be more likely to develop vegetation rafts supporting rich fen vegetation where there was a strong influence from groundwater. Poor-fen, and in one case embryonic raised bog, has developed on the fen surface which has become isolated from groundwater inputs.;
- The occurrence and rate of discharge of springs. Where drainage remained good on sloping sites with discharging springs, flushed rich-fen vegetation, and wet grassland would probably occur.
- The source of the colonising material. This would depend on the presence of species present in others areas of the site, and in the vicinity, and the practise of "shoeing" the moss - returning the turf at the top of the peat to the base of the cutting.

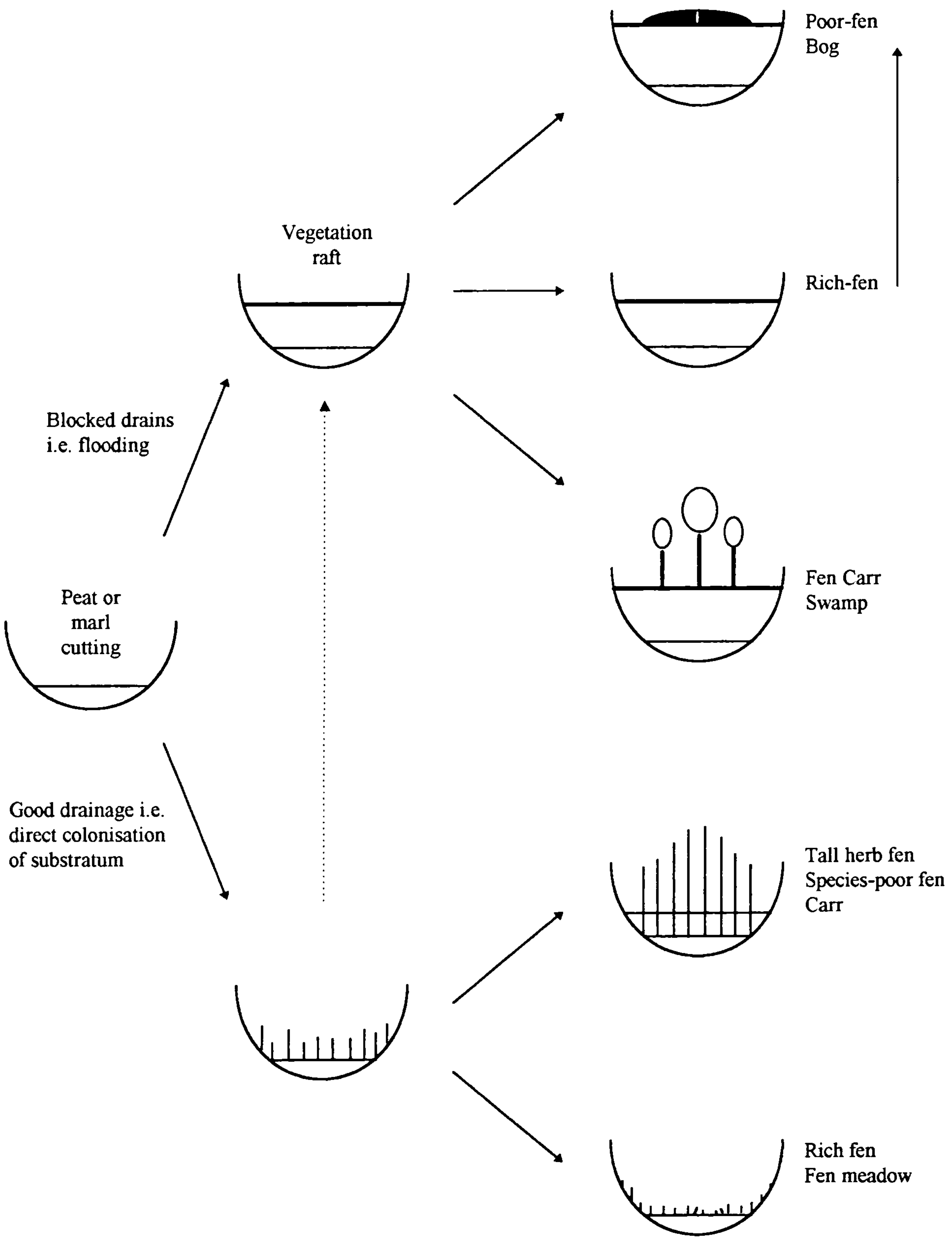


Figure 3.9. Probable pathways of re-vegetation of peat cuttings and marl pits.

Chapter 4: Investigations into Relationships between Fen Water Chemical Conditions, Peat Fertility and Vegetation Composition.

4.1 Introduction.

Plants derive nutrients for growth from the substratum in which they grow. Different plants thrive under different conditions. In fens plants obtain nutrients from decomposing organic matter in the peat and from the water which irrigates the peat. The source and chemical composition of water irrigating fens has been regarded as important in determining the occurrence of particular vegetation types (Du Rietz 1949). Many studies have demonstrated the correlation of a gradient of decreasing pH and base-richness in mire waters with the change in vegetation types from rich-fen to poor-fen to bog (Sjors 1950, Malmer 1986,Vitt & Chee 1990). However the specific chemical requirements and constraints on the distribution of particular species and plant communities have been difficult to determine and vary between areas (Sjors 1950, Proctor 1992). Rich-fens are fed mainly by base-rich groundwater whereas poor fens are fed by base-poor water. Where poor-fen develops within rich-fen, then the poor-fen vegetation is fed mainly by rain-water, because the vegetation surface has become isolated from the base-rich groundwater.

The fertility of the substratum, that is its capacity to sustain plant growth, and the availability of the plant growth nutrients nitrogen, phosphorus and potassium can be particularly important in influencing the structure and composition of vegetation (Verhoeven *et al* 1983, Wheeler 1983, Verhoeven *et al.* 1988). Increased nutrient availability often causes increased growth and greater productivity so that the vegetation becomes taller and more robust (Wheeler & Giller 1982). This often just affects a few species and those which cannot compete often become overgrown and perish. Therefore an increase in fertility can lead to a change in vegetation composition and a loss of species, in particular of low-growing herbs and bryophytes. Fewer rare species occur in stands of fen vegetation with a high standing crop (Wheeler & Giller 1982, Shaw & Wheeler 1992).

In lowland Britain fens are often surrounded by intensively farmed agricultural land and inputs of nutrients and silt in the drainage and runoff from the fields can substantially increase the nutrient status and hence the fertility of the fen peat (Wheeler 1983). Increases in the rates of atmospheric nitrogen deposition, nitrogen and phosphorus transport from heavily fertilised agricultural areas via shallow groundwater and surface water flow have caused nutrient enrichment in Dutch wetlands (Verhoeven *et al.* 1993). This enrichment can lead to increased productivity of the vegetation and the decline of rare species (Wheeler 1983, Van Wirdum 1991) and these effects are more severe in sites which are unmanaged (mown or grazed) (Shaw & Wheeler 1992).

The Scottish Borders fens are percolating fens, topogenous fens irrigated by telluric water and springs from Silurian greywackes, and from runoff from the surrounding land. The countryside surrounding the fens is mainly agricultural land ranging from unimproved rough pasture to intensive arable land, and many sites are considered to be at risk from nutrient inputs from the surrounding land, although the impact of the input of nutrients on the vegetation has not been quantified. The fens support a range of vegetation types including both rich and poor-fen. Site management is usually through grazing although this is rare and the majority of sites are fenced off from the surrounding land and are unmanaged.

The objectives of this part of the study were to determine:

1. The variation in chemical composition of interstitial water, peat fertility and inorganic content of peat from Borders fen sites
   (a) from areas supporting different vegetation types;
   (b) along transects, representing possible environmental gradients, across sites.
2. The impact of surrounding land-use on the fertility and chemical composition of peat and interstitial water within fen sites.
3. The impact of differing chemical conditions on the occurrence of different vegetation types.

4.2 Methods

4.2.1 SAMPLE SITES

The relationship between vegetation types and chemical conditions, fertility and surrounding land use of a range of contrasting sites (table 4.1) was investigated using sample points located in different vegetation types and along transects reflecting the vegetation zonation and / or an environmental gradient, for example, from the inflow to the centre of the site. The site maps and locations of transects are presented in Appendix 2.

Table 4.1. Characteristics of the sites selected for investigation of peat fertility and water chemistry.

Code	*Site*	*Habitat*	*Surrounding Land use*
WHM	Whitehaughmoor Moss	quaking rich fen	unimproved flushed pasture
BE	Beanrig Moss	rich fen	improved pasture / rough grassland
MU	Murder Moss	quaking fen /sedge swamp	improved pasture
K	Kippilaw Moss	quaking rich fen	improved pasture / tillage
AL	Ashkirk Loch	quaking poor fen / swamp	recent forestry plantation
WL	Whitmuirhall Loch	sedge and reed swamp	improved pasture
SL	St. Leonard's Moss	rich fen	improved pasture / tillage
MM	Muirfield Moss	wet grassland / rich fen	rough grassland
GM	Groundistone Moss	reedbed / quaking poor fen	improved pasture / tillage
NW	Nether Whitlaw Moss	quaking poor fen	improved pasture
BL	Blind Moss	quaking fen	rough grassland
LM	Long Moss	quaking fen and bog	rough grassland

At each sample point the vegetation was recorded and coded as for the general survey, the field pH and electrical conductivity were recorded, and the gross peat stratigraphy was recorded. Samples of peat and water were collected from the same sample points for assessment of fertility and chemical analysis, respectively.

The adjacent land use to the site was scored on a 14 point scale (table 4.2).

Table 4.2. Catchment Management Score (C.M.S.) used to categorise the agricultural intensity of surrounding land-use.

C.M.S. score	*Description of surrounding land*
1	Unimproved (moorland grassland)
2	Improved moorland / Rough grassland
3	Forest (plantation)
4	Small areas improved
5	>50% unimproved
6	>50% unimproved + intensive farmland
7	25-50% unimproved
8	25-50% unimproved + intensive farmland
9	<25% unimproved
10	<25% unimproved + intensive farmland
11	Mostly improved grassland
12	Mostly cultivated
13	Mostly intensive grassland
14	Mostly intensive cultivation

4.2.2 VEGETATION TYPES

The floristic classes of fen vegetation identified from the Scottish Borders fens in Chapter 2 provided the basis for the ordering of the samples collected. 13 distinct plant communities and variants were sampled (table 4.3).

Table 4.3. Plant communities of fen water and peat sampling sites (for sample site locations see Appendix 2).

Code	*Plant community*
FTH	*Filipendula ulmaria* tall-herb fen community
FRP	*Juncus acutiflorus* rush pasture community
FMC	*Molinia caerulea* species-rich wet grassland community
RFF	*Carex dioica - Carex hostiana* community
RFS	*Carex diandra - Sphagnum contortum* community
POR	*Carex rostrata - Sphagnum recurvum* community
BOG	*Eriophorum vaginatum - Sphagnum papillosum* community
RFM	Mixed sedge rich-fen community
RFCb	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant
RFCa	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant
FSM	*Carex rostrata -Potentilla palustris* species-poor community
FSC	*Carex rostrata* species poor community
RPG	*Phragmites australis* reed-bed

4.2.3 PHYTOMETRIC ASSESSMENT OF PEAT FERTILITY

Simple measurements of available nitrogen, phosphorus and potassium (N,P,K) in samples of mire waters have often produced unreliable indications of substratum fertility (Boyer & Wheeler 1989, Vermeer & Berendse 1983). Phytometric assays aim to measure the fertility of the substratum through its capacity to sustain the growth of a test species in controlled conditions. This method is thought to provide some of the best estimates of the fertility of fen soils (Al Farraj *et al.* 1984 , Wheeler *et al.* 1992) and provides a useful technique for comparing the peat fertility across a large number of fen sites.

Samples of peat were collected to 20cm depth from each sample point during February 1994. The surface vegetation was cut off and replaced and the peat was sealed into black plastic bags, transported back to Sheffield, and stored at 5°C until used. Some sample points were omitted due to inclement weather conditions which made access to Nether Whitlaw Moss, Long Moss, Blind Moss and part of Groundistone Moss impossible.

Each peat sample was sorted and mixed by removing large roots and rhizomes and any animals. The peat was then placed into 10 pots which were then arranged into sandwich boxes. The sandwich boxes were filled to a constant level with distilled water to keep the peat waterlogged. Five matched week-old seedlings of the phytometer species *Phalaris arundinacea* were planted into each pot. These were thinned to 3 matched seedlings after one week. The seedlings were grown under constant light and temperature conditions in a greenhouse for 10 weeks. The seedlings were then harvested and dried to constant weight in a 50^{0}C oven, and weighed. The peat fertility is therefore expressed as mg dry weight per plant.

Sub-samples of peat were collected and 25cm^3 were mixed to a slurry with an equal volume of distilled water. The pH and electrical conductivity of this slurry were recorded. The rest of the sub-sample was oven dried at 40^{0}C, homogenised, and a sample of known weight was ashed at 400°C to determine percentage loss on ignition, as an indication of the organic content of the peat.

4.2.4 WATER CHEMICAL DETERMINATION

Water samples were collected from each sample point during April 1994. Clean, dry, 250ml polythene bottles were completely filled with interstitial water which had re-filled 20cm recently dug pits. pH and electrical conductivity of the samples were measured in the field. The samples were stored in the dark and at 5°C. They were filtered and analysed for cations (ammonium, sodium, potassium, calcium, magnesium, iron and manganese) and anions (phosphate, nitrate, sulphate, chloride) as specified in table 4.4.

Table 4.4. Methods of measuring the concentrations of cations, anions, pH and conductivity of water samples.

Measured variables	*Method*	*Instrument Specification*
Ca, Fe, Mn, Mg	Atomic Absorption Spectrophotometry	Perkin Elmer 2100 A.A.S.
K, Na	Atomic Emission Spectrophotometry	Corning Flame Photometer 410
NO_3, PO_4, SO_4	High Pressure Liquid Chromatography	Dionex 2000I H.P.L.C.
NH_4	Calorimetric Indophenol Method (modified from Scheiner, 1976)	Absorbance measured on Cary 1 UV-visible spectrophotometer
pH	pH electrode	Jenway 3030 portable pH meter
Electrical conductivity	Conductivity electrode	Jenway 4070 portable conductivity meter

4.2.5 DATA ANALYSIS

Water types were classified using the L.A.T. (Lithotrophic, Atmotrophic, Thallasotrophic) model (VanWirdum 1991). This uses the ionic ratio $([^1/_2\,Ca^{2+}] / ([^1/_2\,Ca^{2+}] + [Cl^-])) \times 100$ and electrical conductivity at 25°C to characterise the water type of each sample using three basic types as references: lithotrophic (groundwater), atmotrophic (rainwater) and thalassotrophic (seawater). This model is based on the assumption that electrical conductivity values are often correlated with the concentrations of each major ion (Na, Cl, Mg, HCO_3, Ca) so they are a suitable measure of the distribution of base-poor (rainwater and base-poor telluric water) and base-rich water types (calcium-rich telluric water and brackish water). The ionic ratio is used to differentiate between calcium-rich telluric water and brackish water (Wassen, Barendregt, Bootsma & Schot 1989).

The relationships between vegetation types and water chemistry, peat fertility and loss on ignition were examined using Canonical Community Ordination - CANOCO (Ter Braak 1988). This procedure relates the environmental variables associated with each sample to an ordination of the vegetation data. The ordination method (Canonical Correspondence Analysis) upon which CANOCO is based performs reliable ordination of species data and environmental data in conditions where other programs may distort the data, for example, where there are skewed species distributions, quantitative noise in species abundance data, highly intercorrelated environmental variables and in situations where not all the factors determining species composition are known (Palmer, 1993). The results are presented as biplots where the samples are plotted as a scatter plot on the primary and secondary axes of variation. The environmental variables are represented as vectors radiating from the origin. The direction of the arrow indicates the gradient of its influence and the length indicates the strength of its relationship with the variation in sample species data. A Monte Carlo significance test was used to assess the significance of the species-environment relationships.

Correlation coefficients were calculated for all pairs of measured variables. Nested, one factor analyses of variance with a Tukey multiple comparisons test were performed to assess the difference in concentration of each variable between different vegetation types. Minitab (version 10.5) and Microsoft Excel (version 5.0) were used for statistical analyses.

4.3 Results

4.3.1 VEGETATION TYPES

The total species richness and numbers of rare and characteristic bog, poor-fen and rich-fen species associated with each vegetation type are presented in table 4.5.

Table 4.5. Mean species-richness of samples (4m^2 quadrats) representing different vegetation types. Characteristic wetland species are categorised into rare, rich-fen, poor-fen and bog species (see Appendix 3). n is the number of samples.

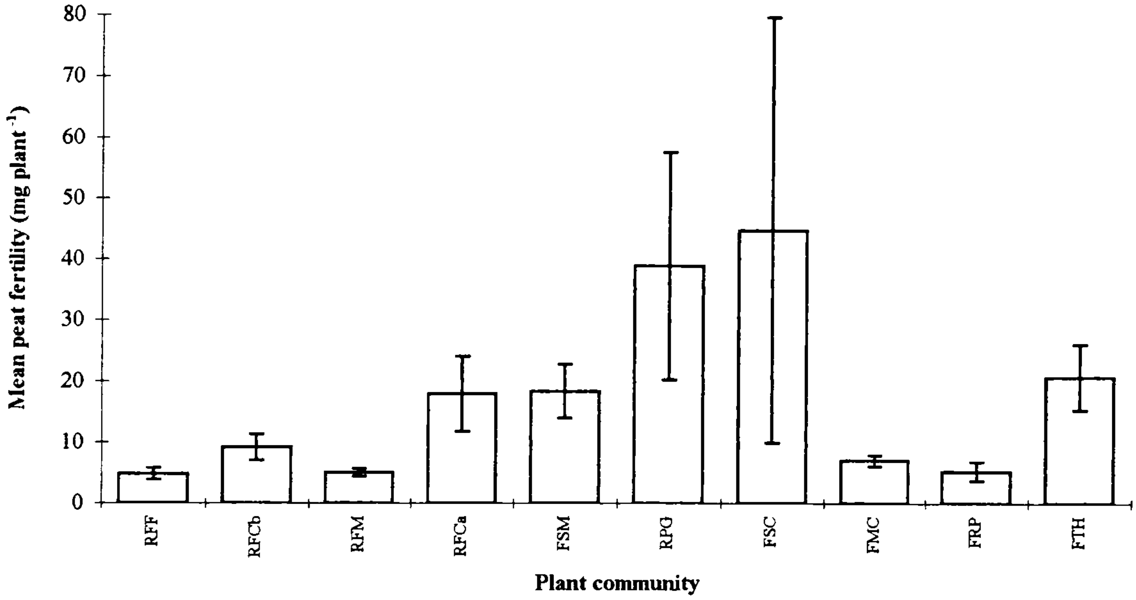
Vegetation type	*n*	*Rare species*	*Rich-fen Species*	*Poor-fen Species*	*Bog Species*	*Total species-richness*
Carex dioica - Carex hostiana community	6	5.8	21.3	11.8	2.5	26.8
Carex diandra - Sphagnum contortum community	2	7.5	26.0	15.5	3.5	32.5
Carex rostrata - Sphagnum recurvum community	4	3.3	17.5	14.3	6.5	26.3
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	12	1.6	13.9	8.6	1.6	16.0
Mixed sedge rich-fen community	7	2.4	14.3	9.7	1.4	17.7
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, Typical variant	6	2.3	14.5	8.7	2.2	16.3
Carex rostrata - Potentilla palustris species-poor community	15	0.9	10.4	6.3	0.7	12.1
Phragmites australis reedbed	5	0.2	6.8	3.4	0.0	8.8
Carex rostrata species-poor community	4	0.3	6.0	4.5	0.8	7.3
Eriophorum vaginatum - Sphagnum papillosum bog community	2	0.0	4.0	8.5	7.5	13.5
Juncus acutiflorus Rush-pasture	2	1.5	15.0	10.5	3.0	21.5
Molinia caerulea Wet grassland	2	2.5	19.0	12.0	2.5	30.0
Filipendula ulmaria Tall-herb fen	3	0.7	11.3	6.0	0.0	16.0

4.3.2 VARIATION BETWEEN VEGETATION TYPES

The relationship between chemical composition of mire waters and vegetation type shows no clear pattern. Generally the concentrations of cations and anions were low, very variable and, with the exception of magnesium and calcium, did not vary consistently between vegetation types. The results for each variable are presented in figures 4.1a-o and table 4.6. Concentrations of magnesium and calcium showed significant variation between plant communities (Mg: $F = 2.44$, $p<0.05$, d.f. 11; Ca: $F = 6.27$, $p<0.001$, d.f. 11). Electrical conductivity and pH also showed significant variation between plant communities.

Table 4.7 summarises the peat fertility and soil water pH and electrical conductivity associated with different plant communities. Greater fertility is associated with species-poor and tall herb vegetation (*Carex rostrata -Potentilla palustris* species-poor community, *Carex rostrata* species poor community, *Phragmites australis* reed-bed, *Filipendula ulmaria* tall-herb fen community) although there is often large variation between samples. The highest values are those associated with particular nutrient input points, and with silt enrichment. These vegetation types are often rooted in a silty or mineralised peat substratum (table 4.7).

(a)



(b)

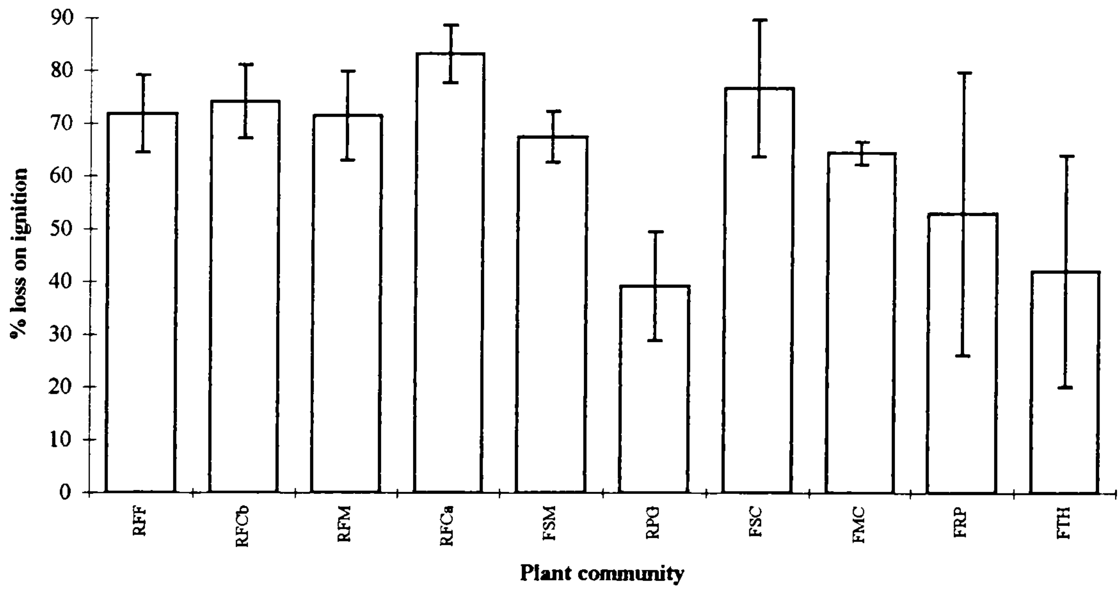
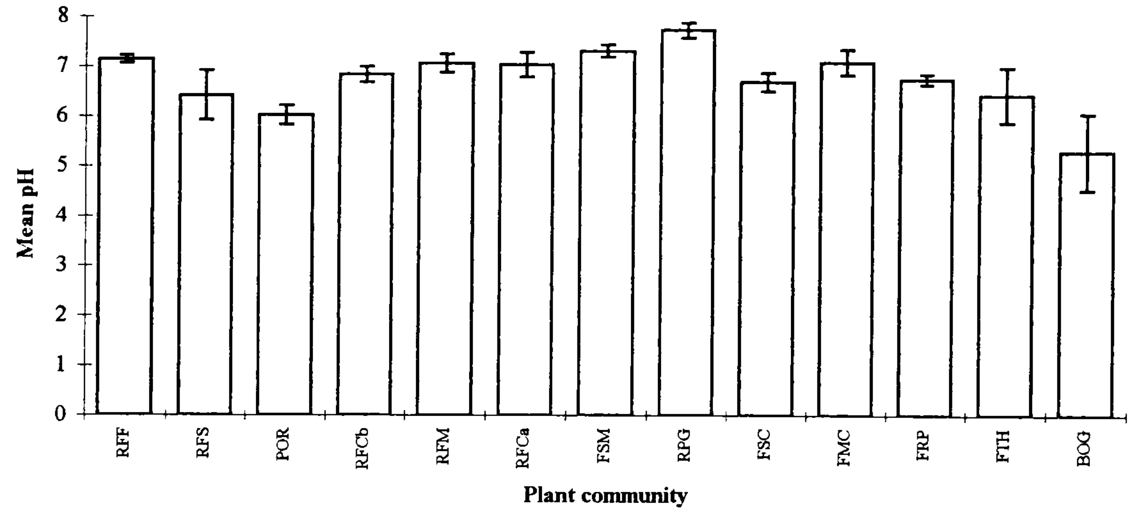


Figure 4.1. Mean values (+/- Standard Error) of environmental variables associated with different plant communities. Plant community codes follow table 4.3.
(a) Peat fertility: not significant $p = 0.097$
(b) % Loss on ignition: not significant $p = 0.107$

(c)



(d)

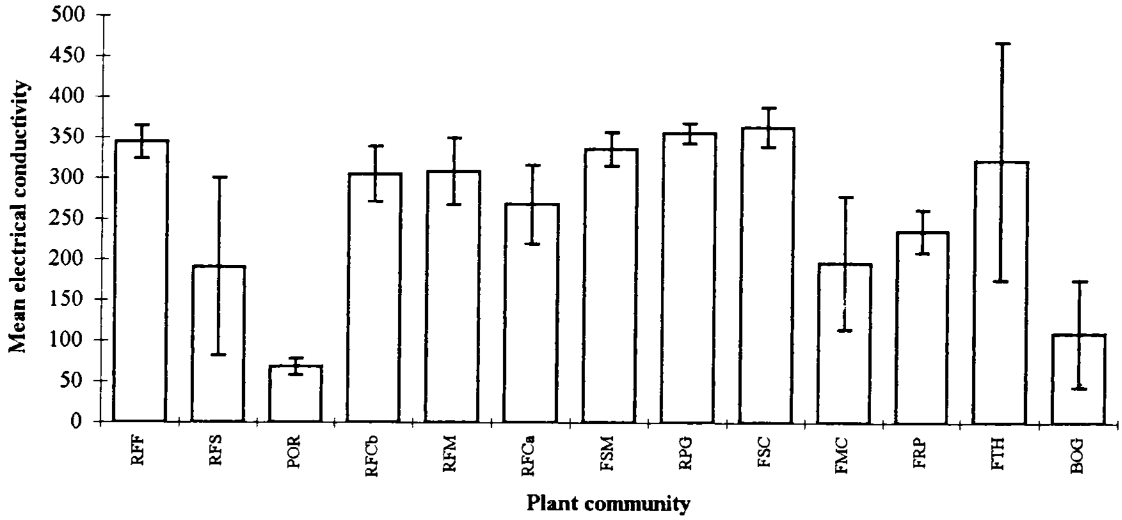
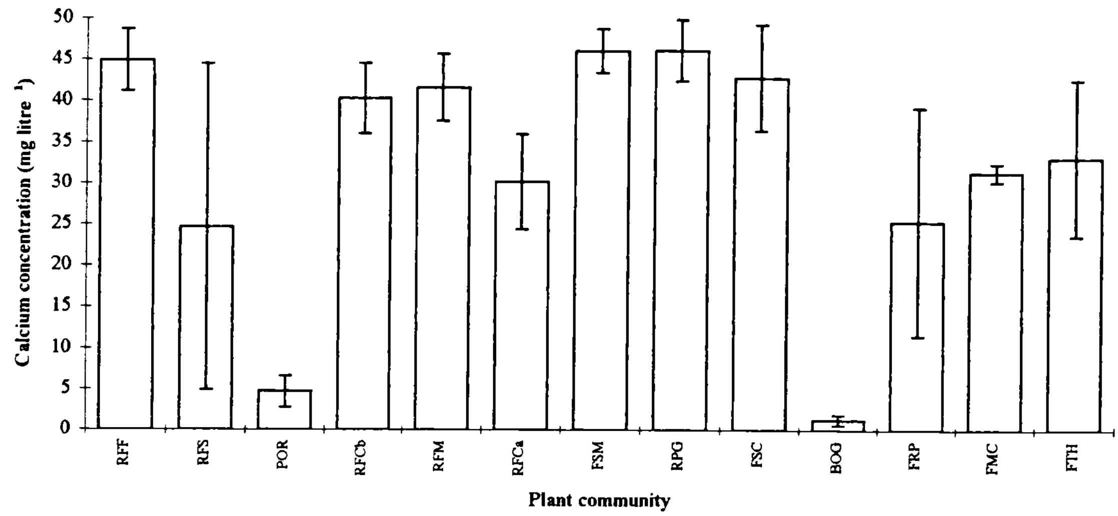
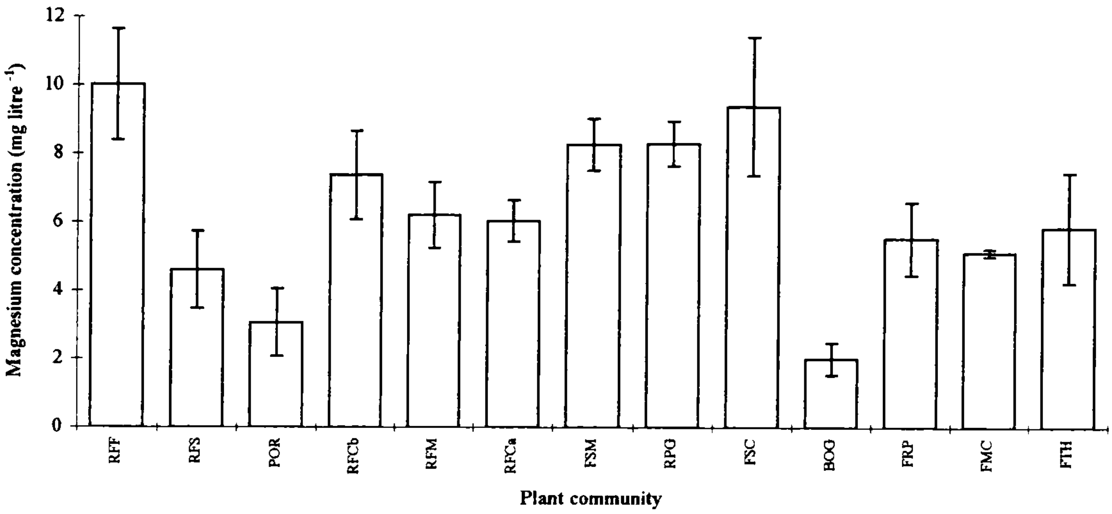


Table 4.1 cont.
(c) pH: $F = 5.81$, $n = 69$, $p < 0.001$.
(d) Electrical conductivity ($\mu S\ cm^{-1}$): $F = 3.57$, d.f. 11, $p = 0.001$.

(e)



(f)



(g)

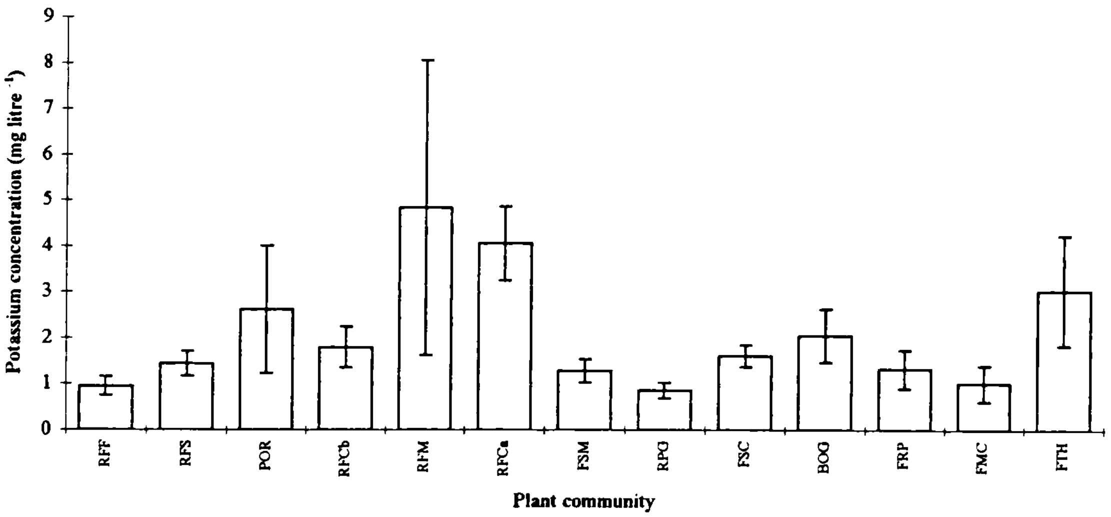


Figure 4.1 cont.
(e) Calcium concentration: $F = 6.27$, d.f. 11, $p < 0.001$
(f) Magnesium concentration: $F = 2.44$, d.f. 11, $p = 0.014$
(g) Potassium concentration: not significant $p = 0.46$

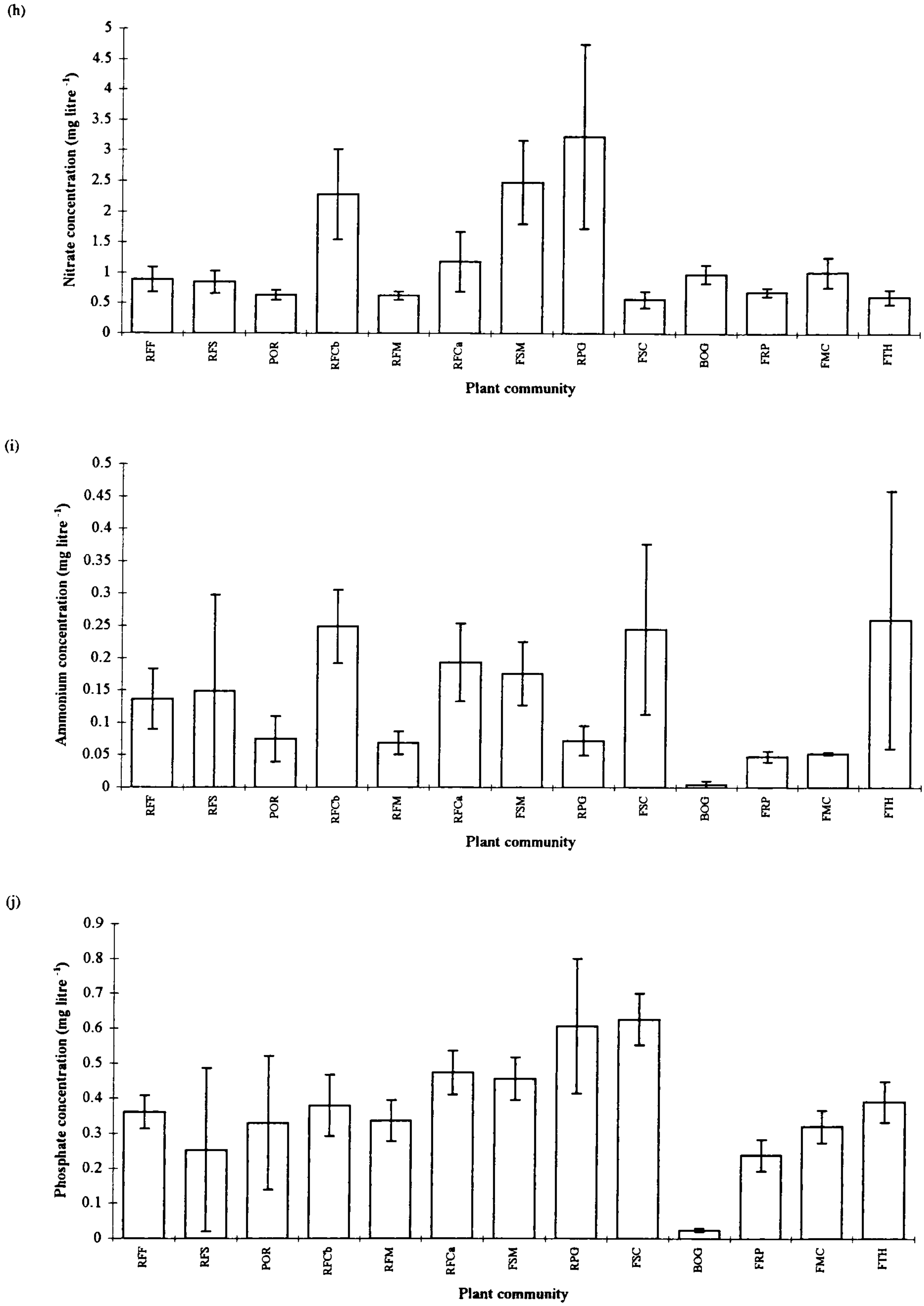
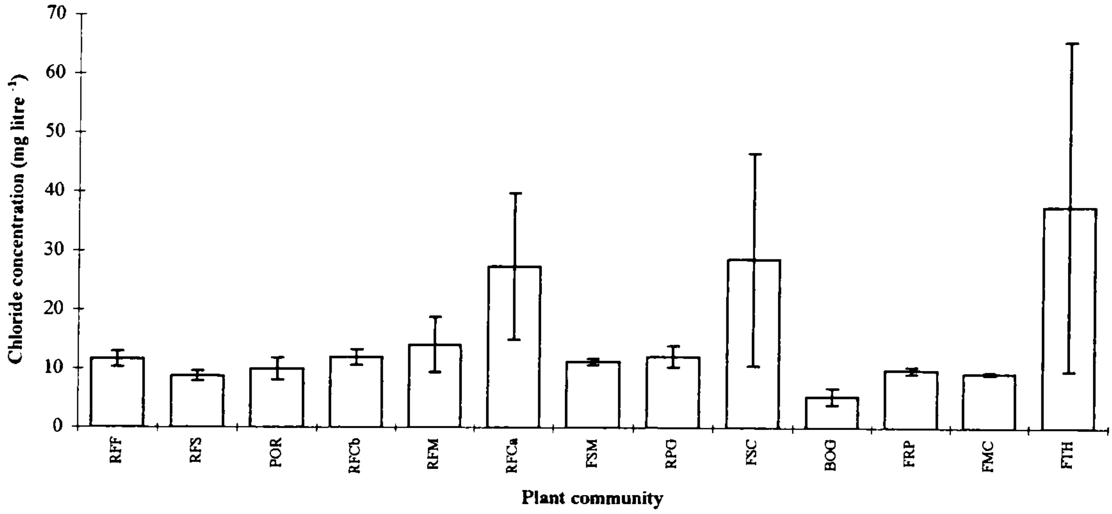


Figure 4.1 cont.
(h) Nitrate concentration: not significant. $p = 0.30$
(i) Ammonium concentration: not significant $p = 0.25$
(j) Phosphate concentration: not significant $p = 0.199$

(k)



(l)

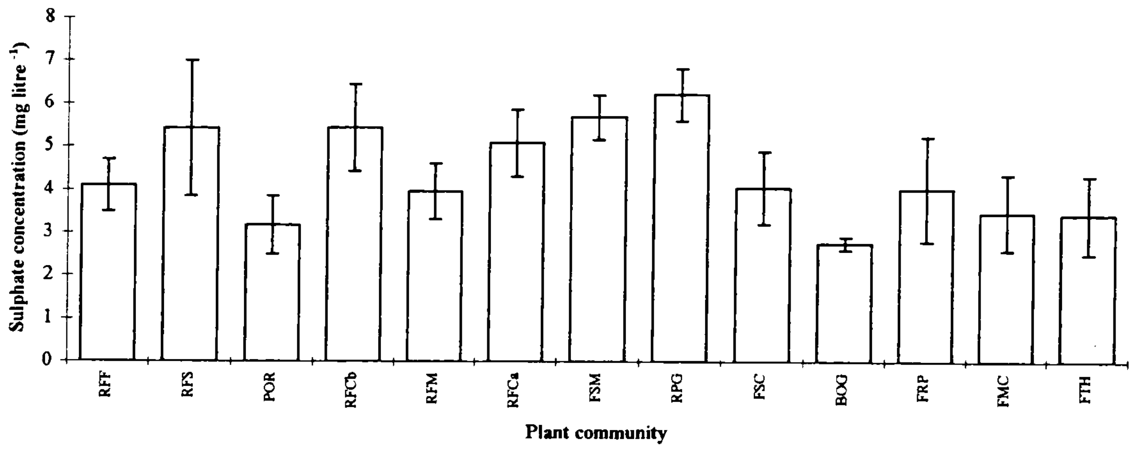


Figure 4.1 cont.
(k) Chloride concentration: not significant. $p = 0.200$
(l) Sulphate concentration: not significant $p = 0.330$

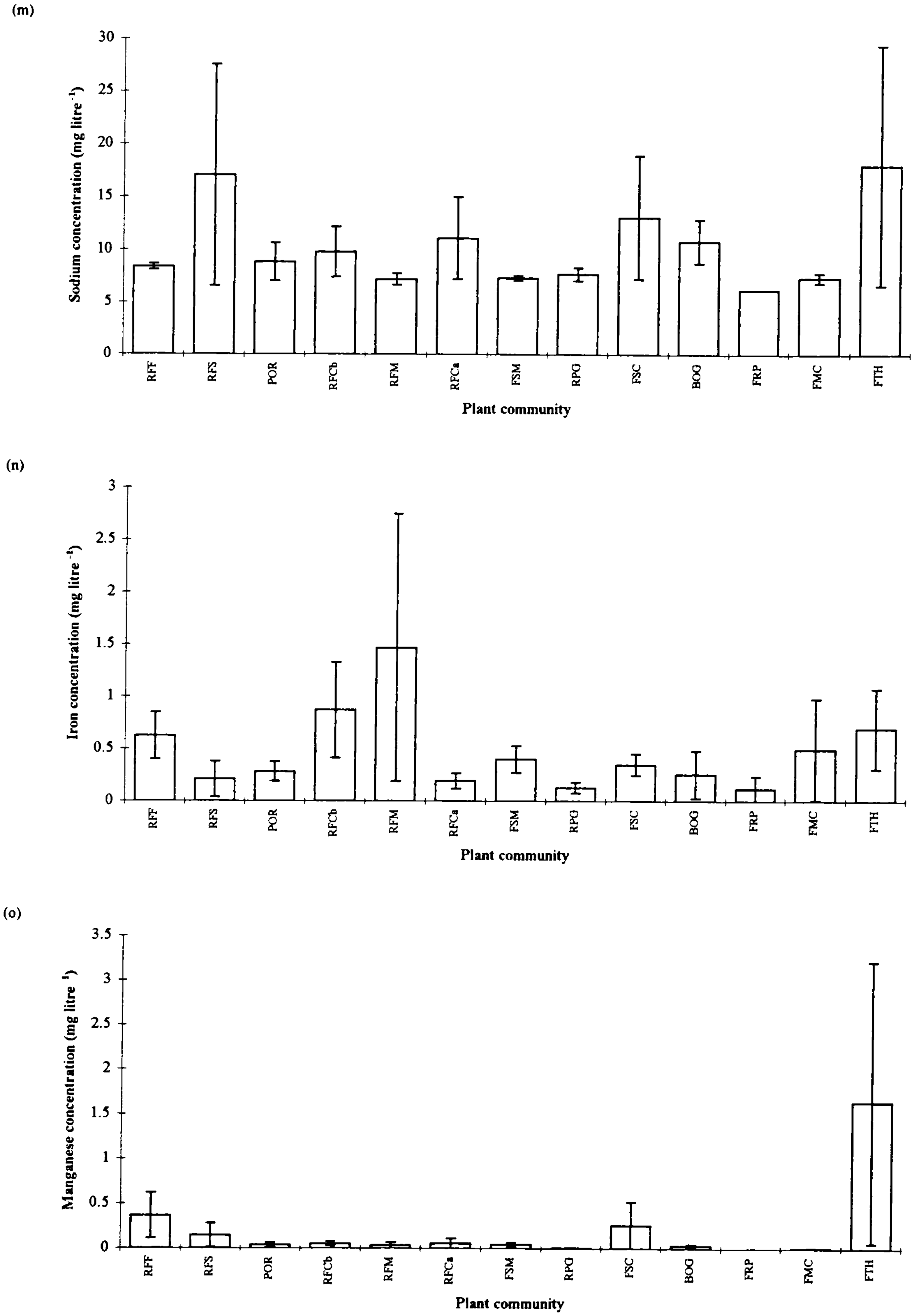


Figure 4.1 cont.
(m) Sodium concentration: not significant. $p = 0.450$
(n) Iron concentration: not significant $p = 0.875$
(o) Manganese concentration: not significant $p = 0.373$

Table 4.6. Mean values (mg l^{-1}) and standard errors (S.E.) of water chemical variables associated with different plant communities in some Scottish Borders fens. n = number of samples.

Plant community	*n*	*Cl*	*S.E*	*NO_3*	*S.E*	*SO_4*	*S.E*	*PO_4*	*S.E*	*Ca*	*S.E*	*Mg*	*S.E*	*Na*	*S.E*	*K*	*S.E*	*NH4*	*S.E*	*Fe*	*S.E*	*Mn*	*S.E*
Carex dioica - Carex hostiana community	6	11.66	1.31	0.89	0.21	4.10	0.60	0.36	0.05	44.97	3.73	10.02	1.62	8.37	0.28	0.96	0.21	0.14	0.05	0.62	0.22	0.37	0.25
Mixed sedge rich-fen community	7	14.0	4.69	0.62	0.07	3.96	0.65	0.34	0.06	41.64	4.09	6.20	0.96	7.21	0.56	4.85	3.22	0.07	0.02	1.47	1.28	0.04	0.03
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostatum community, *Carex diandra* variant	12	11.99	1.30	2.28	0.73	5.44	1.02	0.38	0.09	40.35	4.24	7.37	1.30	9.82	2.37	1.81	0.45	0.25	0.06	0.87	0.46	0.05	0.02
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	6	27.3	12.4	1.19	0.49	5.09	0.78	0.47	0.06	30.22	5.79	6.03	0.60	11.1	3.88	4.07	0.81	0.19	0.06	0.19	0.07	0.06	0.06
Carex rostrata -Potentilla palustris species-poor community	15	11.19	0.52	2.49	0.68	5.69	0.52	0.46	0.06	46.16	2.66	8.26	0.75	7.34	0.22	1.29	0.25	0.18	0.05	0.40	0.13	0.04	0.03
Carex diandra - Sphagnum contortum community	2	8.77	0.85	0.85	0.18	5.43	1.58	0.25	0.23	24.72	19.8	4.61	1.14	17.07	10.5	1.45	0.27	0.15	0.15	0.21	0.17	0.15	0.14
Carex rostrata - Sphagnum recurvum community	4	9.98	1.88	0.64	0.08	3.18	0.68	0.33	0.19	4.74	1.94	3.06	0.99	8.85	1.82	2.62	1.39	0.07	0.04	0.28	0.09	0.04	0.03
Eriophorum vaginatum - Sphagnum papillosum community	2	5.34	1.42	0.99	0.16	2.76	0.15	0.03	0.00	1.25	0.64	2.00	0.47	10.82	2.07	2.06	0.58	0.01	0.01	0.26	0.23	0.04	0.02
Carex rostrata species-poor community	4	28.65	18.1	0.57	0.14	4.06	0.84	0.63	0.07	42.91	6.46	9.39	2.03	13.1	5.85	1.62	0.24	0.24	0.13	0.35	0.10	0.26	0.26
Phragmites australis reedbed	5	12.10	1.80	3.24	1.50	6.22	0.61	0.61	0.19	46.19	3.72	8.29	0.66	7.71	0.60	0.86	0.17	0.07	0.02	0.13	0.05	0.01	0.00
Juncus acutiflorus Rush-pasture	2	9.84	0.60	0.69	0.07	4.02	1.22	0.24	0.05	25.43	13.9	5.52	1.07	6.20	0.01	1.33	0.41	0.05	0.01	0.12	0.12	0.00	0.00
Molinia caerulea Wet grassland	2	9.33	0.23	1.02	0.25	3.47	0.88	0.32	0.05	31.41	1.10	5.11	0.11	7.33	0.48	1.02	0.39	0.05	0.00	0.50	0.49	0.01	0.01
Filipendula ulmaria Tall-herb fen	3	37.74	28.1	0.61	0.12	3.42	0.91	0.39	0.06	33.14	9.50	5.85	1.61	18.0	11.4	3.04	1.20	0.26	0.20	0.69	0.38	1.64	1.58

Table 4.7. Mean fertility, % loss on ignition (%LOI), pH and electrical conductivity values (EC) +/- Standard Error associated with different plant communities.

Vegetation type	*n*	*Fertility (mg/plant)*	*+/- S.E.*	*%LOI*	*+/- S.E.*	*pH*	*+/- S.E.*	*EC (µS/cm)*	*+/- S.E.*
Carex dioica - Carex hostiana community	6	4.75	+/-0.93	71.82	+/-7.38	7.14	+/-0.08	343.87	+/-20.59
Carex diandra - Sphagnum contortum community	1-2	6.79		82.90		6.42	+/-0.50	191.00	+/-109.0
Carex rostrata - Sphagnum recurvum community	1-2	18.03		92.20		6.03	+/-0.20	68.28	+/-9.99
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	10	9.13	+/-2.10	74.15	+/-7.01	6.84	+/-0.15	304.65	+/-33.87
Mixed sedge rich-fen community	7	5.02	+/-0.64	71.46	+/-8.42	7.07	+/-0.18	307.82	+/-40.94
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, Typical variant	4	17.82	+/-6.19	83.21	+/-5.44	7.04	+/-0.25	267.67	+/-48.28
Carex rostrata - Potentilla palustris species-poor community	14	18.30	+/-4.40	67.45	+/-4.82	7.32	+/-0.12	335.48	+/-20.37
Phragmites australis reedbed	5	38.92	+/-18.72	39.15	+/-10.36	7.74	+/-0.15	354.96	+/-12.29
Carex rostrata species-poor community	3	44.77	+/-34.91	76.77	+/-12.99	6.70	+/-0.18	362.70	+/-24.31
Eriophorum vaginatum - Sphagnum papillosum bog community	2					5.29	+/-0.77	109.50	+/-65.83
Juncus acutiflorus Rush-pasture	2	6.95	+/-0.94	64.45	+/-2.15	7.09	+/-0.25	196.40	+/-81.60
Molinia caerulea Wet grassland	2	5.24	+/-1.51	52.88	+/-26.88	6.76	+/-0.10	235.00	+/-26.20
Filipendula ulmaria Tall-herb fen	3	20.68	+/-5.37	41.97	+/-21.98	6.43	+/-0.55	321.87	+/-146.2

Flush and rich-fen vegetation types were associated with the lowest fertility peat (table 4.7). There is an interesting gradient in the fertility of peat samples associated with fen plant communities characterised by abundant *Carex rostrata* (table 4.8). The fertility of peat increases from the more variable and usually more species-rich Mixed sedge rich-fen community (associated with the lowest fertility peat) to the distinctive *Carex rostrata - Calliergon cupidatum / Plagiomnium rostratum* community, *Carex diandra* variant to the *Carex rostrata - Calliergon cupidatum / Plagiomnium rostratum* community, typical variant to *Carex rostrata - Potentilla palustris* species-poor community (associated with the highest fertility peat).

Table 4.8. Fertility of peat samples associated with *Carex rostrata* - based plant communities. Statistical significance between values is indicated by letters a,b,c. Differing letters indicates that the values are statistically significant (P<0.05). No difference indicates no statistical significance.

Vegetation type	*Mean peat fertility (mg dry weight / plant +/- S.E.)*
Mixed sedge rich-fen community	5.02 +/- 0.64^{a}
Carex rostrata - Calliergon cupidatum / Plagiomnium rostratum community, *Carex diandra* variant	9.13 +/- 2.10^{b}
Carex rostrata - Calliergon cupidatum / Plagiomnium rostratum community, typical variant	17.82 +/- 6.19^{c}
Carex rostrata - Potentilla palustris species - poor community	18.30 +/- 4.4^{c}

4.3.3 WITHIN SITE VARIATION IN PEAT FERTILITY AND WATER CHEMISTRY

The chemical composition of interstitial water and peat fertility were often variable within sites (tables 4.9 - 4.18). Generally the largest differences are seen in electrical conductivity, calcium, magnesium and chloride concentration, fertility and percentage loss on ignition of the peat. These are most markedly different in areas of spring water discharge and at the edges of sites, near inflows and drains. The fertility values of samples from apparently spring-fed areas are consistently small (Beanrig Moss, Whitehaughmoor Moss, Muirfield Moss).

Ashkirk Loch (table 4.9)

The fertility of samples AL7 and AL8 were the lowest at this site. These represented Mixed sedge rich fen vegetation closer to spring-fed areas at the northern margins of the site. The electrical conductivity, calcium, magnesium, and organic content of the peat also increased towards this end of the transect. The sample from the inflow (AL3) contained a relatively high proportion of inorganic matter, probably due to inwashed silt from the surrounding land. The surrounding land supports an immature forestry plantation.

Beanrig Moss (table 4.10)

The peat fertility at this site was greatest further from the spring-fed areas towards the centre of the site. Electrical conductivity was highest in spring fed areas (BE3 and BE6), probably because of the correspondingly higher calcium, magnesium and chloride concentrations. Loss on ignition was lowest in areas with the shallowest peat (BE6 and BE5) at the margins of the site.

Groundistone Moss (table 4.11)

This site was surrounded by intensively farmed land, permanent pasture and arable cultivation. The central *Sphagnum*-rich area is surrounded by a silty moat containing *Phragmites australis* swamp, *Carex rostrata* swamp and *Glyceria fluitans* swamp. All these marginal areas were very fertile probably due to the inwashed silt deposits from the adjacent land. The flooded margins prevented access to the central areas of the site at the time of substratum sampling.

Kippilaw Moss (table 4.12)

The fertility of the substratum was generally greater near the edges of the site but one sample nearer the centre of the site had the highest recorded fertility in the Scottish Borders fens (K2). This sample was taken from a very swampy area near a large pool. The land surrounding Kippilaw Moss is intensively farmed with permanent pasture along the northern edge and

Table 4.9. Ashkirk Loch. Values of environmental variables and standard errors (S.E.) from samples at Ashkirk Loch. Locations of samples are presented in Appendix 2. Samples AL3, AL4, AL6, AL7, AL8 are located along transect A-B. Plant communities are coded as for table 4.3. Units are as follows: E.C (electrical conductivity mS cm^{-1}), Fertility (substratum fertility, mg dry weight of phytometer species), water chemical variables calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), manganese (Mn), chloride (Cl), phosphate (PO_4), nitrate (NO_3), sulphate (SO_4) and ammonium (NH_4), in mg l^{-1}.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
AL1	RFCb	181.8	10.5	6.4	0.0	62.7	0.8	5.7	0.6
AL2 (edge)	FMC	318.6	1.5	6.8	0.1	29.0	0.6	7.6	1.0
AL3 (inflow)	FTH	184.8	0.9	7.3	0.0	12.9	0.1	20.9	2.1
AL4	RFCb	128.0	6.8	7.0	0.1	20.4	0.1	23.7	3.4
AL5	RFM	171.0	4.3	6.5	0.0	55.1	0.2	4.2	0.3
AL6	FSM	170.4	1.0	6.6	0.0	61.1	0.1	25.4	3.6
AL7	RFCb	258.2	3.4	6.6	0.1	89.9	0.9	4.5	0.1
AL8	RFCb	307.2	1.4	7.3	0.1	83.9	0.4	3.6	0.2

table 4.9 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Fe*	*S.E.*	*Cl*	*S.E.*	*NH_4*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
AL1	26.5	1.6	3.9	0.3	0.6	0.1	6.2	0.2	0.7	0.3	8.9	0.3	0.1	0.0	0.3	0.2	2.3	0.8	0.5	0.2
AL2 (edge)	53.5	1.3	4.8	0.2	0.0	0.0	5.7	0.2	0.2	0.1	9.3	0.2	0.0	0.0	0.3	0.2	2.2	0.2	0.5	0.2
AL3 (inflow)	24.5	1.0	4.1	0.2	1.0	0.0	5.9	0.2	0.0	0.0	9.2	0.2	0.0	0.0	0.3	0.2	5.1	0.2	0.8	0.1
AL4	16.3	1.3	2.6	0.2	1.7	0.1	5.4	0.2	4.5	1.4	8.5	0.6	0.2	0.1	0.6	0.2	1.8	0.2	0.8	0.2
AL5	23.1	0.3	3.5	0.3	23.2	22.3	6.6	0.4	7.3	2.1	9.7	0.2	0.2	0.0	0.1	0.1	2.2	0.3	0.8	0.2
AL6	24.1	0.7	3.7	0.2	2.4	0.1	7.4	0.3	0.5	0.2	10.5	0.2	0.1	0.1	0.2	0.1	2.0	0.2	0.7	0.1
AL7	37.1	2.0	5.3	0.3	1.3	0.1	8.0	0.3	1.2	0.5	11.7	0.3	0.1	0.0	0.2	0.2	2.3	0.2	0.2	0.1
AL8	48.1	1.4	7.2	0.4	0.8	0.2	8.4	0.3	0.0	0.0	24.2	6.7	0.6	0.1	0.4	0.2	11.0	0.5	1.8	0.6

Table 4.10. Beanrig Moss. Values of environmental variables and standard errors (S.E.) from samples at Beanrig Moss. Locations of samples are presented in Appendix 2. Samples BE1, BE2 and BE3 are located along transect A-B. Samples BE4, BE5 and BE6 are located along transect C-D. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
BE1(edge)	RFS	82.6	2.5	5.9	0.1	92.2	0.0	18.0	1.7
BE2	RFCa	192.4	25.8	6.6	0.1	89.1	0.0	29.6	3.1
BE3 (edge)	RFF	364.2	6.1	7.3	0.1	90.1	0.0	3.3	0.1
BE4 (edge)	RFCa	143.0	4.4	7.1	0.1	88.5	0.1	10.9	1.1
BE5	FMR	114.8	2.7	6.8	0.1	66.6	0.1	7.9	1.2
BE6 (edge)	RFF	312.0	3.2	7.1	0.0	51.8	0.4	3.2	0.2
BE7	RFS	82.0	1.7	5.9	0.0	-	-	-	-

Table 4.10 cont.

sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
BE1(edge)	10.0	1.0	3.9	0.2	2.0	0.2	5.8	0.2	0.3	0.2	0.1	0.0	8.6	0.4	0.6	0.2	1.9	0.4	0.6	0.0
BE2	22.2	1.6	5.7	0.3	1.6	0.4	8.0	0.4	0.4	0.1	0.2	0.1	17.6	7.3	0.2	0.1	2.9	0.5	0.6	0.1
BE3 (edge)	45.5	2.8	16.1	0.7	0.6	0.0	8.9	0.3	0.0	0.0	0.2	0.1	10.0	0.5	0.4	0.2	4.7	0.4	0.5	0.1
BE4 (edge)	14.7	1.2	5.3	0.4	2.3	0.2	6.6	0.2	0.1	0.1	0.0	0.0	8.9	0.1	0.5	0.3	3.1	0.1	0.6	0.1
BE5	11.5	1.9	4.5	0.4	1.7	0.1	6.2	0.3	0.0	0.0	0.0	0.0	9.2	0.2	0.2	0.1	2.8	0.1	0.6	0.1
BE6 (edge)	32.1	2.2	12.3	0.8	0.7	0.0	8.6	0.2	0.2	0.1	0.1	0.0	17.3	2.2	0.5	0.2	6.4	0.5	0.5	0.1
BE7	4.9	3.3	3.5	1.5	1.2	0.5	27.6	18.7	0.4	0.0	0.0	0.0	7.9	0.1	0.0	0.0	7.0	1.2	1.0	0.2

Table 4.11. Groundistone Moss. Values of environmental variables and standard errors (S.E.) from samples at Groundistone Moss. Locations of samples are presented in Appendix 2. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
GM1(inflow)	FSM	402.8	3.8	7.5	0.1	52.4	0.6	23.7	2.3
GM2 (edge)	RPG	311.4	1.5	8.2	0.2	19.2	1.1	112.2	5.3
GM3 (edge)	FSM	309.0	2.3	6.7	0.1	22.6	0.1	63.5	4.5
GM4	BOG	23.0	2.1	4.45	0.1	-	-	-	-

Table 4.11 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
GM1(inflow)	50.0	6.6	8.0	0.4	0.9	0.2	6.8	0.4	0.2	0.2	0.0	0.0	10.2	0.2	0.6	0.4	6.4	0.6	3.8	0.8
GM2 (edge)	35.5	0.8	6.9	0.4	0.5	0.0	6.2	0.6	0.1	0.1	0.0	0.0	9.4	0.2	0.4	0.2	5.8	0.1	0.3	0.0
GM3 (edge)	43.5	1.2	7.7	0.2	1.2	0.1	6.7	0.2	1.3	0.2	0.0	0.0	16.6	1.1	0.7	0.1	6.0	0.2	0.6	0.1
GM4	0.61	0.2	2.5	1.2	1.5	0.7	8.8	1.5	0.0	0.0	0.0	0.0	3.9	0.3	0.0	0.0	2.9	0.4	0.8	0.2

Table 4.12. Kippilaw Moss. Values of environmental variables and standard errors (S.E.) from samples at Kippilaw Moss. Locations of samples are presented in Appendix 2. Samples K1, K2, K6, K5 and K4 are located along trasect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
K1(edge)	RFCb	355.2	15.8	6.7	0.1	88.2	0.1	16.2	1.7
K2	FSC	305.6	14.0	6.8	0.2	89.2	0.2	114.3	11.7
K6	RFCb	390.8	12.0	6.6	0.1	93.3	0.4	8.3	0.5
K5	FSC	409.2	22.2	6.2	0.1	90.5	0.0	4.4	0.3
K4 (edge)	RFCb	473.0	5.3	6.5	0.0	59.7	0.7	13.4	2.3
K3	FSM	409.4	19.0	6.7	0.1	51.0	1.3	7.7	0.9
K7	FSM	430.4	1.6	7.0	0.0	75.8	0.2	5.4	0.7

Table 4.12 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Mn*	*se*	*Fe*	*S.E.*	NH_4	*S.E.*	*Cl*	*S.E*	PO_4	*S.E*	SO_4	*S.E.*	NO_3	*S.E.*
K1(edge)	51.2	5.0	7.2	0.6	9.0	3.5	6.8	0.8	0.1	0.1	0.1	0.1	0.5	0.3	13.9	4.1	1.0	0.3	5.7	0.9	0.5	0.1
K2	46.0	3.5	7.4	0.4	1.8	0.6	6.1	0.4	0.0	0.0	0.1	0.1	0.1	0.0	8.8	0.3	0.8	0.5	4.5	0.6	0.4	0.1
K6	53.7	1.0	13.6	0.5	2.3	0.5	7.9	0.5	0.1	0.1	0.0	0.0	0.5	0.2	10.2	0.2	0.5	0.2	1.6	0.6	0.3	0.1
K5	55.8	4.4	15.0	0.7	1.7	0.2	5.7	1.9	0.4	0.3	0.5	0.1	0.6	0.5	11.3	0.1	0.7	0.1	1.6	0.1	0.4	0.1
K4 (edge)	51.9	5.2	17.3	0.5	2.0	0.7	7.4	2.2	0.0	0.0	1.0	0.5	0.4	0.4	10.2	0.3	0.8	0.1	2.0	0.1	7.1	5.6
K3	58.2	3.9	11.7	0.3	2.9	0.2	7.6	0.2	0.1	0.1	1.1	0.5	0.7	0.6	9.1	0.6	0.7	0.2	2.9	0.5	8.8	8.3
K7	49.6	4.4	15.4	0.3	0.9	0.1	9.0	1.0	0.0	0.0	0.0	0.0	0.2	0.1	11.3	0.3	0.1	0.1	8.9	1.7	8.2	3.7

alternating grass and arable crops along the southern edge. This site may therefore receive substantial nutrient inputs from runoff from the surrounding land.

Muirfield Moss (table 4.13)

Fertility gradually increased along the transect although the values were generally low. Calcium concentrations were highest at sample points MM5 and MM6 , which appear to be areas of spring discharge. EC was highest at point 5. Percentage loss on ignition was lowest at MM4, a sample from *Molinia caerulea* grassland at the margin of the site. Part of the site was excavated for the laying of a pipeline. This area is disturbed and supports species poor *Carex rostrata* dominated fen (MM2), which is growing in a silty substratum, probably resulting from the inwashing of silt to this area after the ground excavation. The surrounding land is mainly unimproved rough grassland and there appeared to be no obvious points of nutrient enrichment.

Murder Moss (table 4.14)

Fertility was highest at the inflows from Lindean reservoir (MU6) and from the adjacent farmland (MU1). Electrical conductivity values and chloride concentratons were highest near the southern edge of the site (MU2). Loss on ignition was lowest near the inflows, probably indicating inwashed silt deposits.

Nether Whitlaw Moss (table 4.15)

The calcium concentration of the sample nearest the centre of the site (NW3 *Carex rostrata - Sphagnum recurvum* poor-fen) was lower than those from other samples. Chloride and sodium concentrations were higher in some samples, in particular at the inflow. This may be due to the proximity of the inflow to the road and inwashing of salt. The site is surrounded by intensive pasture land with occasional arable crops.

St. Leonard's Moss (table 4.16)

At this site, sample SL5 was more fertile, had lower pH and electrical conductivity than other samples along the transect. This sample was adjacent to the drain and did not appear to receive inputs from marginal springs. Samples near the edge (SL3, SL6) appeared to receive inputs from spring discharge.

Chloride concentration, and electrical conductivity were higher in the edge area (SL3) than in other samples along the transect. The samples from the inflow, outflow and drain were more fertile than those from other areas. Silt ponded back at the outflow sluice supported a distinct

Table 4.13. Muirfield Moss. Values of environmental variables and standard errors (S.E.) from samples at Muirfield Moss. Locations of samples are presented in Appendix 2. Samples MM4, MM5, MM6 and MM7 are located along trasect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
MM1	RFCb	397.6	2.6	7.6	0.1	72.4	0.0	6.9	1.1
MM2	FSM	291.4	3.5	7.7	0.0	65.0	0.1	28.0	1.4
MM3	FMR	278.0	2.2	7.3	0.1	62.3	0.0	6.0	0.8
MM4 (edge)	FMC	208.8	3.4	6.9	0.0	26.0	0.2	3.7	0.2
MM5	RFF	360.0	17.6	7.3	0.1	48.9	0.1	3.5	0.2
MM6	RFM	290.0	1.2	7.7	0.0	90.1	0.0	4.8	0.2
MM7 (edge)	FMC	261.2	5.9	6.7	0.1	79.8	0.1	6.7	0.5

Table 4.13 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
MM1	57.4	3.1	9.3	0.4	0.5	0.1	6.2	1.9	0.0	0.0	0.1	0.0	11.4	0.5	0.3	0.2	7.3	0.4	2.4	0.1
MM2	41.6	4.4	6.5	0.4	0.9	0.1	8.1	0.3	0.0	0.0	0.1	0.0	10.9	0.2	0.5	0.2	5.8	0.3	0.8	0.1
MM3	39.3	1.6	6.6	0.4	0.9	0.0	6.2	1.9	0.0	0.0	0.1	0.0	10.4	0.2	0.3	0.2	5.2	0.4	0.8	0.1
MM4 (edge)	32.5	2.4	5.0	0.3	1.4	0.1	6.9	0.1	0.0	0.0	0.1	0.0	9.1	0.3	0.4	0.2	4.4	0.4	1.3	0.5
MM5	49.8	2.2	7.2	0.1	0.4	0.1	7.5	0.3	0.5	0.3	0.0	0.0	9.5	0.3	0.3	0.2	4.0	0.4	0.8	0.1
MM6	41.7	1.7	6.4	0.2	0.3	0.0	7.5	0.2	0.0	0.0	0.0	0.0	9.5	0.2	0.3	0.3	6.6	0.4	0.8	0.2
MM7 (edge)	30.3	5.6	5.2	0.9	0.6	0.1	7.8	0.3	1.0	0.4	0.1	0.0	9.6	0.3	0.3	0.1	2.6	0.2	0.8	0.0

Table 4.14. Murder Moss. Values of environmental variables and standard errors (S.E.)from samples at Murder Moss. Locations of samples are presented in Appendix 2. Samples MU2, MU3, MU4, MU5 and MU6 are located along transect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
MU1 (inflow)	RPG	387.8	1.2	7.7	0.1	23.6	0.2	25.7	2.0
MU2 (edge)	RFCa	417.0	17.1	7.7	0.1	88.4	0.2	4.0	0.2
MU3	RFM	314.8	5.3	7.5	0.1	87.6	0.1	6.8	0.3
MU4	FSM	322.0	2.2	7.1	0.2	87.8	0.1	16.3	1.0
MU5	FSM	305.8	3.6	7.2	0.1	83.4	0.1	6.1	0.7
MU6 (inflow)	RFCa	295.0	2.2	7.8	0.0	66.9	0.2	26.9	9.4
MU7	RFCb	291.6	4.5	7.4	0.0	86.7	0.1	3.1	0.1
MU8	RFCb	401.4	23.8	7.7	0.0	85.1	0.0	5.9	0.7

Table 4.14 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E.*	*PO_4*	*S.E.*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
MU1 (inflow)	39.1	3.1	8.2	0.4	0.6	0.1	9.9	0.3	0.1	0.0	19.2	1.6	1.3	0.7	8.5	0.3	8.7	2.0
MU2 (edge)	50.6	3.5	8.6	0.4	6.9	3.9	9.7	0.3	0.4	0.3	28.0	5.7	0.5	0.2	7.1	0.4	3.5	0.2
MU3	45.4	2.8	7.0	0.4	0.9	0.1	6.9	0.5	0.1	0.0	10.1	0.2	0.4	0.1	4.8	0.4	0.5	0.1
MU4	47.8	2.6	7.5	0.4	0.6	0.0	6.3	0.2	0.0	0.0	10.0	0.3	0.3	0.2	6.8	0.4	1.5	0.2
MU5	46.8	2.9	7.0	0.3	0.9	0.1	6.8	0.4	0.4	0.3	10.4	0.5	0.2	0.1	5.2	1.1	1.0	0.1
MU6 (inflow)	44.6	1.7	6.8	0.3	3.4	1.9	6.5	0.3	0.1	0.0	12.6	2.0	0.5	0.2	7.3	0.2	1.5	0.1
MU7	40.5	3.0	7.1	0.7	0.7	0.0	6.7	0.3	0.2	0.1	10.8	0.2	0.2	0.1	5.8	0.2	1.0	0.4
MU8	50.2	6.3	8.9	0.8	1.9	0.8	7.6	0.1	0.1	0.0	13.9	1.3	0.2	0.2	9.9	0.5	6.7	2.5

Table 4.15. Nether Whitlaw Moss. Values of environmental variables and standard errors (S.E.) from samples at Nether Whitlaw Moss. Locations of samples are presented in Appendix 2. Samples NW2, NW3, NW4 and NW5 are located along transect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
NW1(inflow)	FTH	614.0	10.8	6.5	0.0	28.0	0.2	29.9	2.7
NW2 (edge)	RFCa	166.6	4.2	6.5	0.0	-	-	-	-
NW3	POR	88.2	9.5	6.4	0.1	-	-	-	-
NW4	FSC	396.4	6.7	7.0	0.1	-	-	-	-
NW5 (edge)	RFCa	392.0	5.6	6.5	0.1	-	-	-	-
NW6 (edge)	FSM	173.4	9.8	7.1	0.1	-	-	-	-
NW7	POR	53.3	0.9	4.6	0.0	-	-	-	-

Table 4.15 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Mn*	*se*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
NW1(inflow)	52.1	3.3	9.1	0.9	5.1	0.2	40.8	1.6	3.8	1.2	0.3	0.1	0.1	0.0	93.7	7.0	0.4	0.2	3.2	0.4	0.4	0.1
NW2 (edge)	21.6	0.4	4.4	0.2	3.8	0.2	5.6	0.3	0.3	0.1	0.4	0.1	0.4	0.2	9.3	0.3	0.7	0.2	4.7	0.1	0.5	0.1
NW3	5.2	0.4	1.8	0.2	6.7	2.8	5.6	0.3	0.0	0.0	0.0	0.0	0.1	0.1	14.6	4.7	0.7	0.2	2.1	0.3	0.4	0.1
NW4	25.0	1.3	5.7	0.2	2.0	0.1	30.6	1.1	0.0	0.0	0.0	0.0	0.2	0.1	82.8	5.3	0.4	0.2	4.9	0.3	0.5	0.1
NW5 (edge)	27.7	2.8	5.4	0.2	6.1	2.7	30.3	0.9	0.0	0.0	0.0	0.0	0.1	0.1	87.8	6.6	0.5	0.1	5.5	0.2	0.5	0.1
NW6 (edge)	21.8	0.4	4.1	0.2	3.9	3.1	5.4	0.2	0.0	0.0	0.0	0.0	0.1	0.0	15.2	5.9	0.2	0.1	2.1	0.1	0.5	0.1
NW7	1.8	0.2	5.5	0.3	0.5	0.1	11.4	4.8	0.1	0.0	0.2	0.0	0.0	0.0	11.0	3.2	0.2	0.0	4.3	0.4	0.7	0.3

Table 4.16. St. Leonard's Moss. Values of environmental variables and standard errors (S.E.) from samples at St. Leonard's Moss. Locations of samples are presented in Appendix 2.Samples SL3, SL4, SL5 and SL6 are located along ttransect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
SL1(outflow)	FSC	339.6	1.2	6.8	0.1	50.8	0.1	15.6	1.1
SL2	RPG	356.8	1.3	7.4	0.1	59.6	0.1	8.0	1.2
SL3 (edge)	RFM	522.6	4.3	7.2	0.1	81.7	0.3	4.0	0.2
SL4	RFF	409.8	6.3	7.4	0.1	69.6	0.1	4.9	0.2
SL5	FTH	166.8	3.4	5.4	0.1	85.1	0.3	11.3	1.5
SL6 (edge)	RFF	354.4	5.0	7.0	0.1	83.9	0.0	4.7	0.3
SL7	FSM	354.4	1.0	7.6	0.1	61.5	0.2	37.1	10.7
SL8 (inflow)	FSM	358.6	1.8	8.0	0.1	58.5	0.1	12.3	0.8

Table 4.16 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Mn*	*se*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
SL1(outflow)	44.8	2.0	9.5	0.3	0.9	0.2	8.2	0.4	0.0	0.0	0.2	0.2	0.1	0.0	11.6	0.2	0.6	0.2	5.3	0.7	1.0	0.2
SL2	51.9	1.8	10.7	0.4	1.5	0.1	7.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	11.3	0.2	0.3	0.1	5.4	0.2	1.3	0.4
SL3 (edge)	51.8	6.0	11.3	0.3	7.7	1.4	10.3	0.4	0.1	0.1	0.2	0.2	0.1	0.0	42.2	2.0	0.5	0.2	5.4	0.6	0.8	0.1
SL4	51.1	6.0	9.0	0.9	1.3	0.3	9.2	0.4	0.0	0.0	0.3	0.3	0.2	0.1	13.3	0.8	0.2	0.1	4.2	1.3	1.3	0.5
SL5	22.8	2.1	4.4	0.9	3.0	0.4	7.4	0.6	0.0	0.0	1.5	0.4	0.7	0.3	10.3	0.3	0.5	0.2	1.9	0.5	0.6	0.3
SL6 (edge)	55.4	1.9	10.8	0.3	1.8	0.2	8.1	0.5	0.2	0.1	0.1	0.1	0.3	0.1	11.2	0.3	0.4	0.2	1.9	0.2	1.7	0.7
SL7	50.1	1.9	10.4	0.3	0.9	0.1	7.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	10.7	0.2	0.7	0.2	8.1	0.4	2.5	0.2
SL8 (inflow)	48.3	1.4	10.9	0.3	0.9	0.0	7.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.1	0.7	0.6	7.2	0.1	2.6	0.6

Table 4.17. Whitehaughmoor Moss. Values of environmental variables and standard errors (S.E.) from samples at Whitehaughmoor Moss. Locations of samples are presented in Appendix 2. Samples WHM1, WHM2 and WHM 3 are located along trasect A-B. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
WHM1(outflow)	RFM	237.0	3.9	6.8	0.1	71.3	0.3	2.7	0.2
WHM2	RFM	300.8	4.4	6.8	0.0	85.6	0.0	5.0	0.4
WHM3 (edge)	RFF	262.8	2.9	6.9	0.1	86.8	0.1	4.6	0.3
WHM4	RFS	300.0	3.1	6.9	0.1	82.9	0.1	6.8	1.1

table 4.17 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Mn*	*se*	*Fe*	*S.E.*	NH_4	*S.E.*	*Cl*	*S.E.*	PO_4	*S.E*	SO_4	*S.E*	NO_3	*S.E.*
WHM1(outflow)	31.9	1.3	4.6	0.2	1.2	0.5	6.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	9.1	0.2	0.5	0.3	2.9	0.2	0.4	0.0
WHM2	44.1	1.4	5.9	0.1	0.7	0.2	6.8	0.5	0.0	0.0	0.0	0.0	0.1	0.0	8.7	0.3	0.1	0.1	3.6	0.4	0.5	0.1
WHM3 (edge)	35.9	3.4	4.8	0.2	1.0	0.2	7.8	0.2	0.6	0.6	0.1	0.1	0.0	0.0	8.6	0.4	0.4	0.2	3.4	0.2	0.5	0.1
WHM4	44.6	2.0	5.7	0.4	1.7	0.6	6.6	0.3	0.1	0.1	0.0	0.0	0.3	0.1	9.6	0.6	0.5	0.1	3.9	0.2	0.7	0.2

Table 4.18. Whitmuirhall Loch. Values of environmental variables and standard errors (S.E.) from samples at Whitmuirhall Loch. Locations of samples are presented in Appendix 2. Plant communities are coded as for table 4.3. Units and abbreviations follow table 4.9.

Sample	*Plant Community Code*	*EC*	*S.E*	*pH*	*S.E*	*%LOI*	*S.E*	*Peat Fertility*	*S.E*
WL1	FSM	341.0	2.6	7.0	0.1	86.2	0.1	4.5	0.4
WL2	FSM	354.0	1.4	7.9	0.0	76.9	0.4	2.8	0.1
WL3	RPG	360.4	2.2	7.5	0.1			17.9	3.0
WL4 (edge)	FSM	407.0	1.2	7.9	0.0	78.5	0.1	14.9	1.0
WL5 (edge)	FSM	402.6	5.0	7.8	0.0	83.3	0.2	10.3	1.1
WL6 (outflow)	RPG	358.4	1.7	7.9	0.0	54.4	0.1	30.9	8.5

Table 4.18 cont.

Sample	*Ca*	*S.E.*	*Mg*	*S.E.*	*K*	*S.E.*	*Na*	*S.E.*	*Fe*	*S.E.*	*NH_4*	*S.E.*	*Cl*	*S.E*	*PO_4*	*S.E*	*SO_4*	*S.E.*	*NO_3*	*S.E.*
WL1	52.6	3.7	8.1	0.4	1.1	0.1	7.6	0.3	0.2	0.2	0.3	0.3	10.7	0.2	0.6	0.3	5.6	0.6	1.5	0.4
WL2	52.9	2.2	7.6	0.4	0.7	0.2	7.2	0.4	0.1	0.1	0.3	0.2	10.2	0.2	0.5	0.2	6.1	0.1	3.0	0.4
WL3	53.8	2.4	7.5	0.3	0.9	0.1	7.5	0.2	0.0	0.0	0.2	0.1	10.4	0.4	0.7	0.1	6.2	0.3	4.0	0.8
WL4 (edge)	55.6	6.7	7.8	0.4	0.6	0.1	7.7	0.4	0.0	0.0	0.1	0.0	10.6	0.4	0.3	0.1	5.1	0.6	1.2	0.2
WL5 (edge)	49.4	7.4	7.4	0.4	0.6	0.1	8.1	0.3	0.0	0.0	0.1	0.0	10.8	0.2	0.4	0.1	7.3	0.5	1.0	0.3
WL6 (outflow)	50.7	2.6	8.1	0.5	0.9	0.1	7.3	0.3	0.0	0.0	0.0	0.0	10.3	0.1	0.4	0.2	5.1	0.6	1.8	0.4

stand of *Phragmites australis*. The surrounding land was farmed fairly intensively with a mixture of permanent pasture and arable crops.

Whitehaughmoor Moss (table 4.17)

There was little variation in chemical conditions and peat fertility across this small site. Generally the peat fertility was low. The surrounding land is unimproved and there were no obvious potential sources of nutrient enrichment.

Whitmuirhall Loch (table 4.18)

There was little variation in the chemical conditions found within the site. The peat fertility was substantially higher at the outflow (WL6). Samples from the shallower peat near the dry inflow had much lower fertility than those towards the eastern expanse of the site. Fertility values were higher in samples 4 and 5 which were close to the southern edge, adjacent to intensive pasture land.

4.3.4 IMPACT OF CATCHMENT LAND-USE ON SITE CHEMICAL CONDITIONS

In general the highest peat fertility values were associated with peat samples from inflows and the edges of sites (figure 4.2 (table 4.19) and 4.3). The peat fertility of samples from the edges of sites surrounded by unimproved land were consistently low (2.72-7.65 mg/plant). Where the surrounding land was more intensively farmed the peat fertility of samples near the edges was more variable (3.25-112.2 mg/plant) but many values were low, despite the catchment management score being high (table 4.20). The samples from near water inflows were of more consistent fertility (12.2-37.1mg/plant) but still showed considerable variation. The inflows were associated with relatively low values of % loss on ignition, probably because silt is often brought into sites at the inflow. The values of % loss on ignition for samples from the edges of sites were more variable. Smaller values may be associated with areas where the substratum was oxidised or where silt was inwashed (e.g. Groundistone Moss, Murder Moss inflow).

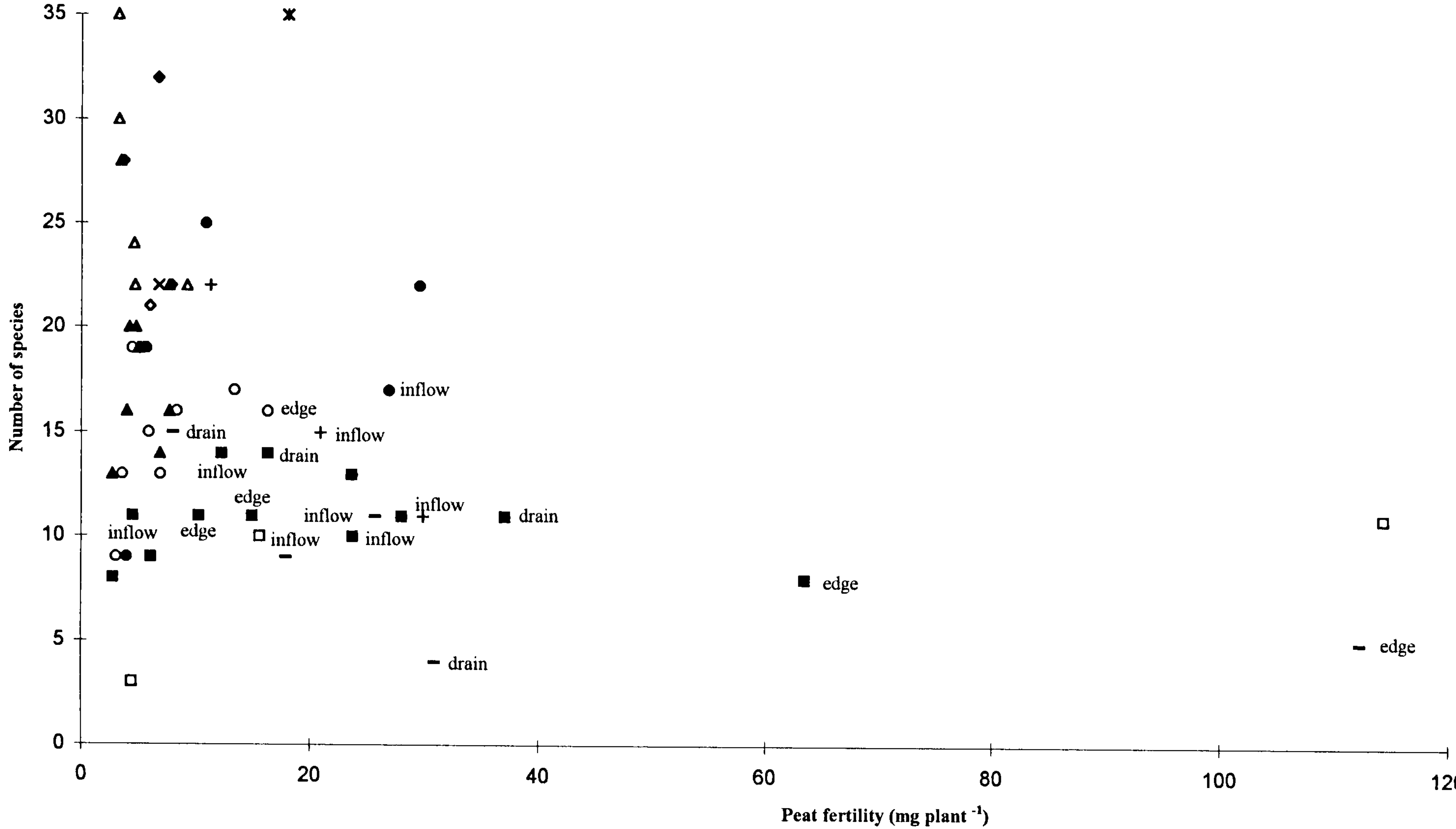


Figure 4.2. The relationship between peat fertility and species-richness of different plant communites. Samples from water inflows, drains and site edges are marked on the figure. Symbols represent different plant communities (see table 4.19).

Table 4.19. Plant community symbols used in figures 4.2, 4.5, 4.6, 4.7, 4.8.

Symbol	*Code*	*Plant community*
+	FTH	*Filipendula ulmaria* tall-herb fen community
◇	FRP	*Juncus acutiflorus* rush pasture community
◆	FMC	*Molinia caerulea* species-rich wet grassland community
△	RFF	*Carex dioica - Carex hostiana* community
×	RFS	*Carex diandra - Sphagnum contortum* community
✱	POR	*Carex rostrata - Sphagnum recurvum* community
▲	BOG	*Eriophorum vaginatum - Sphagnum papillosum* community
△	RFM	Mixed sedge rich-fen community
○	RFCb	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant
●	RFCa	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant
■	FSM	*Carex rostrata -Potentilla palustris* species-poor community
□	FSC	*Carex rostrata* species poor community
–	RPG	*Phragmites australis* reed-bed

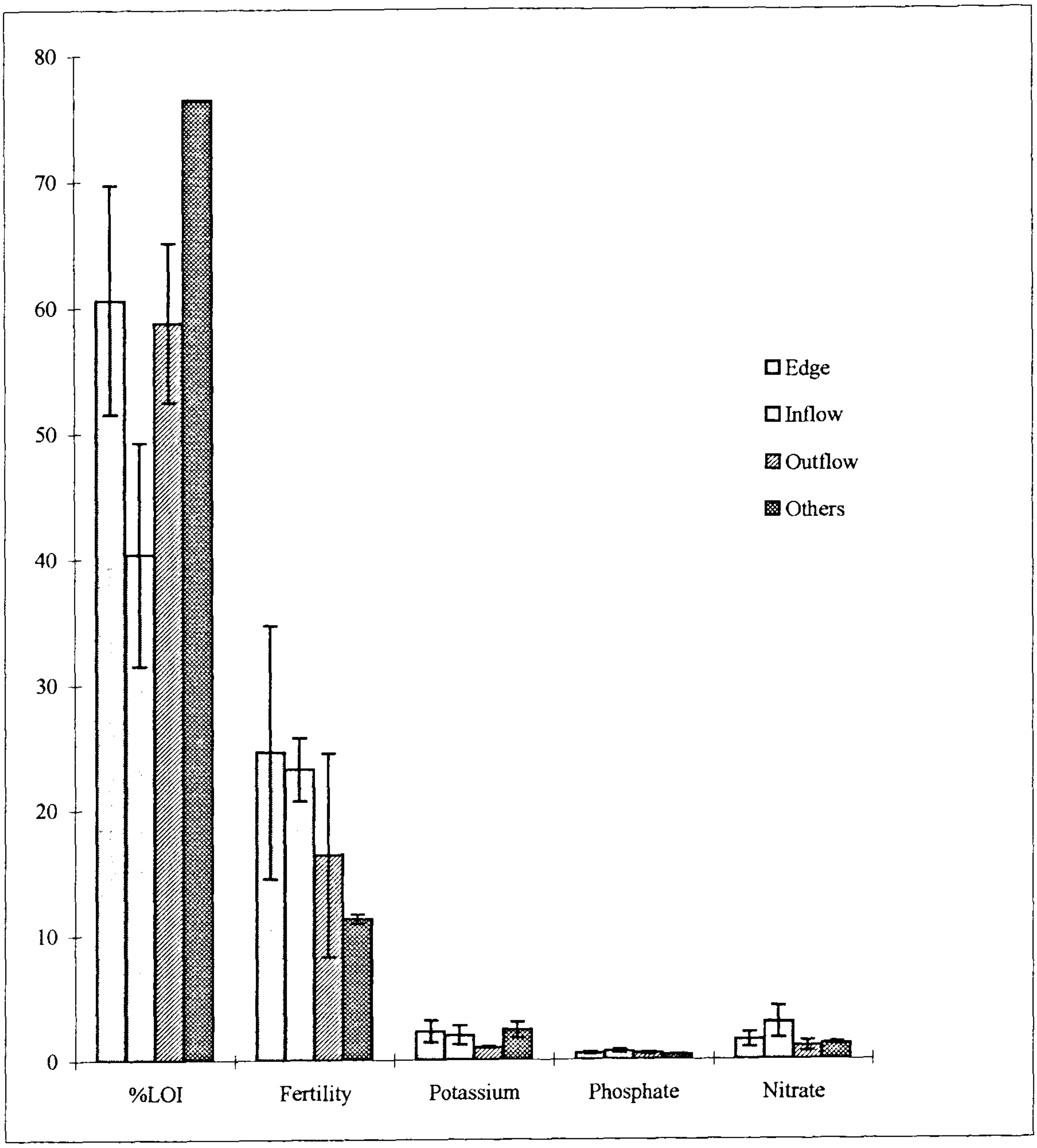


Figure 4.3. Mean % loss on ignition of peat, peat fertility (mg dry weight of phytometer *Phalaris arundinacea*), interstitial water concentrations of potassium (mg l^{-1}), phosphate (mg l^{-1}) and nitrate (mg l^{-1}) from sample sites near the edges, water inflows, water outflows, and other areas of some Scottish Borders fen sites.

Table 4.20. The peat fertlity and % Loss on ignition of samples from the edges of sites surrounded by unimproved land and improved land, and from inflows into sites. C.M.S. is the catchment management score (see section 4.2.1). The edge of the site is defined as the junction of wetland vegetation types with surrounding land. This excludes flushed vegetation on surrounding slopes.

Sample location	*Plant community*	*Sample*	*C. M. S.*	*%LOI*	*S.E.*	*Fertility (mg/plant)*	*S.E.*
Edges C.M.S.<5	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant	AL8	3	83.9	0.4	3.60	0.19
	Molinia caerulea wet grassland	AL2	3	29.0	0.6	7.65	1.02
	Mixed sedge rich-fen community	WHM1	1	71.6		2.72	0.16
	Molinia caerulea wet grassland	MM4	2	26.0	0.2	3.73	0.19
	Molinia caerulea wet grassland	MM7	5	79.8	0.05	6.75	0.52
	Carex dioica - Carex hostiana community	WHM3	1	86.8		4.61	0.28
Edges C.M.S.>5	*Carex diandra - Sphagnum contortum* community	BE1	6	92.2	0	18.0	1.74
	Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	MU2	11	88.4	0.15	4.01	0.24
	Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	K1	13	88.2	0.1	16.3	1.71
	Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	K4	11	59.7	0.65	13.4	2.32
	Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	BE4	6	88.5	0.1	10.9	1.12
	Carex rostrata - Potentilla palustris species-poor community	WL4	11	78.5	0.1	14.9	1.02
	Carex rostrata - Potentilla palustris species-poor community	WL5	5	83.3	0.2	10.3	1.07
	Carex rostrata - Potentilla palustris species-poor community	GM3	13	22.6	0.1	63.5	4.53
	Mixed sedge rich-fen community	SL3	11	81.7	0.25	3.96	0.22
	Phragmites australis reedbed	GM2	14	19.2	1.1	112.2	5.34
	Carex dioica - Carex hostiana community	BE6	6	51.8	0.4	3.25	0.17
	Carex dioica - Carex hostiana community	BE3	6	90.1	0.05	3.27	0.13
	Carex dioica - Carex hostiana community	SL6	8	83.9	0	4.69	0.26
Inflows	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant	MU6	11	66.9	0.2	26.9	9.37
	Carex rostrata - Potentilla palustris species-poor community	SL7	8	61.5	0.2	37.1	10.68
	Carex rostrata - Potentilla palustris species-poor community	GM1	14	52.6	0.55	23.7	2.31
	Carex rostrata - Potentilla palustris species-poor community	SL8	8	58.5	0.1	12.2	0.85
	Filipendula ulmaria tall herb fen	AL3	3	12.9	0.15	20.9	2.14
	Filipendula ulmaria tall herb fen	NW1	11	28.0	0.2	29.9	2.72
	Phragmites australis reedbed	MU1	11	23.6	0.15	25.7	2.04

The catchment management score is positively correlated with the fertility of the peat at the edges of sites ($r = 0.563$, d.f. 16, $p < 0.02$) (figure 4.4) and with calcium and potassium concentrations in interstitial water from the same sample points (table 4.21). However there are some sites where the catchment management score is high but the fertility of the edge samples remains lower than

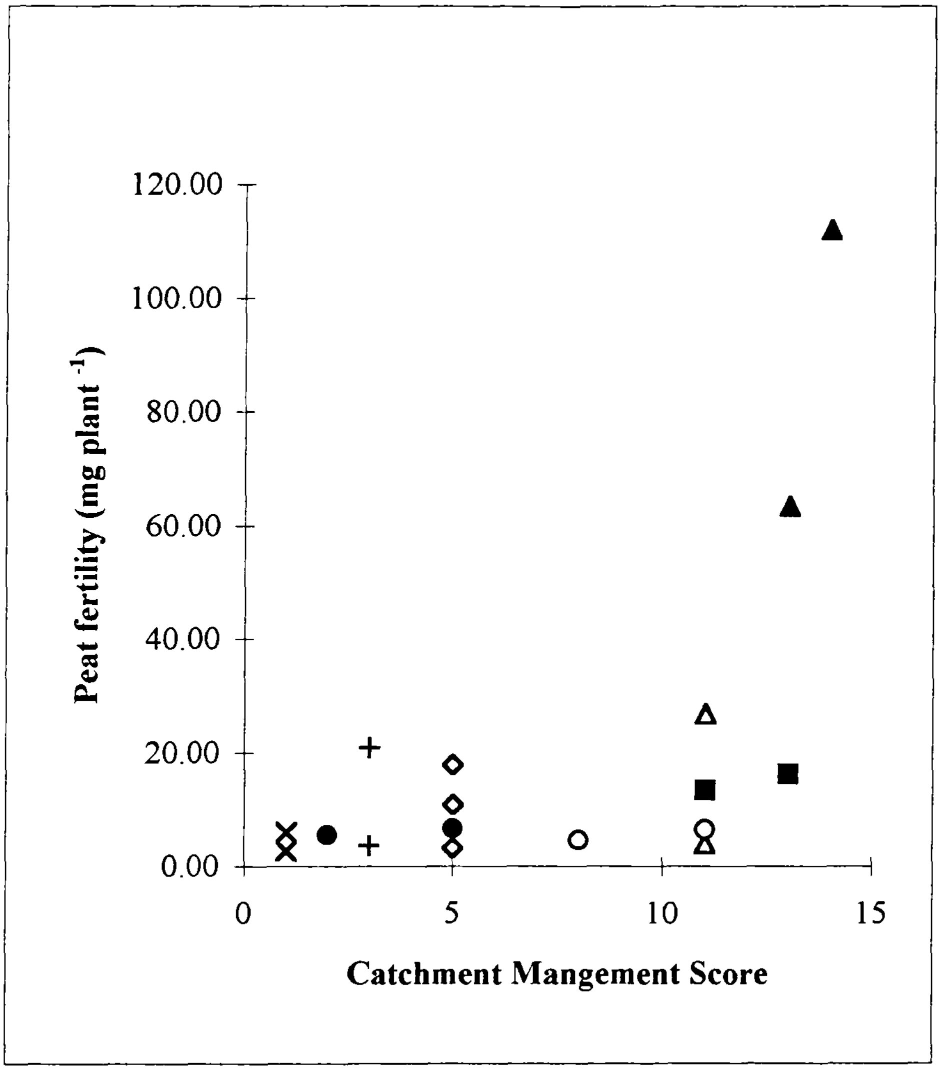


Figure 4.4. Relationship between catchment management score and peat fertility of samples from the edges of fen sites ($r = 0.56$, d.f. 15, $p<0.02$).

- + Ashkirk Loch
- ◇ Beanrig Moss
- ▲ Groundistone Moss
- ■ Kippilaw Moss
- ● Muirfield Moss
- △ Murder Moss
- O St. Leonard's Moss
- × Whitehaughmoor Moss

might have been expected (figure 4.4). The peat fertility values of both edge samples from St Leonard's Moss and the sample from the south side of Murder Moss were low despite the relatively high intensity of the adjacent land-use.

Table 4.21. Correlations of land-use category with mean interstitial water concentrations of cations and anions associated with nutrient status, and mean fertlity and loss-on-ignition of peat from samples at the edges of sites (d.f. 16). NS indicates not significant.

	Fertility	*PO_4*	*K*	*NO_3*	*NH_4*	*Ca*	*LOI*
Catchment Management Score	**0.563** $p<0.02$	0.440 NS	**0.536** $p<0.05$	0.304 NS	0.285 NS	**0.605** $p<0.01$	-0.189 NS

4.3.5 VARIATION IN FEN WATER AND SUBSTRATUM CONDITIONS

The ranges of soil fertility, organic content of the fen soil and water chemical conditions recorded from the Scottish Borders fens are presented in table 4.22.

Table 4.22.Ranges of some environmental variables measured in the substrata and water of the Scottish Borders fens examined in this part of the study.

		mean	*S.E.*	*min*	*max*
Peat	Soil Fertility (mg)	15.9	2.84	2.72	114.3
n=58	% loss on ignition	68.10	2.95	12.85	93.25
Water	pH	6.95	0.08	4.52	8.23
n=68	Electrical Conductivity $\mu S/cm^{-1}$	292.00	14.38	43.67	614.00
	Cl (mg l^{-1})	14.85	1.98	3.92	93.72
	NO_3 (mg l^{-1})	1.59	0.24	0.23	8.79
	SO_4 (mg l^{-1})	4.79	0.27	1.55	11.02
	PO_4 (mg l^{-1})	0.41	0.03	0.00	1.32
	NH_4 (mg l^{-1})	0.16	0.02	0.00	0.67
	K (mg l^{-1})	2.10	0.37	0.03	23.19
	Ca (mg l^{-1})	37.23	1.98	0.61	58.16
	Mg (mg l^{-1})	7.08	0.42	1.16	17.34
	Na (mg l^{-1})	9.41	0.83	5.37	40.79
	Fe (mg l^{-1})	0.56	0.15	0.00	9.13
	Mn (mg l^{-1})	0.15	0.07	0.00	4.79

There is a wide range of fertility with a few extremely fertile samples. Fen vegetation occurs on a range of substrata, from mineralised soil to almost purely organic peat. Calcium concentrations show much variation, with most samples containing 30-50 mg l^{-1} but a few exceptional samples containing less than 10 mg l^{-1}. Concentrations of potentially toxic chemicals, iron and manganese, were generally so low they were undetectable in the chemical analyses.

4.3.5.1 L.A.T model

The water types of the Scottish Borders fens were characterised according to the L.A.T. model of VanWirdum 1991 (figure 4.5). This uses the ionic ratio (I.R.) and electrical conductivity (E.C.) at 25°C to characterise fen waters as one of three types (table 4.23).

Table 4.23. Electrical conductivity (E.C.) at 25 °C and the Ionic ratio (I.R.) of reference water types (after VanWirdum 1981).

Water type	*E.C. (25°C) mS/m^{-1}*	*I.R.*
Lithotrophic (groundwater)	65.2	95
Atmotrophic (rainwater)	5.0	20
Thalassotrophic (seawater)	5200.0	4

Other intermediate types are also recognised:

Monulotrophic (polluted brackish water)

Poikilotrophic (intermediate between lithotrophic and atmotrophic water types).

Most of the samples from the Scottish Borders fens are characterised as lithotrophic because of their high base content, however some approach the atmotrophic reference point, notably those representing poor-fen vegetation. The vegetation types otherwise show no pattern in relation to the water types. A few samples approach the monulotrophic reference point which indicates nutrient enrichment. These are samples from the edges of sites, often near fertilised fields or roads which are salted in the winter.

4.3.6 RELATIONSHIPS BETWEEN WATER CHEMISTRY, FERTILITY AND VEGETATION

The main relationships between fen vegetation and water chemistry and peat fertility are very general. Many of the variables were highly inter-correlated. In particular pH and electrical conductivity were significantly correlated with many of the measured water chemical variables (table 4.24). Peat fertility was not significantly correlated ($p<0.05$) with any water chemical variables and has not been included in table 4.24.

Table 4.24. Correlation of pH and electrical conductivity (E.C.) with water chemical variables. N=58. ns indicates no statistically significant relationship.

	Fe	*K*	*Na*	*Mg*	*Ca*	*SO_4*	*NO_3*	*Cl*	*E.C.*
E.C.	-0.340	ns	0.367	0.481	0.641	0.388	0.279	0.356	1
pH	-0.420	-0.297	ns	0.354	0.643	0.425	0.309	ns	0.430

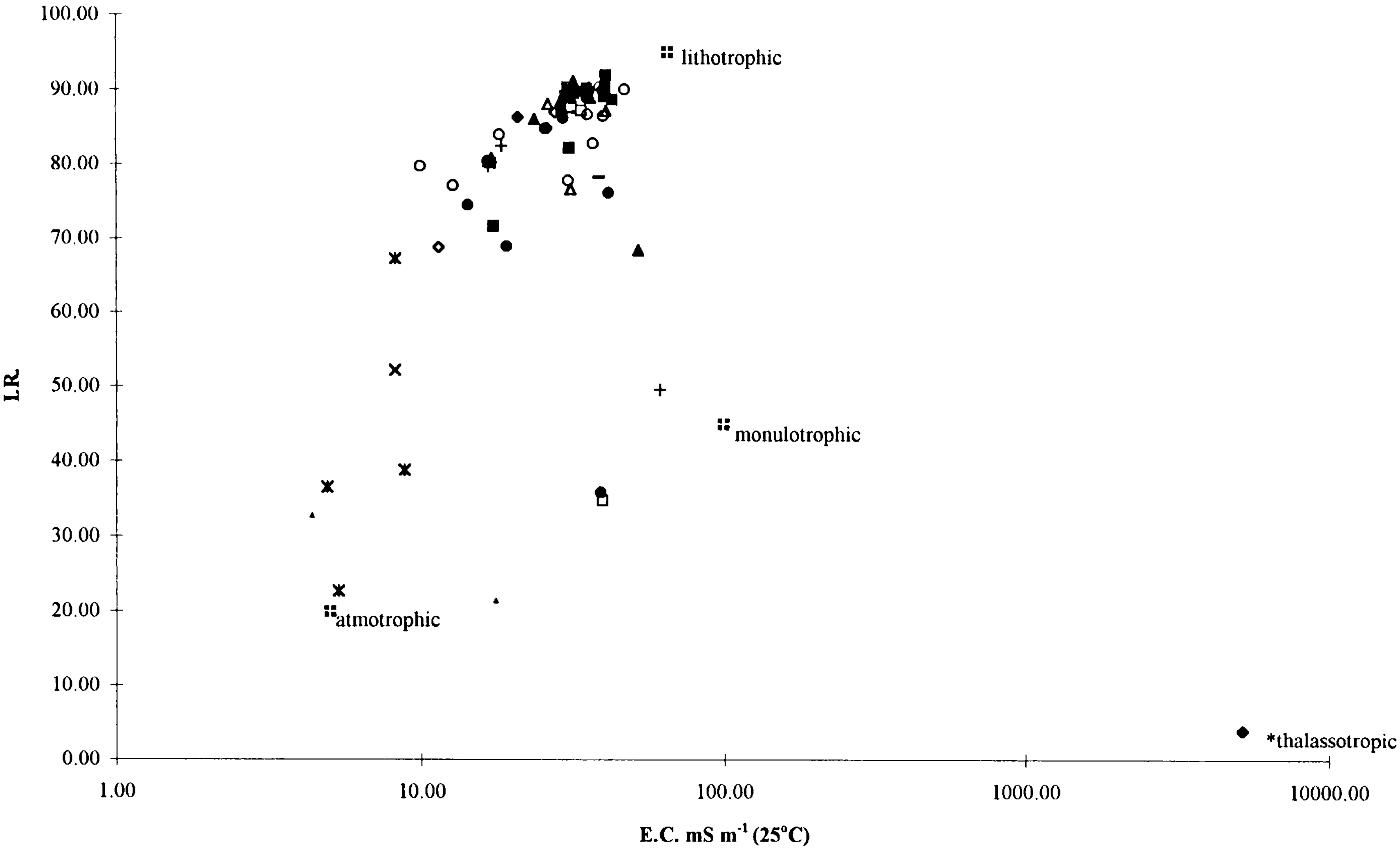


Figure 4.5. L.A.T. (lithotrophic, atmotrophic, thalassotrophic) diagram of water types from samples in some of the Scottish Borders fens (see section 4.2.5). Symbols represent plant communities (see table 4.19). ⁘ represents water type reference points.

Some variables showed significant relationships to the species richness of the samples (table 4.25). In all cases these were negative relationships so higher values of peat fertility, electrical conductivity, calcium concentration and sulphate concentration were associated with lower species richness. The number of rare species was significantly negatively correlated with peat fertility. The number of bog species was negatively correlated with pH.

Table 4.25. Correlations between peat fertility, water pH, Electrical conductivity, calcium and sulphate concentrations and species richness. ns indicates no significant relationship, * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

	total species richness	*Rich-fen species*	*Poor-fen species*	*Bog species*	*Rare fen species*
Fertility (mg/plant)	-0.355**	-0.407**	-0.360**	ns	-0.343*
pH	ns	ns	ns	-0.314*	ns
EC (µS/cm)	-0.343*	-0.401*	-0.407**	-0.378*	ns
Ca (mg/l)	-0.441**	-0.447***	-0.555***	-0.592***	ns
SO^4 (mg/l)	-0.323*	ns	-0.314*	-0.310*	ns

The strong negative relationship between calcium concentration and species richness is surprising because high calcium concentrations are often associated with areas of spring discharge, which are often species-rich. This may explained by liming (in spring) of fertilised fields, so that high calcium concentrations are often associated with increased nutrient concentrations in addition to indicating base-rich water input. This negative relationship does not exist for rare species many of which are concentrated in areas which appear to be fed by base-rich spring water.

4.3.6.1 CANOCO analysis

4.3.6.1.1 Linear combinations of environmental variables

The biplot of linear combinations of environmental variables (figure 4.6) produces an ordination diagram based on the combination of environmental variables (mire water contents) for each sample without taking the species composition into account. The samples with the most distinct water chemistry are those representing poor-fen and bog vegetation, characterised by abundant *Sphagnum*. All other samples (representing rich-fen and species-poor fen and swamp vegetation types) are grouped together, showing no clear distinction between the water types associated with different plant communities.

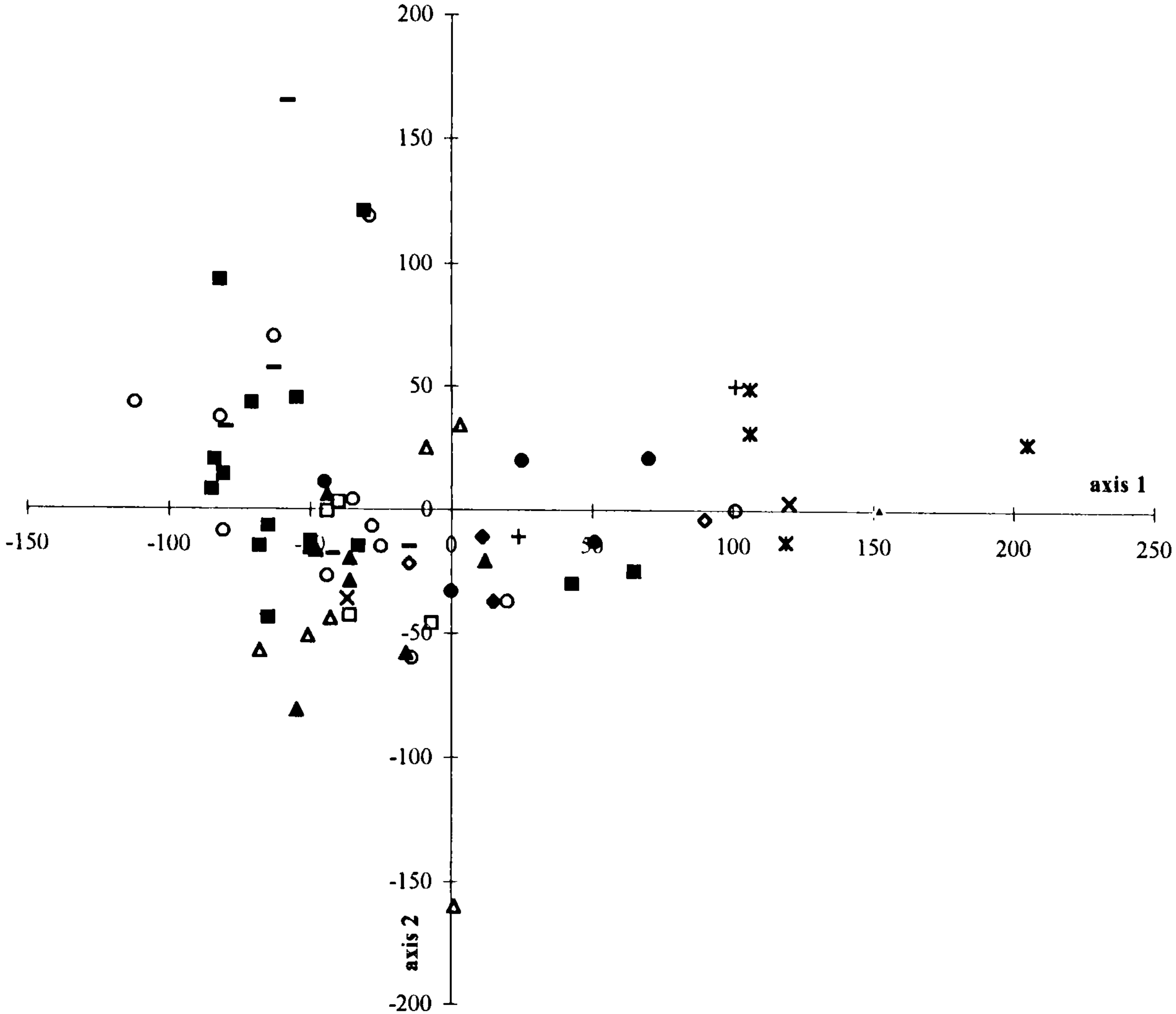


Figure 4.6. CANOCO analysis of linear combinations of environmental variables (water chemical composition) from samples of fen water from different plant communities (n = 68). Symbols represent different plant communites (see table 4.19).

4.3.6.1.2 Vegetation in relation to environmental variables

The CANOCO biplots are based on the sample scores which are derived from the sample ordination with respect to species composition.

(i) Water chemistry (figure 4.7)

(axes 1 and 2 account for 36.2% of the variation in the species ordination; monte carlo test not significant.)

The following gradients represent the primary and secondary axes of floristic variation:

1. Base-rich - base-poor water (represented by calcium concentration and pH vectors)
2. Nutrient-poor - nutrient-rich water (represented by nitrate, ammonium, phosphate and sulphate vectors).

These axes are roughly orthogonal, although the nutrient axis is skewed to the base-rich (high calcium concentration) end of the base richness axis.

The chemical variables potassium, iron, chloride and sodium all show little relation to the sample ordination, as indicated by the short length of the vectors. High manganese concentration is associated with low nutrient status. Samples representing poor-fen vegetation form a distinct cluster towards the negative end of the base-richness gradient (low calcium concentration and low pH). The other vegetation types are not distinctly grouped, although samples of the *Carex rostrata - Potentilla palustris* species-poor community and the *Phragmites australis* reedbed community tend to be concentrated nearer towards the positive end of the nutrient gradient and the *Carex dioica - Carex hostiana* community and *Carex rostrata -Calliergon cuspidatum/ Plagiomnium rostratum* community, *Carex diandra* variant tend to be grouped towards the negative end of the nutrient gradient.

(ii) Water chemistry, peat fertility and % loss on ignition (figure 4.8)

(axes 1 and 2 account for 32.9% of the variation in the species ordination; monte carlo test not significant)

The following gradients represent the primary and secondary axes of floristic variation:

1. Low -high fertility (represented by peat fertility, nitrate, ammonium, phosphate, sulphate potassium vectors).
2. Base-rich - base-poor water (represented by calcium concentration and pH vectors)

This biplot shows again a low to high pH and calcium concentration gradient and, roughly orthogonal to this, a fertility and nutrient status gradient; however it is the variation in nutrient status which corresponds to the primary axis of floristic variation in this analysis. The base-

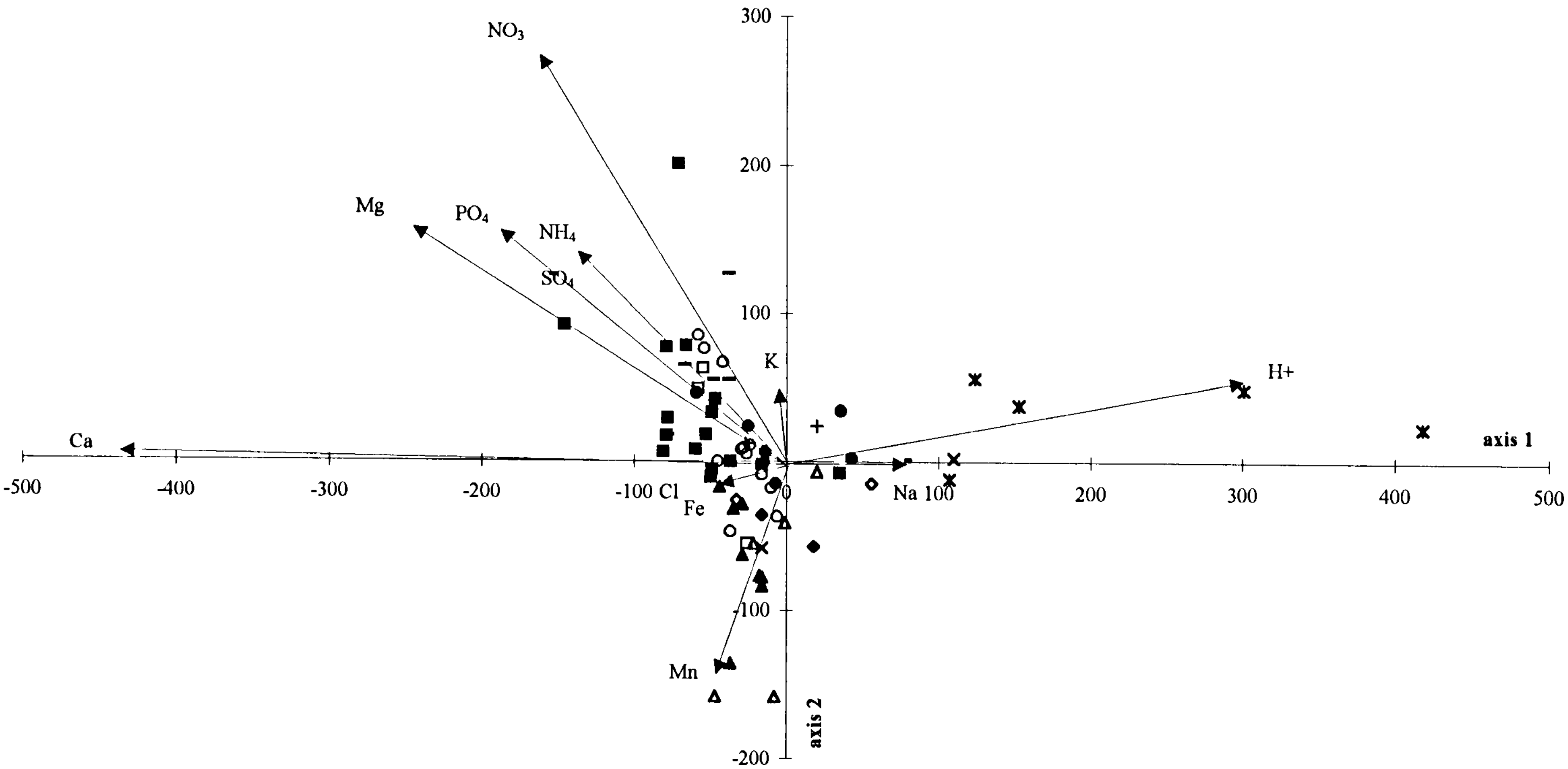


Figure 4.7. CANOCO biplot of sample scores (based on vegetation composition) and environmental variables scores (x 10) showing the relationship between plant communities and water chemical variables (n = 68; monte carlo test not significant). Symbols represent plant communites (see table 4.19).

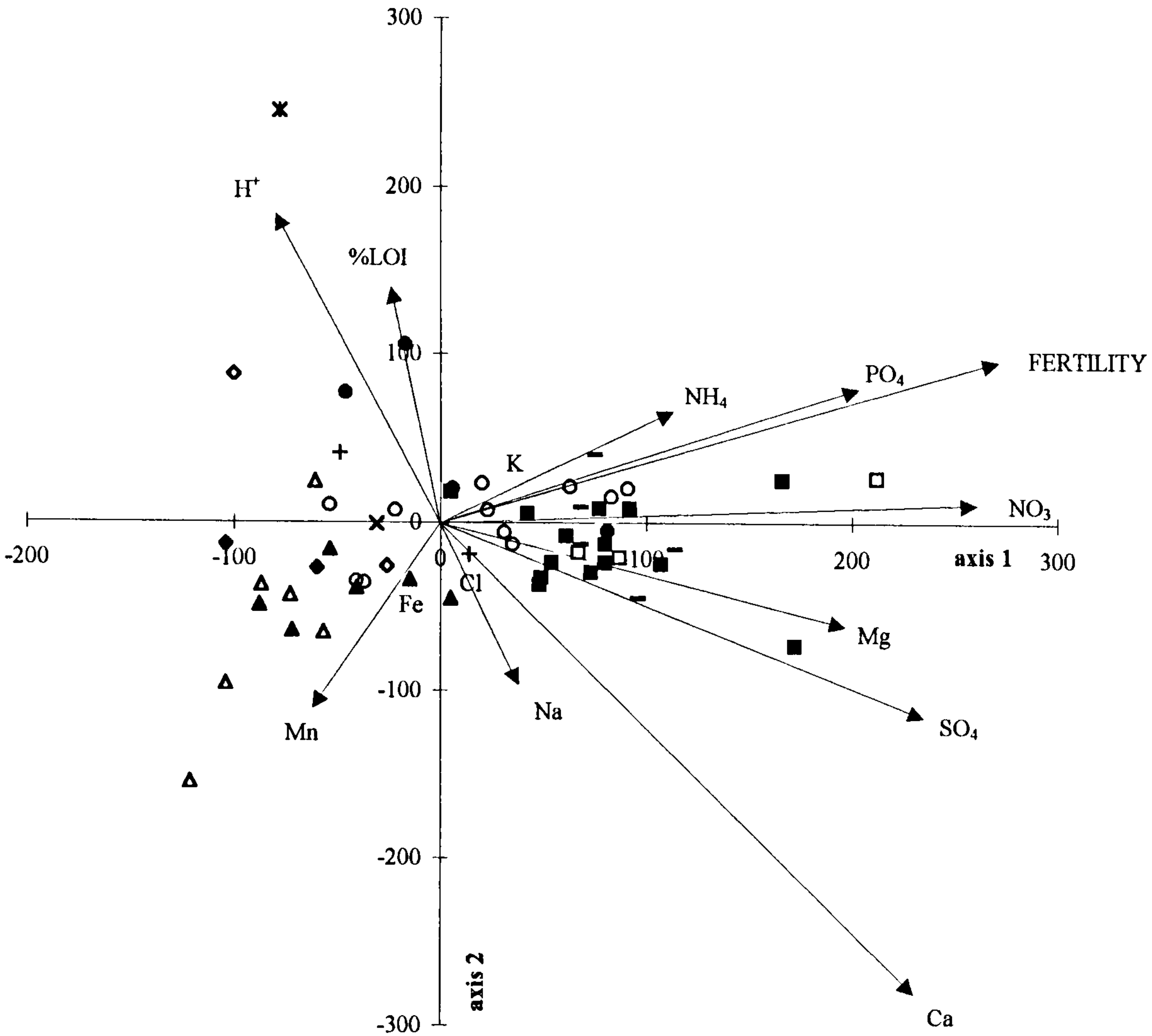


Figure 4.8. CANOCO biplot of sample ordination scores (based on species composition) and environmental variables scores (x 10) showing the relationship between plant communities and peat fertility and % loss on ignition (%LOI) and water chemical variables (n = 57; monte carlo test not significant). Symbols represent plant communities (see table 4.19).

richness gradient is less important in this data set than that without phytometric data because there were fewer samples representing poor-fen vegetation types included in the phytometric trials. Iron, sodium and chloride have little impact on the ordination as indicated by the small magnitude of their representative vectors.

Samples representing *Carex rostrata - Potentilla palustris* species -poor community, *Carex rostrata* species -poor community, and *Phragmites australis* reed-bed vegetation are grouped towards the positive end of the fertility gradient. Samples representing the *Carex dioica - Carex hostiana* community and the mixed sedge rich-fen community are grouped towards the negative end of the fertility gradient. The *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, *Carex diandra* variant and *Carex rostrata -Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant show no distinct grouping.

4.4 Discussion

The objectives of this part of the study were to determine the range of chemical conditions and peat fertility present in the Scottish Borders fens and investigate the relation of the variation in these variables to the surrounding land-use and the occurrence of different plant communities.

4.4.1 COMPARISON WITH OTHER FENS

A wide range of conditions is encompassed by the Scottish Borders fens (see table 4.22) although concentrations of major nutrients (N, P, K) are low compared with other examples from the U.K. (e.g. Wheeler 1983), and from the Netherlands (e.g.Van Wirdum 1991, Kooijman & Bakker 1995). The plant communities of the Scottish Borders fens have synonymous counterparts in other British fens. Some hydrochemical and peat fertility data from other comparable studies are presented in table 4.26. The water associated with fen plant communities at Malham tarn (Proctor 1974, 1995) is more calcareous than that of the Scottish Borders fens. Also water samples associated with sedge fen plant communities in Catfield and Irstead fen in the Norfolk Broads were more calcareous than their counterpart Scottish Borders fens plant communities (Giller & Wheeler 1986).

Table 4.26. Comparison of hydrochemical and peat fertility data from some of the Scottish Borders fens (S.B. fens) with data from synonymous plant communities from other U.K. fens (Wheeler & Shaw 1987, Shaw & Wheeler 1990) and data from Malham Tarn (Proctor 1974).

	pH		*EC* ($\mu S\ cm^{-1}$)		*Peat Fertility* ($mg\ plant^{-1}$)		*Ca* ($mg\ l^{-1}$)	
Scottish Borders fens plant community	*S.B. fens*	*U.K. fens*	*S.B. fens*	*U.K. fens*	*S.B. fens*	*U.K. fens*	*S.B. fens*	*Malham tarn fen*
Mixed sedge rich-fen community	7.0	6.4	307.8	676	5.02	6.6	41.6	60.1
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	6.8	6.1	304.7	274	9.13	13.4	30.2	54.11
Carex dioica - Carex hostiana community	7.1	6.9	347.9	449	4.75	7.3	-	-
Carex rostrata - Sphagnum recurvum community	6.0	4.8	68.28	115	18.0	14.1	4.74	24.1
Carex rostrata - Potentilla palustris species-poor community	7.3	5.6	335.5	227	18.3	12.9	-	-
Phragmites australis reedbed	7.7	6.6	354	630	38.9	33.5		

4.4.2 VARIATION IN ENVIRONMENTAL CONDITIONS ASSOCIATED WITH DIFFERENT VEGETATION TYPES

There was much variation in chemical concentrations in water samples associated with different vegetation types, but few consistent and statistically significant relationships were found between this variation and the occurrence of plant communities. Large variations in the chemical conditions associated with a particular plant community have been highlighted by Summerfield (1974) who found that there were large variations in the concentrations of cations and the electrical conductivity of mire water samples collected at different times of year and in slightly different 'positions' (horizontal and vertical distance) at the same location. Some of this variation can be explained by the existence of microtopographical zonation within vegetation types which is usually expressed as a mosaic of contrasting water conditions (Clapham 1940, Bellamy & Riely 1967, Van Wirdum 1991, Wheeler 1980b, Proctor 1974, 1995). Much of the vegetation of the Scottish Borders fens has developed as a vegetation raft overlying fluid muds. Quaking fens often contain areas of mosaic vegetation which is intermediate in character between poor and rich fen, often with cushions of *Sphagnum* species, including base-tolerant *Sphagnum* species and other bryophytes surrounded by *Carex lepidocarpa*-brown moss fen vegetation. Such areas show a striking vertical variation in their water chemistry, because the vegetation is associated with both the atmocline (calcium poor) water type and lithocline (calcium rich) water type. Plants rooted in different layers of a vegetation raft may be fed by different water types (Kulczynski 1949) again highlighting the potential for variation in vertical water chemistry.

General relationships between site chemical conditions and vegetation were indicated by CANOCO sample-environment biplots. These indicated that two gradients representing base-richness and fertility corresponded with the main axes of floristic variation. The gradients were roughly orthogonal to one another (therefore largely independent), the fertility gradient being skewed towards the positive end of the base-richness gradient probably because few base-poor soils are very fertile (Wheeler & Shaw 1995a) and because calcium concentration is associated with higher fertility as well as base-rich water because of liming of agricultural soils.

4.4.2.1 Base richness

The most obvious distinction in water type was between rich-fen and poor-fen vegetation types. These habitats are also floristically distinguished by the presence of abundant *Sphagnum* species in samples representing poor-fen vegetation.

Vegetation associated with spring-fed areas was generally more species rich and contained more rare species than other plant communities. Base-rich water flow may be important in maintaining populations of rare species. The replacement of *Dactylorhiza incarnata, Fissidens* and *Liparis* by *Sphagnum palustre, Sphagnum flexuosum, Aulacomnium palustre, Carex curta* and *Carex nigra* within a Dutch fen has been attributed to a reduction in the calcium-rich seepage flow (Wassen, Barendregt, Bootsma and Schot 1989).

Base-poor water was associated with an abundance of *Sphagnum* species in the vegetation. The accumulation of rainwater may lead to the invasion of species tolerant of base-poor conditions, for example *Sphagnum* species. Once *Sphagnum* has invaded the storage of rainwater and active hydrogen ion release by *Sphagnum* species (Clymo 1963) leads to the lowering of the pH. In laboratory trials, Kooijman and Bakker (1995) found that *Calliergon cuspidatum* grew better in base-rich ground water than in base-poor rain water. *Sphagnum subnitens* was the opposite and *Scorpidium scorpioides* and *Sphagnum squarrosum* thrived in both water types. However the growth of *Sphagnum squarrosum* was stimulated by increased nutrient supply. These preferences may affect the speed of species replacement and succession in fens where nutrient-poor fens have slow succession and nutrient-rich fens have fast succession (Kooijman & Bakker 1995).

4.4.2.2 Nutrient status and fertility

In the Scottish Borders fens species-richness was negatively related to fertility. The most species-rich fen vegetation recorded in this part of the study was associated with the lowest peat fertlity. The *Phragmites australis* reedbed, *Carex rostrata, Carex rostrata-Potentilla palustris* and *Filipendula ulmaria* tall herb fen species poor communities showed considerable variation in the conditions with which they were associated. Low species richness can be associated both with low and high fertility situations because species poor vegetation types occur as early successional plant communities under a range of conditions and as stable plant communities in high nutrient situations. Inputs of nutrients and silt may favour the growth of tall, robust species such as *Phragmites australis* (e.g. at the western inflow to Murder Moss). In British fens the fen plant communities that are most species rich and which contain the most rare species are confined to low fertility environments (Wheeler 1988, Shaw & Wheeler 1990).

Many of the Scottish Borders fens are at potential risk from nutrient enrichment from the surrounding land. Some plant communities and some areas of a site may be more susceptible to nutrient enrichment, for example the edges of a site and inflows, where inputs from the catchment will be concentrated. Except in a few cases, notably those which appear to be spring-fed, these areas were often more fertile and supported species-poor plant communities.

At some sample points, particularly in areas which appeared to receive inputs from marginal springs, the intensity of the surrounding land-use was not reflected in the peat fertility of the samples near the edge of the sites nor by the concentration of nitrogen, ammonium, phosphate and potassium ions in the interstitial water. Other workers have also found that differences in vegetation types between fens situated in similar catchments can often not be related to the concentration of nutrients (NPK) within the fen waters and peat and that spring-fed (discharge) fens have been less affected by eutrophication than topogenous fens fed by runoff / river water (recharge) (Koerselman *et al.* 1990). It is possible that the base-richness of the spring water affects the availability of the inwashed nutrients, or that the springs are so strong that they form a much more important water source for the vegetation than does the runoff from the catchment.

The availability of certain nutrients to plants may be affected by the base-richness of the fen water and its pH (Koerselman *et al.* 1990). It has been suggested that calcium can adsorb phosphorus so that areas with high interstitial water calcium concentrations can maintain low productivity vegetation through the limitation of phosphorus availability (Boyer and Wheeler 1989). High calcium concentrations in interstitial waters also favour the bacterial decomposition of organic matter leading to low carbon : nitrogen ratios and generally also to mobilisation of nitrogen from organic matter (Kemmers & Jansen 1988, Verhoeven *et al.* 1990, Verhoeven *et al.* 1993). Therefore discharge areas of calcareous groundwater (springs) may have increased turnover of organic matter with much nitrogen but a limited supply of phosphorus and they may therefore be less susceptible to the effects of nitrogen inputs. The calcium ion also has an indirect effect on soil acidity as it interferes with the processes of mineralization, e.g. ammonification and nitrification (Kemmers 1986).

The availability of phosphorus may also be decreased by the presence of aluminium and iron ions in interstitial water (Verhoeven *et al.* 1993).

In areas where the vegetation has developed as a quaking raft, nutrients derived from runoff from the surrounding land may be absorbed by peat layers below the raft or simply be diverted in the water flow beneath the vegetation raft and may therefore have little immediate impact on the vegetation at the surface (Verhoeven 1983).

4.4.2.3 Vegetation management

Management of vegetation can have a drastic effect on species composition (Wheeler 1983). Nutrient enrichment and increased peat fertility can lead to an increase in the standing crop and the productivity of vegetation and impoverishment of species-rich fen (Wheeler & Giller 1982). However increases in productivity often only result in changes in species composition if they are drastic and lead to distinct changes in the vegetation structure (Verhoeven *et al.* 1993). Vegetation management (mowing or grazing) can prevent changes in vegetation structure by maintaining an open sward and preventing the dominance of robust and competitive species which are favoured by nutrient enrichment. Tree species can also be prevented from invading in this way.

Most rich-fen vegetation types were associated with a wide range of fertility and chemical conditions. Fen vegetation occupies a wide range of habitats (Wheeler 1993) and it is often difficult to distinguish between fen plant communities on the basis of the chemical composition of the waters with which they are associated. Other factors may be more important than the influence of water chemical conditions in determining the occurrence and distribution of vegetation. Proctor (1992) demonstrated that it is possible that variation in major ions may have little direct influence on the distribution of ombrogenous bog species or vegetation types.

Much of the variation in chemical conditions in the Scottish Borders fens appears to be a result of the development of the vegetation, especially where rafts have developed and different components of the vegetation are influenced by water of different chemical composition; this will be investigated in Chapter 5. In areas which have been subject to nutrient enrichment the vegetation is generally species-poor and robust; mowing has reduced the dominance of *Phragmites australis* at some sites. Other areas, which appear to be threatened by nutrient enrichment, have low fertility peat and support species rich vegetation. These areas appear to be influenced by inputs of spring water. It may be possible to maintain species-rich plant communities with populations of rare species in sub-optimal chemical conditions, despite nutrient enrichment, through the buffering capacity of fen waters and the continuation of vegetation management (Shaw & Wheeler 1992). The impact of grazing on species richness of fen vegetation will be examined in Chapter 6 of this study.

Chapter 5: Vegetation rafts: composition, development and chemical conditions.

5.1 Introduction

Although not recognised in the "classic" description of the hydrosere (Tansley 1939), hydroseral colonisation of small bodies of open water often occurs by the formation of a quaking raft overlying water or fluid muds (Kulczynski 1949, Segal 1966, Walker 1966, Walker 1970, Van Wirdum et al. 1992). Vegetation rafts can develop naturally over lakes and open water (Walker 1966, Wilcox & Simonin 1988), over subsided peatland (Tallis 1973), and over flooded peat cuttings (White 1930, Lambert *et al.* 1960, Van Wirdum 1991). The raft can develop through the direct colonisation of open water (hydroseral succession), or as a result of the flooding of vegetated solid peat when buoyant rhizomes of rooted species such as *Phragmites australis* and *Typha latifolia* lose their attachment to the solid peat and float to the water surface (H. Piek (1972) cited in Bakker 1979).

Vegetation rafts commonly occupy former peat cuttings (White 1930, Segal 1966, Giller & Wheeler 1986, Van Wirdum 1991) and these semi-natural habitats often contain conservationally important plant communities and rare plant species (Wheeler 1993). The bryophyte flora of all but early successional rafts is often well developed probably because the raft creates a hydrostatic environment which does not suffer large fluctuations in the water table relative to the vegetation surface, reducing the stress of both desiccation and flooding (Green & Pearson 1968, Giller & Wheeler 1986). Under these conditions some bryophyte species, most notably *Sphagnum* spp., can alter the chemical conditions at the vegetation surface and thus can sometimes influence the direction and rate of vegetation development through the rapid formation of peat and the isolation of the vegetation surface from the base-rich water supply (O'Connell 1981, Kooijman & Bakker 1995, Glime *et al.* 1982).

Many of the Scottish Borders fens support vegetation rafts, with a range of plant communities including examples of rich-fen, poor fen and bog vegetation. The objectives of this part of the study were to examine the processes of vegetation raft formation and development through investigations into:

1. the occurrence of different plant communities on vegetation rafts;
2. the composition and thickness of vegetation rafts supporting different plant communities;
3. the impact of basin morphology on raft development;

4. the development of poor-fen vegetation on vegetation rafts and the reasons for the occurrence of two distinctive *Sphagnum* communities:

   (a) *Carex rostrata - Sphagnum recurvum* community rich in *Sphagnum* species typical of poor-fen and bog (e.g. *Sphagnum recurvum, Sphagnum fimbriatum, Sphagnum palustre*);

   (b) *Carex diandra - Sphagnum contortum* community rich in *Sphagnum* species tolerant of base-rich conditions (e.g. *Sphagnum contortum, Sphagnum teres, Sphagnum warnstorfii*).

5. differences in baseline water chemistry between sites and the autogenic alteration of water chemical conditions during raft development and vegetation succession.

5.2 Methods

5.2.1 THE OCCURRENCE OF VEGETATION RAFTS IN DIFFERENT PLANT COMMUNITIES

Quadrat data from the general survey of the Scottish Borders fens were used to determine the occurrence of vegetation rafts in different plant communities. This was calculated as the proportion of all samples representing a particular plant community occurring as a quaking raft or rooted into solid peat.

The average depth from the vegetation surface to solid substratum for quaking samples representing each plant community was calculated. The beginning of the solid substratum was taken as the surface of residual peat deposits beneath the raft or of the clay base where there were no residual peat deposits.

5.2.2 COMPOSITION AND STRATIGRAPHY OF RAFTS

The composition and stratigraphy of vegetation rafts were investigated along transects across 5 sites supporting different vegetation types, usually with clear zonation (table 5.1). A monolith of the raft was extracted using a serrated knife which could extract up to 80cm depth. In some cases this was insufficient to reach the bottom of the raft, but it allowed the composition of the at least the upper layers of the raft to be determined. The thickness of the raft was estimated using a 'bog mat depth sampler' (figure 5.1) and the components of the raft (roots, rhizomes, moss, mud) were separated and quantified. The dominant components in different layers of the raft were recorded.

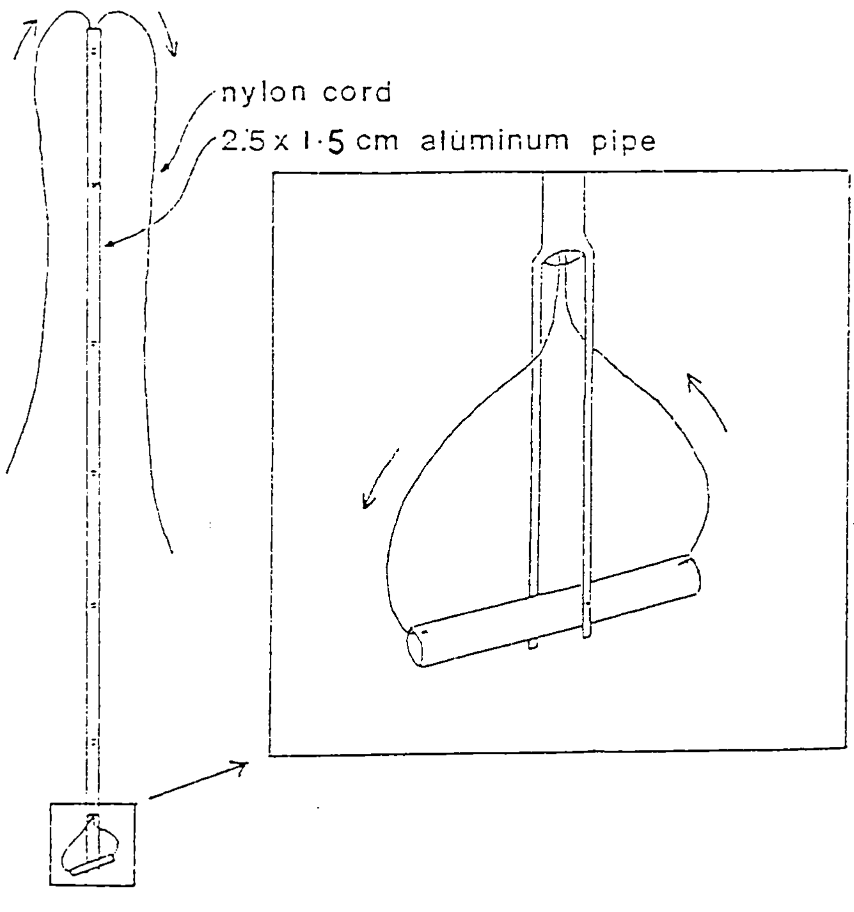


Figure 5.1. 'Bog mat depth sampler' a tool to estimate raft thickness. It is inverted into the core hole, opened to an inverted T, and lifted until resistance is met (after Wilcox & Simonin 1988).

The degree of fibrousness was also noted. The peat stratigraphy was recorded using a Hiller borer at each sample point.

Table 5.1. Sites and principal plant communities used in the study of raft composition. The status of the site (peat-cutting or undisturbed) is indicated.

Site	*Plant communities*
Whitehaughmoor Moss (peat cutting)	*Carex diandra-Sphagnum contortum* community, mixed sedge rich-fen community with rare bryophytes.
Kippilaw Moss (peat cutting)	*Carex diandra-Calliergon cuspidatum - Plagiomnium rostratum* community
Greenside Moss (peat cutting)	*Carex diandra-Calliergon cuspidatum - Plagiomnium rosratum* fen, *Carex rostrata - Sphagnum recurvum* community
Nether Whitlaw Moss (peat cutting)	*Carex rostrata- Potentilla palustris* species-poor community, *Carex rostrata - Sphagnum recurvum* community
Brown Moor Heights (undisturbed)	*Carex rostrata - Sphagnum recurvum* community, *Eriophorum vaginatum - Sphagnum papillosum* community

5.2.3 WATER CHEMISTRY

The differences between measurements of pH and electrical conductivity recorded in the field during the general survey of the Scottish Borders fens (1992 & 1993) from above and below the raft in samples representing different plant communities were analysed.

Water samples were also collected during December 1994 from a selection of sample sites containing comparable and contrasting vegetation types developed as vegetation rafts (table 5.2). The area of *Eriophorum vaginatum - Sphagnum papillosum* bog vegetation at Long Moss on solid peat was also included as a reference sample point.

Table 5.2. Sample locations and vegetation types used for water sampling. Substratum refers to the deposits between the raft and solid (residual) deposits. Sample locations are presented in Appendix 2.

Sample location	*Code*	*Plant community*	*Substratum*
Whitehaughmoor Moss	WHM2	Mixed sedge rich-fen with rare bryophytes	loose peat / grounded
Beanrig Moss	BE7	*Carex diandra - Sphagnum contortum* community	loose peat / grounded
Long Moss fen	LM2	*Carex diandra-Calliergon cuspidatum - Plagiomnium rostratum* community, typical variant	fluid detrital peat
Nether Whitlaw fen	NW2	*Carex rostrata-Calliergon cuspidatum - Plagiomnium rostratum* community, typical variant	fluid detrital peat
Nether Whitlaw poor fen	NW7	*Carex rostrata - Sphagnum recurvum* poor-fen community	fluid detrital peat
Blind Moss	BL1	*Carex rostrata - Sphagnum recurvum* poor-fen community	fluid detrital peat
Groundistone moss bog	GM4	*Eriophorum vaginatum - Sphagnum papillosum* community	fluid detrital peat
(Long Moss bog)	LM1	*Eriophorum vaginatum - Sphagnum papillosum* community	solid peat

Triplicate water samples were collected from the vegetation surface and from beneath the raft at each sample point. Samples were collected in 250ml high density polythene bottles, were stored at <5°C and were filtered and analysed in Sheffield for cations (calcium, magnesium, sodium, potassium, manganese, iron, ammonium) and anions (nitrate, phosphate, sulphate, chloride) using the methods described in Chapter 4 of this thesis. pH and electrical conductivity were recorded in the field. The water type of each sample was characterised using the L.A.T. (lithotrophic, atmotrophic, thallassotrophic) model of Van Wirdum (1991) based on the electrical conductivity and Ionic Ratio (base-status) of each sample, as described in Chapter 4.

5.3 Results

5.3.1 OCCURRENCE OF VEGETATION RAFTS IN DIFFERENT PLANT COMMUNITIES

Most plant communities in the Scottish Borders fens can occur as vegetation rafts (table 5.3); however two communities, the *Carex diandra - Sphagnum contortum* rich-fen community and *Carex rostrata - Sphagnum recurvum* poor-fen community occurred *exclusively* as vegetation rafts.

Table 5.3.The percentage occurrence of plant communities on quaking and solid substrata in the Scottish Borders fens data set.

	Proportion of samples developed as quaking rafts or rooted into solid peat	
Plant Community	*Quaking*	*Solid*
Carex diandra - Sphagnum contortum community	100	0
Carex rostrata - Sphagnum recurvum community	100	0
Glyceria fluitans species-poor community	75	25
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, miscellaneous variant	65	35
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	58	42
Carex rostrata species-poor community, *Menyanthes trifoliata* variant	56	44
Mixed sedge rich-fen community	54	46
Carex lepidocarpa - brown moss community	53	47
Eriophorum vaginatum - Sphagnum papillosum bog	50	50
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	37	63
Carex rostrata- Potentilla palustris species-poor community	34	66
Equisetum fluviatile species-poor community	33	67
Acidified / wooded fen	25	75
Sparganium erectum species-poor community	25	75
Eleocharis palustris species-poor community	20	80
Phragmites australis reedbed	20	80
Carex rostrata species-poor community, *Carex rostrata* variant	14	86
Filipendula ulmaria tall herb fen	13	87
Mixed wet grassland	11	89
Molinia caerulea / Juncus acutiflorus fen meadow	10	90
Carex dioica - Carex hostiana community	9	91
Phalaris arundinacea reedbed	0	100
Carex acutiformis species-poor community	0	100

5.3.2 COMPOSITION OF VEGETATION RAFTS

5.3.2.1 Nether Whitlaw Moss

A long, narrow site containing extensive *Carex rostrata* swamp vegetation with localised development of the *Carex diandra-Calliergon cuspidatum, Plagiomnium rostratum* community, and with a central area of *Carex rostrata-Sphagnum recurvum* poor-fen supporting birch and willow carr.

The thickest and most stable rafts were those supporting poor-fen vegetation, and occurred near the centre of the site (table 5.4). The main components of the rafts are presented in figure 5.2.

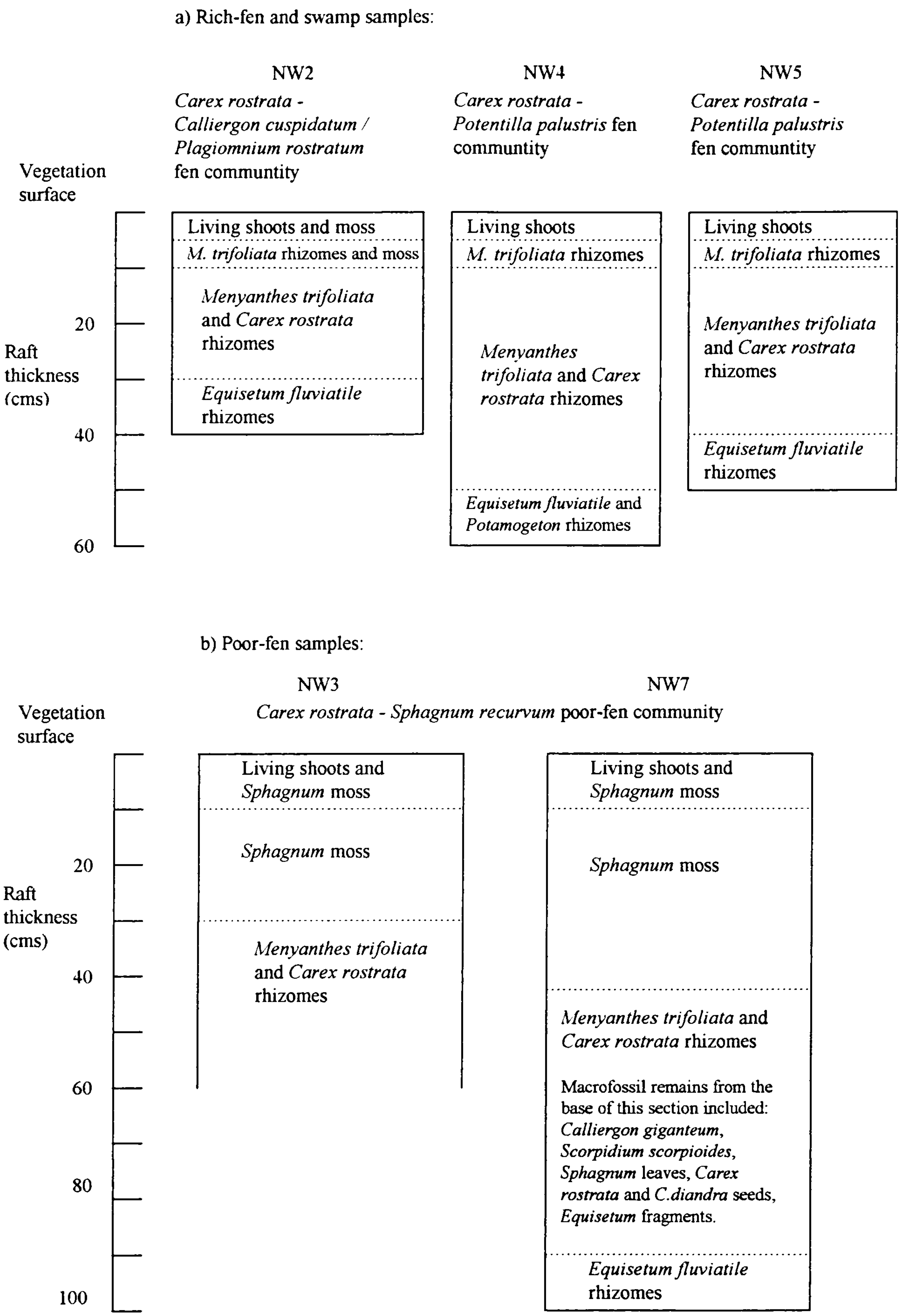


Figure 5.2. Raft monoliths showing the main structural components extracted from rich-fen, swamp (a) and poor-fen (b) vegetation types at Nether Whitlaw Moss

Table 5.4. The abundance of different species and components of the raft at different locations on Nether Whitlaw Moss. The locations of the transect and samples are presented in Appendix 2.
The vegetation types on the raft surface and the main components of the raft were recorded using the following scale:

Habitat type		Abundance scale	
RF	Rich-fen	xxxx	>50%
PF	Poor-fen	xxx	31-50%
S	Swamp	xx	21-30%
		x	5-20%
		+	<5%

Sample	NW2	NW3	NW4	NW5	NW7
Habitat type	RF	PF	S	S	PF
Raft Thickness (cm)	40	70	60	50	80-100
Menyanthes trifoliata	xxx	xx	xxxx	xxx	+
Carex rostrata rhizomes	xxx	xx	xxx	xxx	xx
Eriophorum angustifolium		xxx			
mud	x	x	+	+	xx
Sphagnum moss		+			xxx
Hypnoid moss	+	+			+
Equisetum fluviatile	x	x	x	xxx	x
Potamogeton roots			x		
Depth from vegetation surface to solid substratum (cm)	160	180	220	100	200
Distance from nearest edge (m)	3	24	47	5	45

5.3.2.2 Kippilaw Moss

A small, triangular site containing 3 central pools surrounded by *Carex rostrata* swamp, *Carex paniculata* swamp, *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* rich-fen and *Salix* carr.

The raft thickness varied across the site (table 5.5). Areas nearer the centre of the site, where there was patchy *Salix* scrub, were the thickest recorded at Kippilaw Moss (60cm). Other areas of *Carex rostrata* swamp occurred as a treacherous, thin raft (30cm). Both these areas were near pools of open water. The main structural components of the raft were *Carex rostrata* and *Menyanthes trifoliata* rhizomes. *Equisetum* rhizomes were abundant at the base of the raft and mosses and mud tended to occur throughout although these were more abundant near the surface. Where scrub occurred the tree roots were present near the surface of the raft (table 5.5 and figure 5.3).

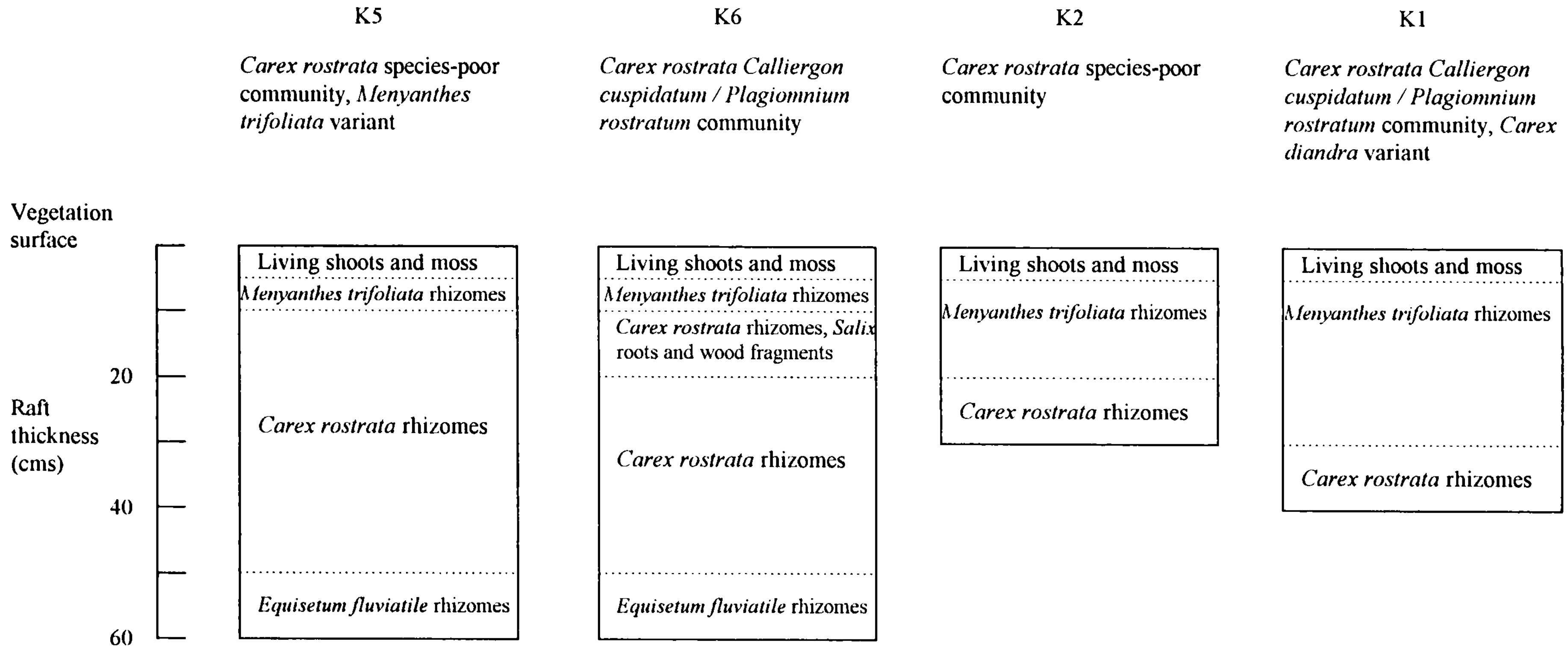


Figure5.3. The main structural components of vegetation raft monoliths extracted from Kippilaw Moss. Sample locations are presented in Appendix 2.

Table 5.5. The abundance of different species and components of the raft at different locations on Kippilaw Moss. The location of the transect and sample locations are presented in Appendix 2.
Habitat types and the abundance of raft components are scored as for table 5.4.

Sample code	K4	K5	K6	K2	K1
Habitat type	RF	S	S	S	RF
Raft Thickness (cm)	grounded	60	60	30	40
Menyanthes trifoliata	xxxx	xxxx	xxx	xx	xxxx
wood			x		
mud	xx	x	x	+	xxx
Carex diandra	x				
Carex rostrata	xx	xxx	xxx	xxxx	xx
Plagiomnium rostratum	x		x		xx
Calliergon cuspidatum	x		x		x
Equisetum fluviatile	+	x	x	+	
Depth from vegetation surface to solid substratum (cm)	25	150	100	120	125
Distance from nearest edge (m)	3	16	21	11	5

5.3.2.3 Brown Moor Heights

A small, circular site mostly containing poor-fen vegetation. A narrow strip around the edge supported *Carex diandra - Sphagnum contortum* fen which merged into *Carex rostrata - Sphagnum recurvum* poor-fen with *Sphagnum papillosum - Eriophorum vaginatum* bog vegetation in the centre.

The peat at this site is considered to be uncut and the vegetation raft is mostly "grounded" over up to 4 metres of undisturbed peat deposits. Only the vegetation around the margins of the site is still strongly quaking (this being the area where the raft was sampled). *Sphagnum* moss is abundant in the raft and at the surface (table 5.6).

Table 5.6. The abundance of different species and components of the raft at Brown Moor Heights Moss. The sample location is presented in Appendix 2.
Habitat types and the abundance of raft components are scored as for table 5.4.

Sample code	BMH1
Habitat type	PF
Raft Thickness (cm)	50
Living *Sphagnum*	xx
Sphagnum	xxxx
Menyanthes trifoliata	x
Carex diandra rhizomes	+
Carex rostrata rhizomes	xxx
Depth from vegetation surface to solid substratum (cm)	100
Distance from nearest edge (m)	10

Menyanthes trifoliata and *Carex rostrata* rhizomes are the main components of the raft and these are mixed with a superficial layer of *Sphagnum* remains (figure 5.4).

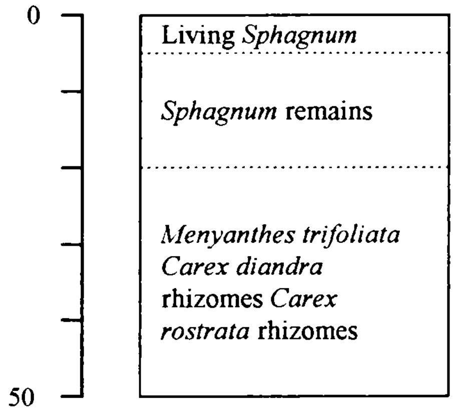


Figure 5.4. Main components in layers of the vegetation raft at Brown Moor Heights Moss (sample BMH1).

5.3.2.4 Whitehaughmoor Moss

A very small site containing a mosaic of *Carex lepidocarpa* brown moss rich fen (including *Cinclidium stygium*) and *Carex diandra - Sphagnum contortum* fen with hummocks of *Homalothecium nitens*.

This is a shallow site with a part-floating, part-"grounded" vegetation raft, which is up to 80cm thick in places (table 5.7).

Table 5.7. The abundance of different species and components of the raft at different locations on Whitehaughmoor Moss. The sample locations are presented in Appendix 2.
Habitat types and the abundance of raft components are scored as for table 5.4.

Sample code	WHM1	WHM2
Habitat type / location	RF	RF
Raft Thickness (cm)	40	80
Menyanthes trifoliata	x	x
Carex rostrata rhizomes	xxxx	xxx
Calliergon giganteum	x	xxx
Scorpidium scorpioides	x	xx
Equisetum fluviatile	+	+
Depth from vegetation surface to solid substratum (cm)	70	120
Distance from nearest edge (m)	15	30

The bulk of the raft is made up of sedge rhizomes, in particular *Carex rostrata*, and *Menyanthes trifoliata* rhizomes. *Equisetum fluviatile* rhizomes become abundant at the base of the raft (figure 5.5). Hypnoid moss fragments occurred throughout the raft and in detrital peat beneath the raft (table 5.7).

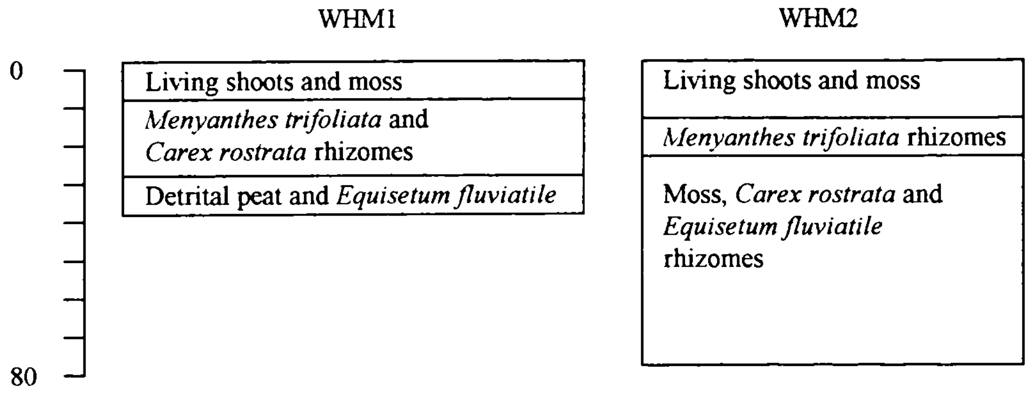


Figure 5.5. Main components in layers of vegetation rafts at different locations on Whitehaughmoor Moss.

5.3.2.5 Greenside Moss

A small site with a central area of *Carex rostrata - Sphagnum recurvum* poor-fen surrounded by *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* rich-fen. Other areas represent the *Carex rostrata, Eleocharis palustris* and *Carex rostrata - Potentilla palustris* species-poor communities.

The thickest part of the raft contained abundant *Sphagnum* remains overlying a layer which contained substantial quantities of *Aulacomnium palustre*. The junction between these layers was striking and coincided with an increase in the abundance of *Carex rostrata* rhizomes and *Equisetum* fragments towards the base of the raft (table 5.8 and figure 5.6).

Table 5.8. The abundance of different species and components of the raft at different locations on Greenside Moss. The location of samples are presented in Appendix 2.
Habitat types and the abundance of raft components are scored as for table 5.4.

Sample code	GREEN1	GREEN2
Habitat type	PF	RF
Raft Thickness (cm)	70	60
Sphagnum	xxx	
Aulacomnium palustre	x	
Calliergon		x
Menyanthes trifoliata		x
Carex rostrata rhizomes	xxx	xx
Equisetum fluviatile	xx	xxx
Depth from vegetation surface to solid substratum (cm)	200	70
Distance from nearest edge (m)	30	5

The thinner fen raft did not contain *Sphagnum* but was otherwise similar in structure to the poor-fen raft (figure 5.6).

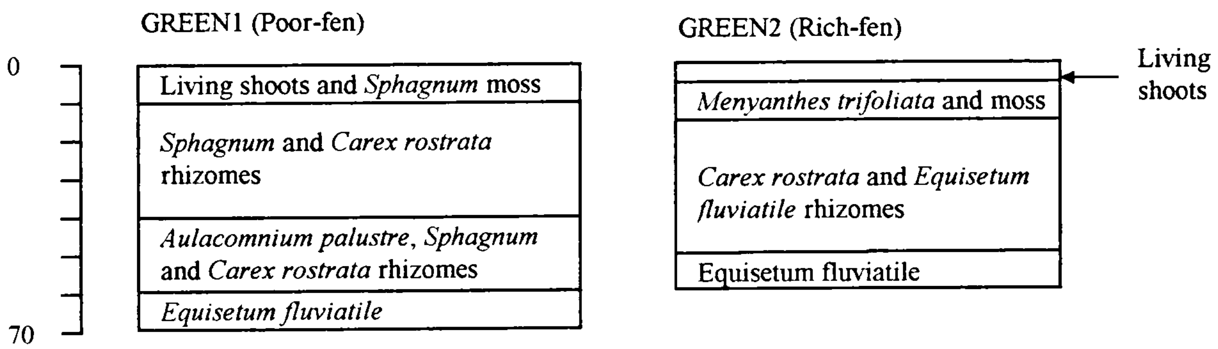


Figure 5.6. Dominant components in layers of the vegetation raft at different locations on Greenside Moss.

5.3.3 RAFT DEVELOPMENT AND BASIN MORPHOLOGY

There was no significant relationship between the raft thickness and the depth from the vegetation surface to solid substratum ($r=0.466$, d.f. 12, not significant). Therefore the depth of water or fluid peat beneath a raft has no simple relation to its thickness. However, raft thickness was positively correlated with distance from the nearest edge (defined as the edge of the basin area, not including marginal flushes etc.) ($r= 0.737$, d.f. 12 $p<0.01$, figure 5.7), so the thickest rafts were encountered near the centre of the sites. The depth from the vegetation surface to solid substratum was also greater further from the site edge showing that at most sites hydroseral succession has occurred in a shallow basin ($r=0.709$, d.f. 12 $p<0.01$). Areas of well developed poor-fen vegetation also tended to occur furthest from the edges of sites and in the deepest areas (table 5.9).

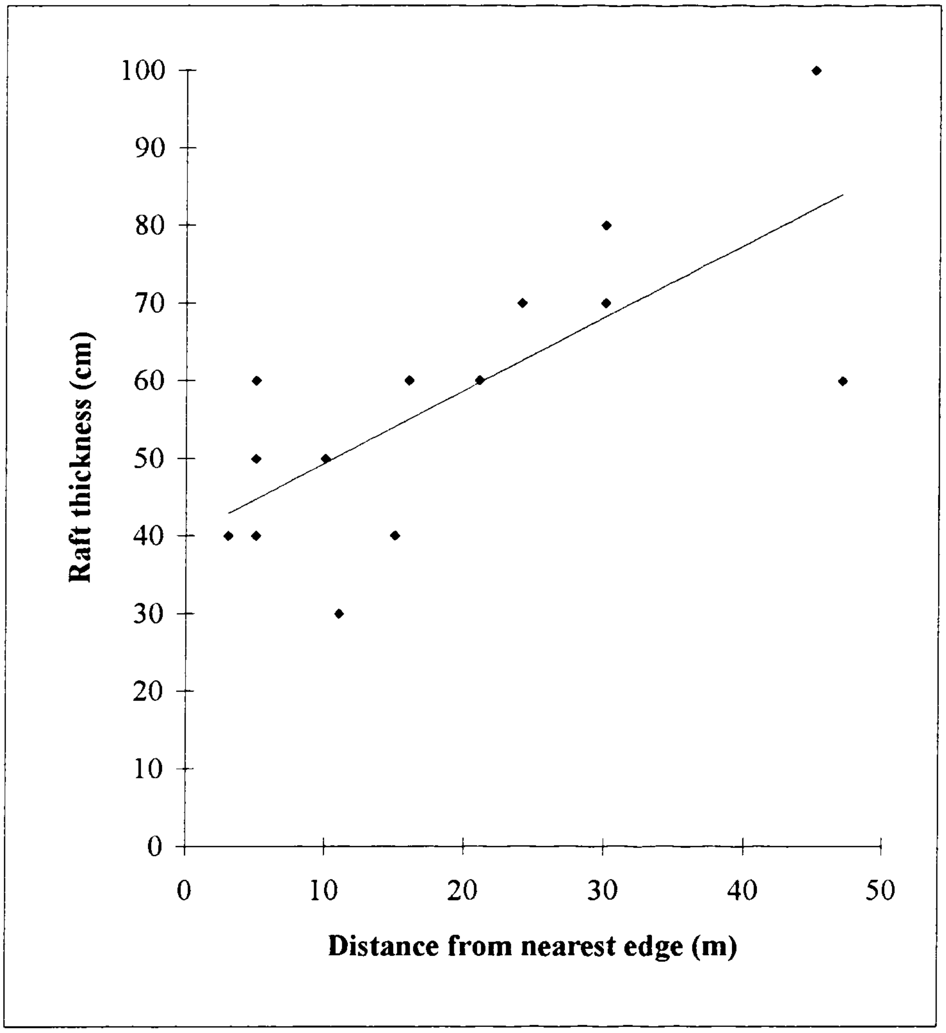


Figure 5.7. Relationship between vegetation raft thickness and the distance from the edge of the fen site in some Scottish Borders fens. r = 0.737, d.f. 12, p<0.01.

The depth from the vegetation surface to solid substratum within plant communities is presented in table 5.9. Rafts occupying the deepest areas of flooded basins supported poor-fen and swamp communities. Rich-fen and swamp vegetation was found in shallower areas.

Table 5.9. The mean depth from the vegetation surface to solid substratum within different plant communities.

Plant community	*Habitat type*	*Number of samples*	*Mean depth from vegetation surface to solid peat (cm)*
Glyceria fluitans community	Swamp	3	58
Carex lepidocarpa - brown moss community	Rich-fen	9	83
Menyanthes trifoliata community	Swamp	9	87
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	Rich-fen	7	88
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	Rich-fen	11	89
Acidified degraded fen	Rich-fen	2	90
Filipendula ulmaria tall herb fen community	Tall herb fen	2	100
Carex diandra - Sphagnum contortum community	Rich-fen	17	105
Carex rostrata- Potentilla palustris species-poor community	Swamp	14	107
Mixed sedge rich-fen community	Rich-fen	7	114
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, miscellaneous variant	Rich-fen	15	130
Carex rostrata species-poor community	Swamp	2	135
Equisetum fluviatile species-poor community	Swamp	2	160
Eriophorum vaginatum - Sphagnum papillosum community	Bog	4	178
Phragmites australis reedbed community	Swamp	2	205
Carex rostrata - Sphagnum recurvum community	Poor-fen	10	212

5.3.4 WATER CHEMISTRY

5.3.4.1 Spatial variation in water chemistry

Much vertical variation was found in the water chemistry. In some samples surface measurements were very different from sub-surface samples (table 5.10). T-tests were performed between surface and sub-surface measurements for each variable.

Table 5.10. Relationship between surface and subsurface water samples at each sample point. - indicates surface concentrations were significantly lower than subsurface concentrations: + indicates surface concentrations significantly higher than subsurface concentrations; - indicates surface concentrations significantly lower than sub-surface concentrations. ns indicates no significant difference.

Site	*Habitat type*	*Sample Code*	*pH*	*EC*	*Cl*	*Ca*	*NH_4*	*Fe*	*Mg*	*Na*
Whitehaughmoor Moss	rich-fen	WHM2	ns	-	ns	+	ns	ns	ns	ns
Nether Whitlaw Moss	rich-fen	NW2	+	-	-	-	-	ns	-	-
Long Moss	rich-fen	LM2	ns	-	-		ns	ns	ns	ns
Beanrig Moss	fen	BE7	-	-	-	-	ns	ns	ns	ns
Nether Whitlaw Moss	poor-fen	NW7	-	-	ns	-	ns	ns	+	ns
Blind Moss	poor-fen	BL1	-	-	-	-	ns	+	ns	ns
Groundistone Moss	bog	GM4	-	-	-	-	ns	ns	ns	ns
Long Moss	bog	LM1	-	-	-	-	ns	ns	ns	ns

The most striking differences were in the measurements of pH, electrical conductivity, chloride and calcium concentrations. The results for each variable are presented in figures 5.8 a-m and table 5.11. The difference between measurements from surface and sub-surface samples were greatest in poor-fen and bog communities. In some cases in rich-fen vegetation there was no significant difference in the measurements from the surface and sub-surface samples.

Potassium, nitrate, phosphate and sulphate concentrations were not significantly different between samples from the surface water and the sub-surface water.

Generally where there were significant differences between the surface and sub surface values, the surface values were lower, indicating the prevalence of telluric water beneath the vegetation raft.

pH values of all surface samples (except WHM2, NW2 and LM2) were significantly lower than subsurface samples. The pH of surface water was significantly greater than sub-surface water in sample NW2.

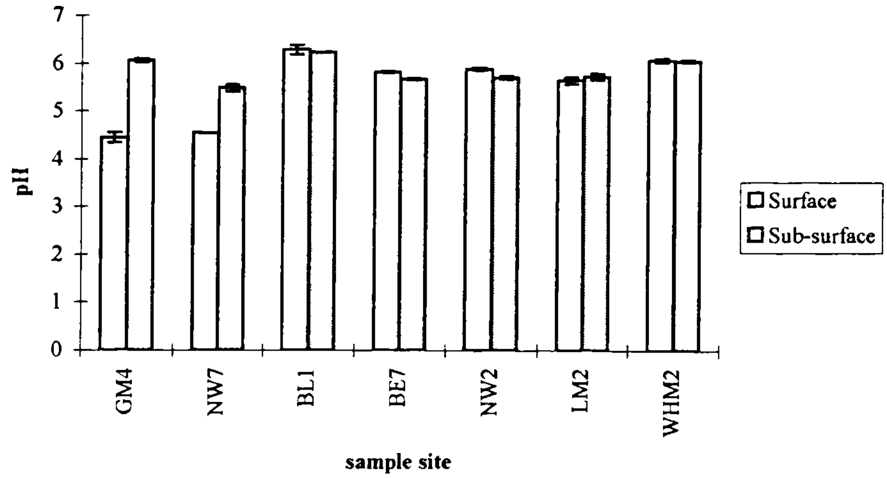
Electrical conductivity values of all surface samples was significantly smaller than sub-surface values. Calcium concentrations of all surface samples (except WHM2) were significantly smaller than sub-surface concentrations. At Whitehaughmoor Moss surface calcium concentrations were significantly higher than sub-surface. There was no significant difference between surface and sub-surface concentrations of calcium at Long Moss (LM2)

Chloride concentrations of all surface samples (except WHM2) were significantly smaller than sub-surface concentrations.

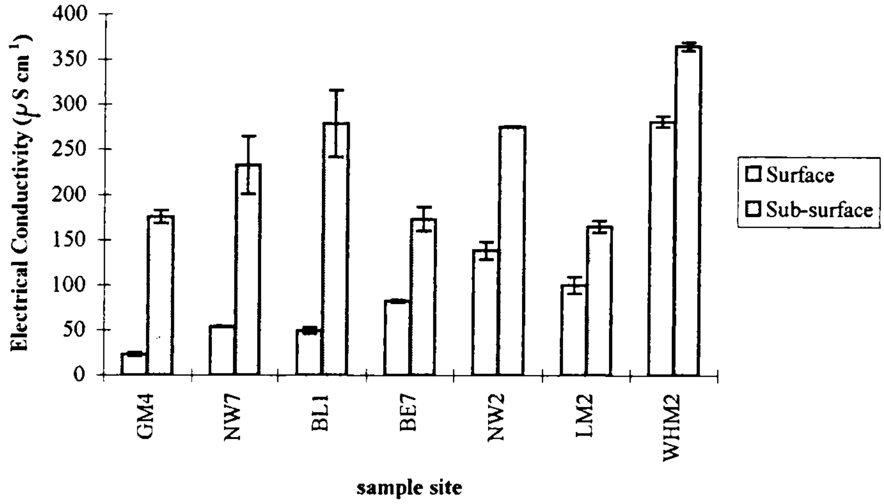
5.3.4.2 Vertical variation in water chemistry in different plant communities

Measurements of electrical conductivity were significantly lower in surface water samples than sub-surface water samples in certain plant communities (*Carex rostrata - Calliergon cuspidatum*

(a)



(b)



(c)

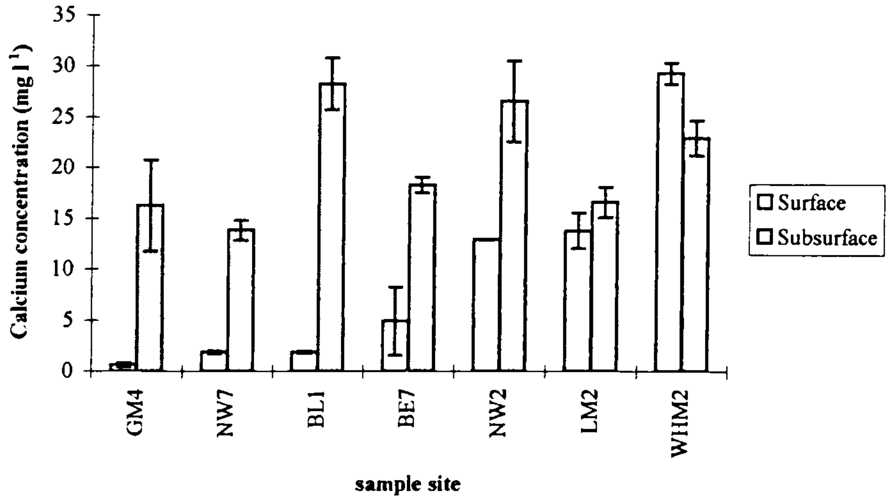
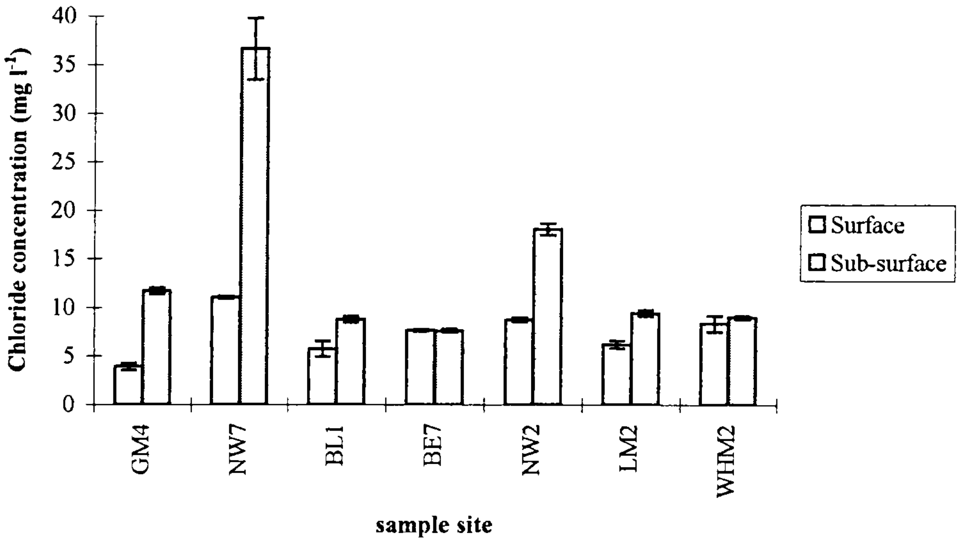


Figure 5.8. Mean values (+/- standard error) of chemical variables in surface and sub-surface water samples from vegetation rafts in some Scottish Borders fens.
(a) pH
(b) Electrical conductivity
(c) Calcium

(d)



(e)

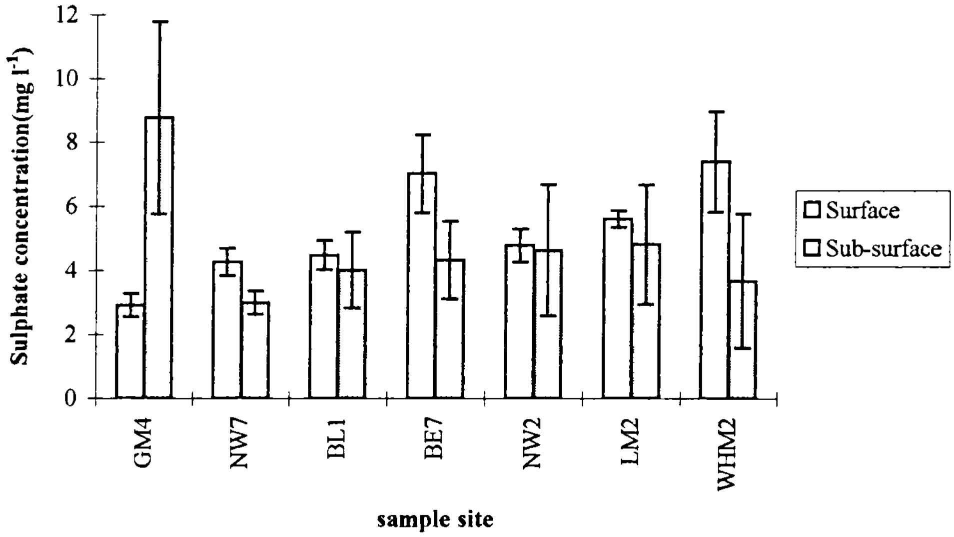
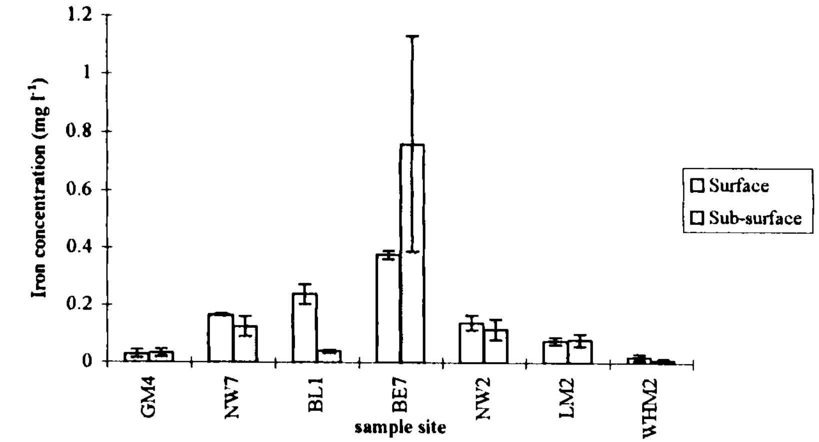
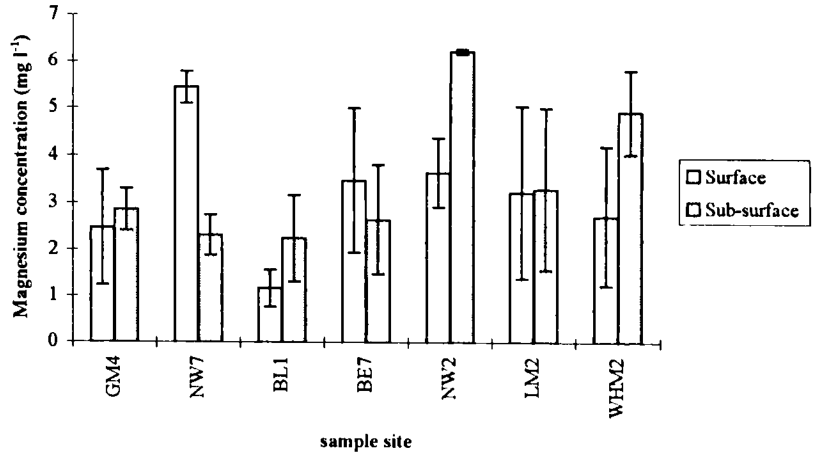


Figure 5.8 cont.
(d) Chloride
(e) Sulphate

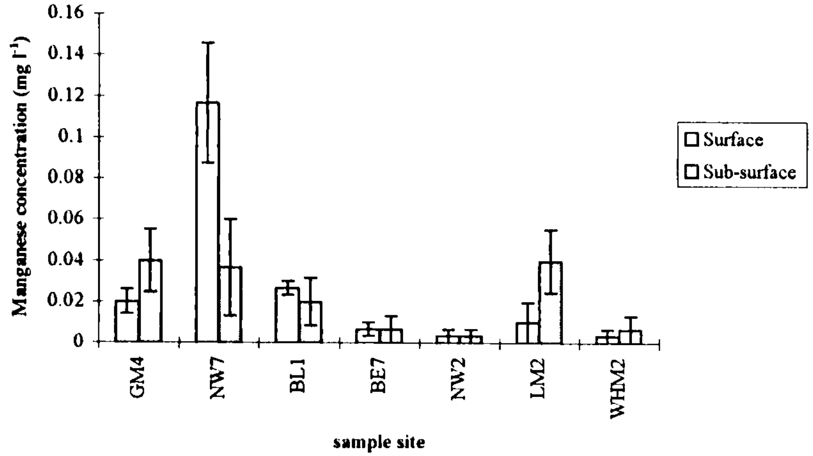
(f)



(h)



(g)



(i)

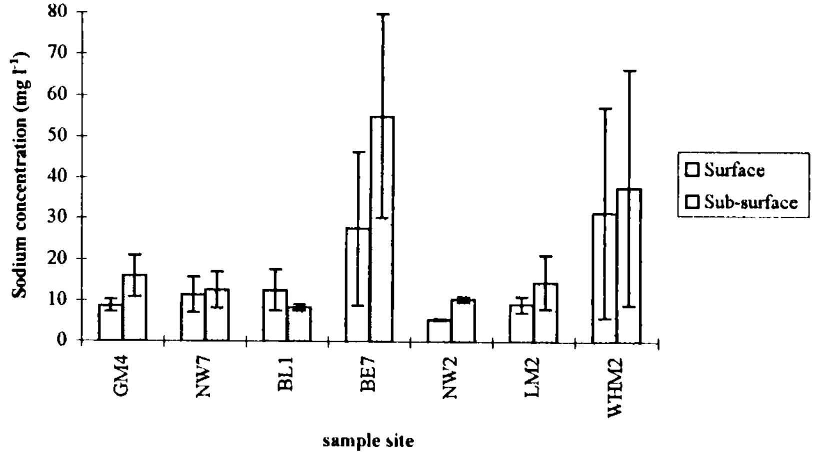


Figure 5.8 cont.
(f) Iron (h) Magnesium
(g) Manganese (i) Sodium

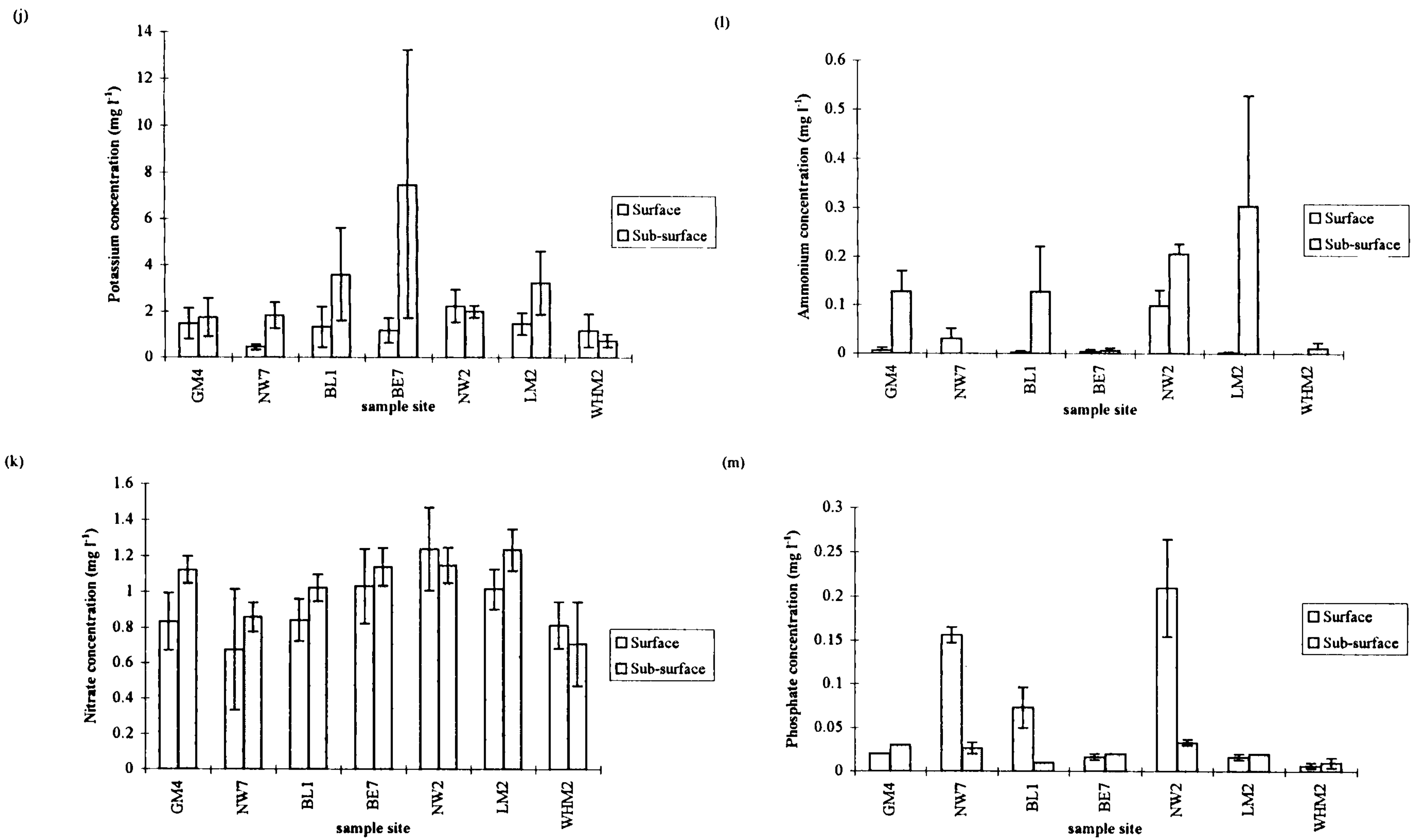


Figure 5.8 cont.
(j) Potassium (l) Ammonium
(k) Nitrate (m) Phosphate

Table 5.11. Mean values and standard errors (S.E.) of chemical variables at the vegetation surface (Surface) and beneath the vegetation raft (Sub-surface) (except LM1 which is on solid peat)

Surface

Habitat	*Sample*	*pH*	*S.E.*	*EC*	*S.E.*	*Ca*	*S.E.*	*K*	*S.E.*	*NO_3*	*S.E.*	*NH_4*	*S.E.*	*PO_4*	*S.E.*	*SO_4*	*S.E.*	*Cl*	*S.E.*	*Fe*	*S.E.*	*Mn*	*S.E.*	*Mg*	*S.E.*	*Na*	*S.E.*
bog	(LM1)	4.04	0.10	44	4	1.88	0.08	2.63	0.93	1.14	0.17	0.00	0.00	0.03	0.00	2.61	0.22	6.76	0.50	0.48	0.16	0.05	0.01	1.53	1.09	12.89	4.99
bog	GM4	4.45	0.11	23	2	0.61	0.23	1.48	0.66	0.83	0.16	0.01	0.01	0.02	0.00	2.91	0.36	3.92	0.37	0.03	0.02	0.02	0.01	2.47	1.22	8.75	1.47
poor-fen	NW7	4.55	0.01	53	1	1.83	0.15	0.46	0.12	0.68	0.34	0.03	0.02	0.16	0.01	4.25	0.42	11.03	0.16	0.17	0.00	0.12	0.03	5.45	0.34	11.40	4.20
poor-fen	BL1	6.29	0.11	49	4	1.86	0.13	1.33	0.88	0.84	0.12	0.00	0.00	0.07	0.02	4.46	0.45	5.70	0.82	0.24	0.04	0.03	0.00	1.16	0.39	12.55	4.97
rich-fen	BE7	5.82	0.01	82	2	4.89	3.33	1.18	0.54	1.03	0.21	0.00	0.00	0.02	0.00	7.01	1.22	7.62	0.11	0.38	0.01	0.01	0.00	3.47	1.53	27.59	18.73
rich-fen	NW2	5.88	0.03	138	10	12.93	0.04	2.24	0.71	1.24	0.23	0.10	0.03	0.21	0.06	4.77	0.51	8.72	0.24	0.14	0.03	0.00	0.00	3.65	0.73	5.44	0.24
rich-fen	LM2	5.65	0.08	100	9	13.79	1.78	1.47	0.47	1.02	0.11	0.00	0.00	0.02	0.00	5.61	0.26	6.20	0.41	0.08	0.01	0.01	0.01	3.22	1.83	9.12	2.01
rich-fen	WHM2	6.07	0.04	281	6	29.31	1.06	1.18	0.72	0.82	0.13	0.00	0.00	0.01	0.00	7.40	1.57	8.35	0.86	0.02	0.01	0.00	0.00	2.71	1.49	31.67	25.78

Sub-Surface

Habitat	*Sample*	*pH*	*S.E.*	*EC*	*S.E.*	*Ca*	*S.E.*	*K*	*S.E.*	*NO_3*	*S.E.*	*NH_4*	*S.E.*	*PO_4*	*S.E.*	*SO_4*	*S.E.*	*Cl*	*S.E.*	*Fe*	*S.E.*	*Mn*	*S.E.*	*Mg*	*S.E.*	*Na*	*S.E.*
bog	(LM1)	4.71	0.03	71	3	8.92	2.54	2.22	0.54	1.02	0.12	0.03	0.02	0.05	0.00	2.95	0.68	9.05	0.39	0.25	0.03	0.06	0.02	1.99	0.96	5.93	0.65
bog	GM4	6.06	0.04	175	7	16.24	4.50	1.74	0.83	1.12	0.08	0.13	0.04	0.03	0.00	8.76	3.01	11.68	0.33	0.03	0.01	0.04	0.02	2.86	0.45	15.99	5.01
poor-fen	NW7	5.49	0.07	232	32	13.81	0.96	1.83	0.55	0.86	0.08	0.00	0.00	0.03	0.01	2.98	0.36	36.65	3.17	0.13	0.04	0.04	0.02	2.31	0.43	12.58	4.36
poor-fen	BL1	6.23	0.01	279	37	28.24	2.57	3.62	2.01	1.02	0.07	0.13	0.09	0.01	0.00	4.00	1.18	8.76	0.31	0.04	0.01	0.02	0.01	2.24	0.93	8.41	0.79
rich-fen	BE7	5.67	0.02	173	13	18.30	0.79	7.49	5.75	1.14	0.11	0.01	0.01	0.02	0.00	4.32	1.22	7.60	0.16	0.76	0.37	0.01	0.01	2.64	1.16	55.08	24.76
rich-fen	NW2	5.71	0.04	275	1	26.58	3.99	2.01	0.26	1.15	0.10	0.21	0.02	0.03	0.00	4.63	2.04	18.07	0.61	0.12	0.04	0.00	0.00	6.22	0.06	10.40	0.63
rich-fen	LM2	5.74	0.07	165	6	16.63	1.49	3.25	1.36	1.24	0.12	0.30	0.22	0.02	0.00	4.81	1.87	9.44	0.30	0.08	0.02	0.04	0.02	3.29	1.72	14.62	6.60
rich-fen	WHM2	6.07	0.02	365	5	22.95	1.74	0.75	0.28	0.71	0.24	0.01	0.01	0.01	0.01	3.66	2.09	9.02	0.16	0.01	0.01	0.01	0.01	4.92	0.89	37.82	28.74

/ *Plagiomnium rostratum* community, mixed sedge rich-fen and *Carex rostrata - Sphagnum recurvum* poor-fen). The pH of surface water samples was significantly lower than that of sub-surface water samples from poor-fen and bog vegetation types (table 5.12). There was no significant difference between surface and sub-surface pH and electrical conductivity in the *Carex diandra - Sphagnum contortum* community.

Table 5.12. T-tests between surface and subsurface measurements of pH and electrical conductivity from different vegetation types occurring as rafts in the Scottish Borders fens.* p<0.05, **p<0.02, ***p<0.01

	pH (mean)		*µS/cm (mean)*	
Vegetation type	Surface	Sub-surface	Surface	Sub-surface
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	6.2	6.3	200*	468
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, typical variant	6.6	6.6	337***	467
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, miscellaneous variant	6.5	6.3	241***	376
Mixed sedge rich-fen community	6.2	6.2	245**	405
Carex diandra-Sphagnum contortum community	6.1	6.3	255	339
Carex lepidocarpa brown moss community	6.7	6.5	370	376
Carex rostrata - Potentilla palustris species-poor community	6.5	6.3	336	420
Carex rostrata species-poor community, Menyanthes trifoliata variant	6.3	6.0	374	460
Carex rostrata - Sphagnum recurvum community	4.9**	5.8	118*	135
Eriophorum vaginatum - Sphagnum papillosum community	4.2*	5.4	100	134

5.3.4.3 Variation between sample sites

Surface water measurements of electrical conductivity (r=0.679), pH (r=0.668), chloride (r=0.660), iron (r=0.494), nitrate (r=0.402) and sodium (r=0.569) were positively correlated (p<0.05, d.f.= 46) with sub-surface measurements at sample sites; all other variables showed no significant relationship between surface and sub-surface measurements.

The between sample site variation in chemical conditions at the vegetation surface and underneath the raft was assessed statistically (oneway analysis of variance, Tukey test p<0.05). Generally there was more variance in surface samples than sub-surface samples indicating that base-line conditions, prior to vegetation development, may have once been more similar in sites which now support different vegetation types and different surface water chemistry (table 5.13).

Table 5.13. Mean values, standard errors and maximum and minimum values of chemical variables of surface and sub-surface water samples from different areas of vegetation developed as a quaking raft. *** p<0.001, **p<0.01, * P<0.05, ns not significant.

	Surface					Sub-surface				
	mean	S.E	min	max		mean	S.E	min	max	
pH	5.34	0.30	4.04	6.29	F=145.06***	5.71	0.17	4.71	6.23	F=99.27***
EC (μS cm^{-1})	96.21	29.37	23.00	281.0	F=137.74***	216.9	31.94	71.00	365.0	F=15.69***
Ca (mg l^{-1})	8.39	3.51	0.61	29.31	F=50.76***	18.96	2.32	8.92	28.24	F=5.34**
Cl (mg l^{-1})	7.29	0.76	3.92	11.03	F=18.26***	13.78	3.47	7.60	36.65	F=60.27***
Fe (mg l^{-1})	0.19	0.06	0.02	0.48	F=7.67***	0.18	0.09	0.01	0.76	F=2.87*
Mn (mg l^{-1})	0.03	0.01	0.00	0.12	F=10.58***	0.03	0.01	0.00	0.06	ns
SO_4 (mg l^{-1})	4.88	0.61	2.61	7.40	F=4.97*	4.52	0.65	2.95	8.76	ns
PO_4 (mg l^{-1})	0.07	0.03	0.01	0.21	ns	0.02	0.00	0.01	0.05	ns
K (mg l^{-1})	1.50	0.24	0.46	2.63	ns	2.86	0.73	0.75	7.49	ns
NO_3 (mg l^{-1})	0.95	0.07	0.68	1.24	ns	1.03	0.06	0.71	1.24	ns
NH_4 (mg l^{-1})	0.02	0.01	0.00	0.10	ns	0.10	0.04	0.00	0.30	ns
Mg (mg l^{-1})	2.96	0.47	1.16	5.45	ns	3.31	0.53	1.99	6.22	ns
Na (mg l^{-1})	14.93	3.34	5.44	31.67	ns	20.10	6.08	5.93	55.08	ns

There was significant variation in the measurements of pH, electrical conductivity, chloride, sulphate , calcium, iron and manganese in surface water samples from different sampling points. The concentrations of potassium, nitrate, phosphate, magnesium, and sodium did not differ significantly between surface water samples from different sampling points.

There was significant variation in the measurements of pH, electrical conductivity, chloride, calcium and iron in sub-surface water samples from different sampling points. The two samples from Nether Whitlaw Moss contained chloride concentrations significantly greater than those from other samples. For the other variables samples from areas of bog and poor-fen tended to cause most of the variation that was present.

The concentrations of ammonium, nitrate, phosphate, potassium, sulphate, magnesium, sodium and manganese did not differ significantly between sub-surface water samples from different sampling points.

5.3.4.4 Water types

The samples form a continuum between the atmotrophic (calcium poor) and lithotrophic (calcium rich) water types of Van Wirdum (1991) (figure 5.9). The samples from beneath the vegetation raft were usually closer to the lithotrophic reference point than those from the vegetation surface indicating the prevalence of telluric water beneath the raft. The samples of surface waters showed wider variation with samples from poor fen vegetation falling nearer the atmotrophic reference point and rich fen and swamp samples occurring nearer the lithotrophic reference point. In

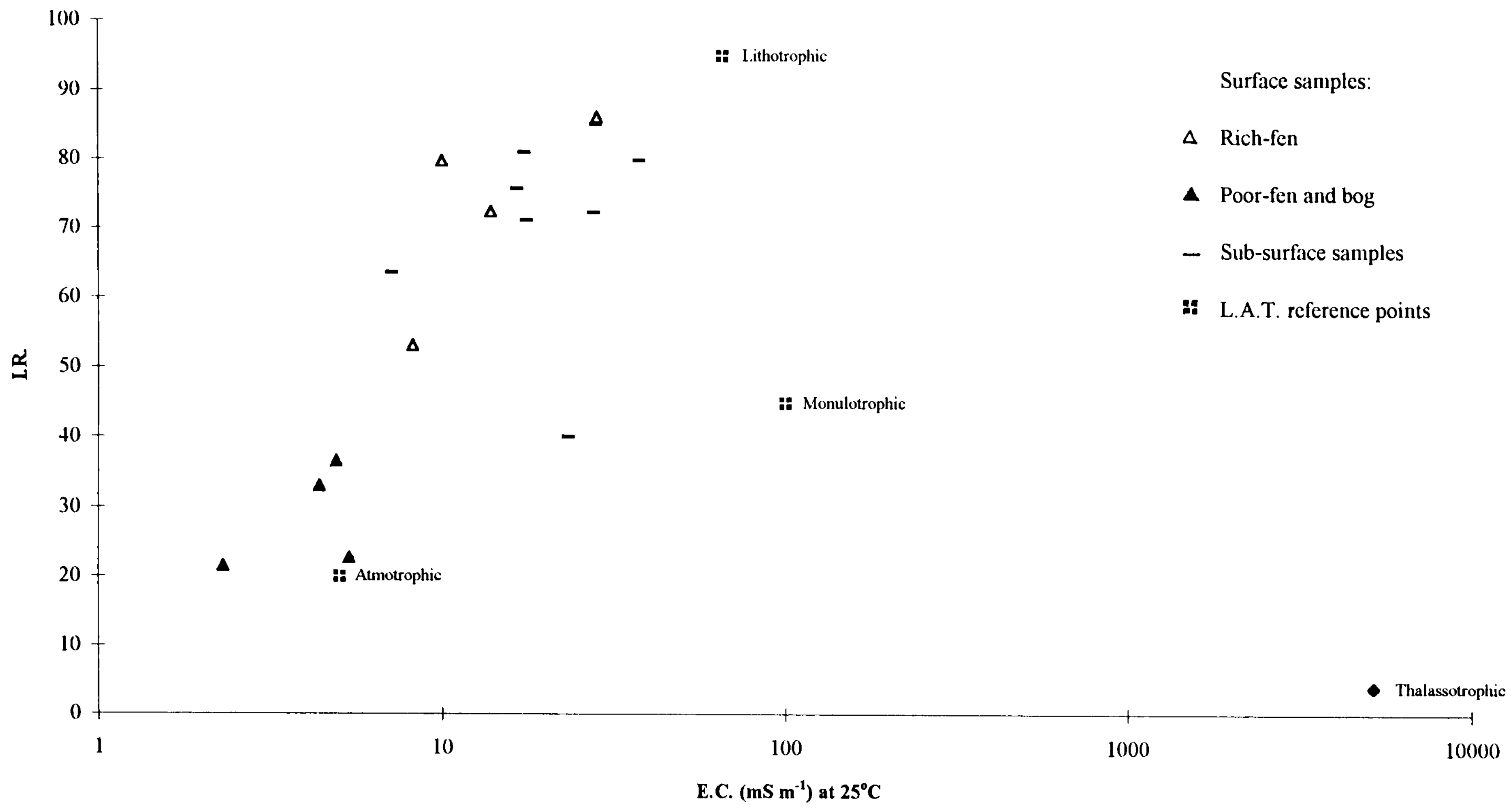


Figure 5.9. L.A.T. diagram (after Van Wirdum 1991) of water types of surface and sub-surface water samples from vegetation rafts in some Scottish Borders fens.

addition some samples showed some evidence of nutrient enrichment indicated by their proximity to the monulotrophic reference point (which represents the water type of polluted river water).

The ratio of key cations in water samples has been used to characterise early hydroseral and ombrotrophic water types (Pearsall 1921, Tallis 1983). Many of the samples from the Scottish Borders fens show ombrotrophic tendencies (table 5.14), mainly in areas of poor fen or in areas with abundant bryophytes, particularly *Sphagnum* species. This may reflect the ability of bryophyte species to alter the surface water chemistry and isolate the vegetation surface from the water beneath the raft (Clymo 1963, Glime *et al.* 1982, O'Connell 1981). In some samples the sub-surface waters were also characterised as ombrotrophic. This may be a result of *Sphagnum* fragments altering the water chemistry beneath the raft, or of high inputs of sodium and potassium into the mire waters. The concentrations of these cations in some surface replicates were very variable and exclusion of certain replicates produced very different values of the Pearsall ratio (table 5.15). This may be due to the mosaic hummock-hollow nature of the vegetation in some sample areas, for example Beanrig Moss and Whitehaughmoor Moss.

Table 5.14. S (surface); SS (sub-surface) Pearsall ratio from Tallis 1983 ([Na]+[K])/([Ca]+[Mg]) <0.6 = early hydroseral water types, >1.5 = ombrotrophic water types.

	Sample	*Pearsall ratio*
Early hydroseral (<0.6)	WHM2 S (excluding 1 replicate)	0.32
	NW2 SS	0.55
	WHM2 SS	0.59
	BL1 SS	0.62
	NW2 S	0.64
	LM2 S	0.92
	LM1 SS	1.06
	GM4 SS	1.40
Ombrotrophic (>1.5)	NW7 SS	1.53
	LM2 SS	1.57
	WHM2 S (all replicates)	1.74
	NW7 S	1.84
	BE7 SS	4.71
	GM4 S	5.37
	LM1 S	5.95
	BL1 S	6.08
	BE7 S	6.29

5.4 Discussion

5.4.1 OCCURRENCE OF DIFFERENT PLANT COMMUNITIES AS VEGETATION RAFTS: ZONATION AND SUCCESSION

Many of the vegetation rafts in the Scottish Borders fens have developed in former peat-cuttings. Vegetation rafts supporting contrasting vegetation types vary in thickness (figure 5.10) but have stratigraphical similarities (figure 5.11). A summary of the main characteristics of vegetation rafts from rich-fen and poor-fen vegetation types is presented in figure 5.10. The lowest layers of the rafts are usually dominated by *Equisetum fluviatile* which was subsequently colonised by a network of *Carex rostrata* rhizomes. Bryophytes can be present in this layer and other sedge rhizomes also occur, in particular *Carex diandra* and *Eriophorum angustifolium*. In fen vegetation *Menyanthes trifoliata* rhizomes become abundant nearer the raft surface. In poor fen vegetation the upper layers of the raft are dominated by *Sphagnum* remains, interwoven to a varying extent with *Carex rostrata*, *Eriophorum angustifolium* and *Menyanthes trifoliata* rhizomes.

The thickest rafts are characteristic of poor-fen habitats (table 5.15, figure 5.10); however at some sites poor-fen occurs on rafts which are thinner than those supporting swamp at other sites.

Table 5.15. The thickness of rafts and range of depths from the vegetation surface to the solid substratum from rafts supporting contrasting plant communities.

Site (habitat type)	*Plant communities*	*raft thickness (cm)*	*depth from vegetation surface to solid substratum (cm)*
Whitehaughmoor Moss (rich-fen)	*Carex diandra-Sphagnum contortum* community, and *Mixed sedge* rich-fen community	40-80	70-120
Kippilaw Moss (rich-fen)	*Carex diandra-Calliergon cuspidatum - Plagiomnium rostratum* community	40	125
Kippilaw Moss (swamp)	*Carex rostrata* species-poor community	30-60	120-150
Greenside Moss (rich-fen)	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rosratum* community	60	70
Greenside Moss (poor-fen)	*Carex rostrata - Sphagnum recurvum* community	70	200
Nether Whitlaw Moss (rich-fen)	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rosratum* community	40	160
Nether Whitlaw Moss (swamp)	*Carex rostrata -Potentilla palustris* species-poor community	50-60	100-220
Nether Whitlaw Moss (poor-fen)	*Carex rostrata - Sphagnum recurvum* community	70-100	180-200
Brown Moor Heights (rich-fen)	*Carex diandra - Sphagnum contortum* community (edge)	50	100
Groundistone Moss (embryonic bog)	*Eriophorum vaginatum - Sphagnum papillosum* community	~80	360

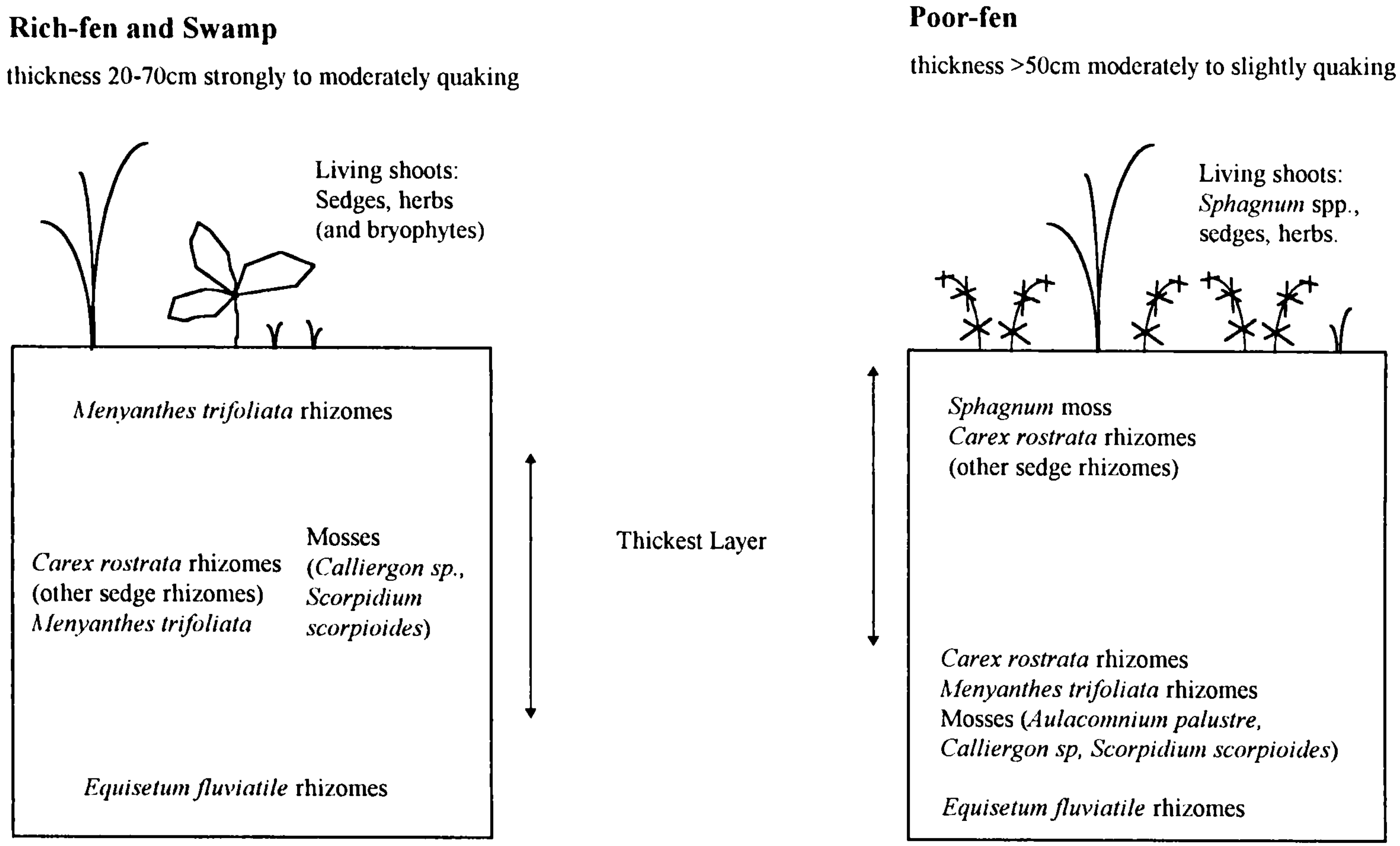


Figure 5.11. Summary of the stratigraphy of vegetation rafts supporting different habitat types.

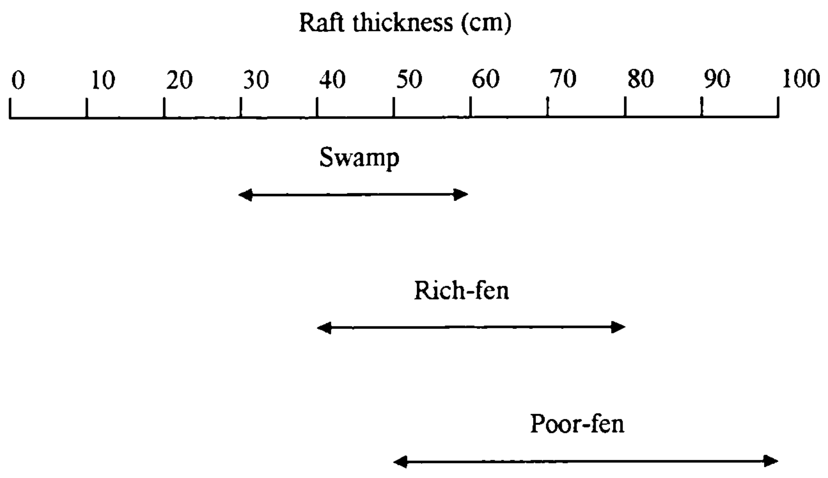


Figure 5.10. Range of thickness of rafts supporting different habitat types.

The rate of succession may be different at different sites, so the vegetation at one site may represent an earlier phase in succession to that at another site. The controls on rates of succession in re-vegetated peat cuttings have received little attention although White (1930) found that the sequence of succession and the colonising vegetation in abandoned peat cuttings depended on the depth of the peat cutting, so aquatic and fen plant communities were pioneers in the deepest peat-cuttings whereas *Sphagnum* poor-fen communities were pioneers in shallower peat-cuttings, and that succession proceeded faster in small sites. This, however does not appear to apply in the Scottish Borders fens as some of the deepest cuttings now support poor-fen vegetation and the shallowest support rich-fen. Also poor-fen occurs extensively on some of the largest sites.

The reasons for the occurrence of different habitats and plant communities therefore appears to be dependent on the conditions present at individual sites and their influence on the rate of succession from rich-fen and swamp to poor-fen and bog.

Successional relationships may exist between plant communities developed as vegetation rafts. Raft vegetation can be described by dividing the vegetation into different components (table 5.16) which represent phases in hydroseral succession (Segal 1966, Van Wirdum 1991) seen in the stratigraphy of the raft. Initial raft builders are often present throughout the vegetation succession (e.g. pioneer *Phragmites australis* shoots persist amongst embryonic raised bog vegetation at Groundistone Moss).

The following components of rafts can be assigned to plant communities developed as quaking rafts in the Scottish Borders fens (after Van Wirdum 1991):

- Pioneer component: a few species with extensive rhizomes exploiting the resources underneath the raft (*Carex rostrata, Menyanthes trifoliata, Equisetum fluviatile, Phragmites australis*). These communities are often species-poor and form a strongly quaking raft.
- Intermediate component: species rooted in the top 20-40 cms of the raft, usually slender *Carex* spp. and *Amblystegious* or *Sphagnaceous* bryophytes.
- Hummock and hollow components: species thriving on the substratum provided by the hummock building species, with wetter hollows in between. (*Carex paniculata*, trees, *Erica tetralix, Sphagnum* spp, *Vaccinium oxycoccos, Valeriana dioica, Drosera rotundifolia*)
- Microzonation component: seedlings, mosses, hepatics and algae found at the base of taller species and dead stems of large helophytes.

Table 5.16. Plant communities of vegetation rafts and the component of the raft succession they represent.

n = number of samples; D = mean depth from vegetation surface to solid peat (cm)

Plant community	*component*	*n*	*D*
Menyanthes trifoliata species-poor community	pioneer	9	87
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community typical variant	pioneer	11	89
Carex rostrata - Potentilla palustris species-poor community	pioneer	14	107
Carex rostrata species-poor community	pioneer	2	135
Equisetum fluviatile species-poor community	pioneer	2	160
Phragmites australis reedbed	pioneer	2	205
Carex lepidocarpa - brown moss community	Intermediate	9	83
Carex rostrata-Calliergon cuspidatum / Plagiomnium rostratum community, *Carex diandra* variant	Intermediate	7	88
Mixed sedge rich-fen community	Intermediate	7	114
Carex diandra - Sphagnum contortum community	Intermediate / hummock	17	105
Carex rostrata - Sphagnum recurvum poor-fen community	Intermediate / hummock	10	212
Acidified /wooded fen	hummock	2	90
Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum community, miscellaneous variant	hummock	15	130
Eriophorum vaginatum - Sphagnum papillosum bog community	hummock	4	178

The *Carex diandra - Sphagnum contortum* community often occurs as a small scale mosaic with pronounced microtopographical zonation. This type of hummock-hollow vegetation can persist for a long time (Segal 1966, O'Connell 1981) possibly due to competitive interactions of the species in the "hollow" areas (such as *Scorpidium scorpioides*) with potential invaders more typical of the *Carex rostrata - Sphagnum recurvum* community (Kooijman & Bakker 1995). It may be that this community is a transitional but prolonged phase in the hydroseral succession from rich-fen to poor-fen which will ultimately develop into the *Carex rostrata - Sphagnum recurvum* community and then possibly into ombrotrophic *Eriophorum vaginatum - Sphagnum papillosum* bog. This successional sequence has been described in the fens of N.W. Overijesel in the Netherlands where the *Sphagnum recurvum* phase of the *Caricetum diandrae* (+/- synonymous with the *Carex diandra - Sphagnum contortum* community described in this study) develops into the *Sphagnum palustris* phase (+/-synonymous with the *Carex rostrata - Sphagnum recurvum* community described in this study). However the latter phase is scarce in the Netherlands, so other possible successional sequences leading to its development are unknown (Segal 1966).

The raised bog plant community, *Eriophorum vaginatum -Sphagnum papillosum* community, is recorded in an embryonic form from a raft at Groundistone Moss which has developed in a former base-rich peat-cutting.

5.4.2 AUTOGENIC ALTERATION OF CHEMICAL CONDITIONS

Vegetation which has developed as a quaking vegetation raft can show pronounced microtopographical zonation. This is often expressed as a mosaic of contrasting water conditions, where in the most striking examples the hummock or tussock tops can provide an environment favourable for the establishment of calcifuge species such as *Calluna vulgaris*, within a matrix of base rich vegetation (Segal 1966, Wheeler 1980b, 1993).

High spatial (vertical and horizontal) variation in water measurements at some sites may reflect the mosaic nature of the vegetation and the corresponding environmental heterogeneity resulting from the influence of different water types (Van Wirdum 1991, Wheeler 1993). For example the values of the Pearsall ratio at Whitehaughmoor Moss represent both early successional and ombrotrophic water types.

In this study in all samples the chemical composition of the sub-surface water was more characteristic of telluric water than of rainwater. This suggests that where the surface water chemistry is significantly different from that beneath the raft the surface conditions have arisen either through the alteration of the chemical conditions of the surface water by certain species or through the local accumulation of lenses of rainwater at the vegetation surface.

Non-*Sphagnum* mosses may facilitate the succession from rich-fen to *Sphagnum* bog (O'Connell 1981, Glime *et al.* 1982). Green and brown portions of many bryophytes can reduce the electrical conductivity and calcium content of fen water, especially in hummocks where they are buffered from the influence of mire waters. These areas provide a suitable substratum for the invasion of *Sphagnum* species (Glime *et al.* 1982). The differences found in sub-surface water chemistry in this study may therefore be largely attributable to the ability of brown parts of bryophytes, in particular *Sphagnum*, to alter the chemistry of fen water.

5.4.3 RAFT FORMATION AND HYDROSERAL SUCCESSION

5.4.3.1 Patterns of hydroseral succession in the Scottish Borders fens

Examples of terrestrialisation in the Scottish Borders fens seem to follow a general pattern which contradicts many standard concepts of the hydrosere. Accounts of hydroseral succession from fens in Britain describe the centripetal encroachment of vegetation, sometimes as a raft, from the edge into the centre of the site (Tansley 1939, Lambert *et al.* 1960, Walker 1966, Tallis 1973) where the firmest deposits are near the edge and the most treacherous in the centre (figure 5.12 b). This pattern has been described from the Norfolk Broads (figure 5.12 bi) (Lambert *et al.* 1960) and many other sites of different location and extent in the UK (Walker 1966, Walker 1970).

However in the Scottish Borders fens (and probably in other basin mires (B.D. Wheeler, pers. comm.) this pattern is reversed and the thickest and firmest rafts are developed in the central areas with treacherous "lagg" areas around the mire margins. This applies even where the vegetation *appears* to be colonising centripetally with vegetation encroaching gradually from the edges. For example at Kippilaw Moss the rafts nearer the centre are usually thicker than any found nearer the edge ,even though they may be adjacent to open water or areas with a thin raft.

Two patterns are particularly striking in the Scottish Borders fens:

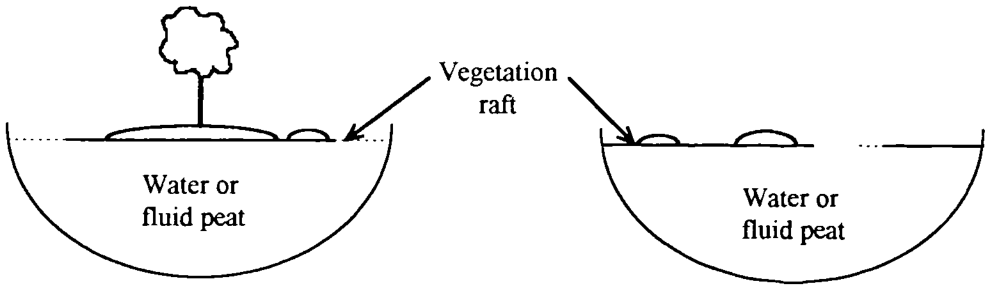
- A central island supported by a very firm raft, often containing poor-fen vegetation surrounded by a very thin raft (figure 5.12 ai).

  Examples: Nether Whitlaw Moss, Blind Moss north end, Greenside Moss, Brown Moor Heights, Groundistone Moss, Selkirk Racecourse Moss.

- A more uniform raft; either a generally treacherous vegetation raft with isolated moss hummocks, up to 3m diameter; or a thicker, more stable raft containing poor-fen vegetation or rich-fen with plentiful bryophytes (figure 5.12 aii).

  Examples: Woolaw Loch, Whitehaughmoor Moss East and Middle basins, Long Moss north end, Kippilaw Moss.

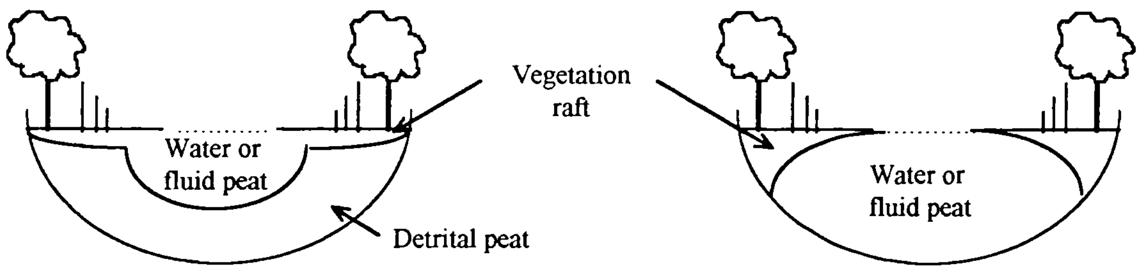
a) Hydroseral succession in the Scottish Borders fens



(i) Increasing raft thickness from the edge to the centre, distinct macrotopographical vegetation zonation

(ii) Variable raft thickness, although the thickest rafts occur further from the edge. Variable vegetation zonation either microtopographical or distinct macrotopographical

b) Hydroseral succession (centripetal)
(Norfolk Broads (Lambert et al. 1960), Cheshire Meres (Tallis 1973), Cumbrian kettleholes (Walker 1966))



(i) "Littoral" terrestrialisation

(ii) "Hover" terrestrialisation

Figure 5.12. Patterns of hydroseral succession

5.4.3.2 Factors affecting raft formation and development

Basin morphology

The processes of raft formation in the Scottish Borders fens are unclear. After the cessation of peat and marl extraction the drains could have been immediately blocked and the subsequent vegetation raft development would have been through the direct colonisation of open water. Alternatively the pits may have been colonised when the drains were still effective so that a vegetation cover established loosely rooted into the substratum. Subsequent gradual flooding may have detached buoyant rhizomes or turves to form a raft, a process which has been described in the Netherlands (H. Piek (1972) cited by Bakker 1979). The source of colonising material could have been from uncut areas, from nearby sites, from 'shoeing' (replacement of turves removed before peat cutting, this was a common practice). The regrowth of rhizomes occurring beneath the cutting base and from seed banks would be unlikely in totally stripped pits (Giller &Wheeler 1986).

Other workers have attributed raft formation to the presence of raft-forming species and the occurrence of deep, steep-sided basins that allow horizontal mat growth to exceed vertical peat accumulation (Kratz & DeWitt 1986, Wilcox & Simonin 1988). Clay lined basins and lack of inlets and outlets resulting in water level changes in the basin and weakly minerotrophic waters conducive to *Sphagnum* growth have also been identified as important contributing factors (Wilcox & Simonin 1988); however most of the Scottish Borders fens have inlets and all have outlets.

Diversion of water flow

The pattern of central thickening of a vegetation raft has been attributed to the diversion of water flow around the mire margins by an accumulating plug of peat (Kulczynski 1949, Moore & Bellamy 1974). The diversion of telluric water beneath the raft and around the mire margins leads to the isolation of the central area from telluric water inputs and to the development of base-poor conditions at the vegetation surface. These conditions favour the establishment and fast growth of bryophytes, in particular *Sphagnum* (Kulczynski 1949). This theory explains the mechanism of positive feed-back leading to development of poor-fen vegetation once the pattern of central thickening is established. It does not explain the mechanism of *initiation* of central raft thickening in sites where the main flow of telluric water is along the central axis.

Cattle poaching

Cattle grazing of the mire margins is also associated with the pattern of central raft thickening (e.g. Selkirk Racecourse Moss, Groundistone Moss, Nether Whitlaw Moss before fencing), and peripheral trampling damage may perhaps explain the thinness of the marginal raft. However cattle grazing has not occurred at all the sites exhibiting this zonation so cannot solely explain its occurrence.

Raft attachment to margins

One possible explanation of the pattern of raft development in the Scottish Borders fens is that because most of the sites are small and sheltered, the colonising network of *Equisetum fluviatile* rhizomes and subsequently *Carex rostrata* rhizomes spread quickly and fairly uniformly over the entire site. Central areas would then be expected to suffer smaller water table fluctuations relative to the vegetation surface than edge areas because in these areas the raft would be firmly anchored to the basin edge, and thus more susceptible both to flooding by telluric water, and to drying out. The processes of decomposition would therefore be faster at the edges of the sites than in central areas which would be more buffered from the impact of water table fluctuations. Decomposition rates of peat at the mire margins may also be encouraged by flow of water from fields and from groundwater inputs leading to slower rates of peat accumulation at the edge relative to the centre of the site. Hence the central areas of the site, buffered from the decomposition processes experienced by the edge zones, would become relatively thicker.

Limited data from recording of the water table relative to the vegetation surface at Nether Whitlaw Moss (by wardens at Scottish Natural Heritage, Galashiels) appear to support this hypothesis (table 5.17) where more variation is found in the water table relative to the vegetation surface in edge sample points than in central sample points.

Table 5.17. Measurements of water table fluctuations relative to the vegetation surface from transects across Nether Whitlaw Moss. Depths are in mm, the data were recorded during 1991-1992 on 36 occasions.
* *(standard deviation ./ mean) x100*

Water table fluctuations relative to the vegetation surface	*Sample location* *Dipwell 1 (edge)*	*Dipwell 5 (edge)*	*Dipwell 3 (centre)*
Mean	-16.2	39.9	-22.3
Standard deviation	47.2	56.2	28.9
*Coefficient of variation**	291	141	130
	Dipwell 6 (edge)	*Dipwell 10 (edge)*	*Dipwell 8 (centre)*
Mean	44.6	13.5	99.1
Standard deviation	63.1	53.9	64.2
*Coefficient of variation**	141	400	65

5.4.4 FACTORS AFFECTING THE DEVELOPMENT OF DIFFERENT VEGETATION TYPES

Distinct macrotopographical zonation of vegetation with central poor-fen surrounded by rich-fen and swamp habitats is characteristic in some Scottish Borders fens. However, in many small, shallow sites and at the margins of larger sites the raft is colonised by a mosaic of hummock-hollow vegetation showing no clear macrotopographical zonation (e.g. Beanrig Moss, Woolaw Loch, Whitehaughmoor Moss Middle and Eastern basins, basin area of Muirfield Moss). The central areas of small shallow sites may be more susceptible to flooding by base-rich telluric water than central areas of larger, deeper sites because:

- there is less central area relative to the edge; therefore the influence of base-rich water may extend further into the site, particularly where there are strong marginal springs,
- in shallower sites the water flow may be directed nearer to the vegetation surface whereas in deeper sites it may be directed well beneath the raft.

Physical features of some sites where the vegetation has developed hydroserally as a raft over the entire site are presented in table 5.18. At Whitehaughmoor Moss and Brown Moor Heights the raft is "grounded" so there is little fluid peat between the raft and the solid substratum. The peat at Brown Moor Heights is believed to be uncut whereas the peat at the other sites investigated here is believed to have been removed to varying extents (see Chapter 3). The smallest sites (Whitehaughmoor Moss and Kippilaw Moss) are dominated by rich-fen and swamp vegetation, and do not exhibit the characteristic zonation described above with central development of poor fen. The thickest rafts are, however, developed further from the site edges. These sites have the smallest area:edge ratios indicating a long edge relative to area. Whitehaughmoor Moss also has the most gently shelving basin edge. The sites dominated by poor-fen habitats (Greenside Moss, Brown Moor Heights Moss and Nether Whitlaw Moss) are generally larger and have a larger area relative to perimeter than the sites dominated by rich-fen. These sites all show the characteristic vegetation zonation with central development of poor-fen described above. The raft at Brown Moor Heights is "grounded" in the centre where there is development of bog vegetation with *Eriophorum vaginatum* and *Sphagnum papillosum*. This site is believed to be uncut and the vegetation it supports may therefore represent a successional "climax" of raft vegetation development.

Table 5.18. Physical features of sites where the vegetation has developed as a raft over the entire site.

Site	*Principal habitat types*	*Area (ha)*	*Area / perimeter ratio*	*approximate gradient of slope of basin edge*
Whitehaughmoor Moss	rich-fen (hummock-hollow)	0.331	13.74	1:20 (5%)
Kippilaw Moss	swamp, rich-fen and pools	0.76	17.55	1:10 (10%)
Greenside Moss	poor-fen, rich-fen and swamp	1.1	20.94	1:7 (14%)
Brown Moor Heights	poor-fen and bog	1.13	27.83	1:10 (10%)
Nether Whitlaw Moss	poor-fen and swamp	4.23	38.16	1:2-1:5 (20-50%)

In small, shallow sites the microtopographical vegetation zonation may result from the colonisation of small lenses of relatively base-poor water producing hummock-hollow vegetation mosaics. This situation is also frequently found around the edges of sites with distinct macrotopographical zonation (e.g. Nether Whitlaw Moss, Brown Moor Heights Moss). The presence of areas of open water and thin rafts in central areas of sites (e.g. Kippilaw Moss) may be due to the non-uniform initial colonisation of the basin.

5.4.5 DEVELOPMENT OF *SPHAGNUM*-DOMINATED PLANT COMMUNITIES

The colonisation of *Sphagnum* species within base-rich fens is favoured in areas of acidic or weakly minerotrophic water. Within rich-fens *Sphagnum* invasion may be facilitated by non-*Sphagnaceous* bryophytes which depress the pH of the substratum through cation exchange (Glime *et al.* 1982, O'Connell 1981). Alternatively lenses of relatively base-poor water may develop in areas where the flow of base -rich water has been diverted (Kulczynski 1949, Van Diggelen *et al.* 1996) allowing the colonisation of *Sphagnum* species.

At some sites the relative stability of the water table in central areas described above may particularly favour the growth of mosses, and the accumulation of rainwater. As soon as a lens of base-poor water is established and *Sphagnum* colonises then succession continues aided by positive feedback mechanisms where the active exchange of hydrogen ions by *Sphagnum* further decreases the pH of the surface water and rapid growth of bryophytes increases the thickness of the raft. This leads to the isolation of the vegetation surface from the influence of telluric water and favours the growth of species characteristic of base-poor conditions in central areas, confining rich-fen vegetation to the edges of the site and producing the characteristic vegetation zonation described in the Scottish Borders fens.

In the Scottish Borders fens the factors controlling the development of *Sphagnum*-dominated communities are complicated by the occurrence of two *Sphagnum* rich plant communities which occur exclusively on quaking rafts, never on a solid substratum. The *Carex diandra - Sphagnum contortum* community, characterised by base-tolerant species of *Sphagnum* (*Sphagnum contortum*, *Sphagnum warntorfii*, *Sphagnum teres*), is found extensively at Beanrig Moss, Whitehaughmoor Moss East basin, Woolaw Loch, Wester Branxholm Loch, and at the margins of Brown Moor Heights.

The *Sphagnum recurvum - Carex rostrata* community, characterised by *Sphagnum* species more typical of poor fen (*Sphagnum recurvum*, *Sphagnum squarrosum*, *Sphagnum fimbriatum*, *Sphagnum palustre*), is well developed at Greenside Moss, Groundistone Moss, Nether Whitlaw Moss, Buckstruther Moss, Brown Moor Heights and Wester Branxholm Moss.

The *Carex diandra - Sphagnum contortum* community occurs in shallower basins (mean depth from vegetation surface to solid substratum 105 cm), where the raft is often "grounded", than the *Carex rostrata - Sphagnum recurvum* community (mean depth from vegetation surface to solid substratum 212 cm) where the raft is often floating over fluid detrital peats.

Table 5.19. Site and vegetation features associated with the occurrence of two contrasting *Sphagnum* - rich plant communities in the Borders fens.

Carex rostrata - Sphagnum recurvum community	*Carex diandra - Sphagnum contortum* community
small scale mosaic	uniform vegetation
shallow basins (grounded raft)	deep basins (floating raft)
small sites or marginal areas	larger sites, central areas
strong inputs of base-rich telluric water	isolated from telluric water

Differences in the physical features (table 5.19) of a site may be responsible for the different pathways of development and the occurrence of different plant communities and species at sites. These contrasts can be emphasised by comparing the site and vegetation features of two sites included in the Whitlaw Mosses National Nature Reserve, Beanrig Moss which supports the *Carex diandra - Sphagnum contortum* community, and Nether Whitlaw Moss which supports the *Carex rostrata - Sphagnum recurvum* community (table 5.20 & table 5.21).

Table 5.20. Site features of Beanrig Moss and Nether Whitlaw Moss.

Site features	*Beanrig*	*Nether Whitlaw*
Size	1.35ha	4.23ha
Altitude	245m	275m
Basin shape (area/perimeter)	27.2	38.2
Range of depth from vegetation surface to solid substratum	40-130cms	85-335cms
Gradient of slope	5-16%	33-50%

Beanrig Moss and Nether Whitlaw Moss have many similarities but Beanrig Moss contains more species and more rare species than Nether Whitlaw Moss (table 5.21). It also supports extensive development of base-tolerant *Sphagnum* communities from rich-fen, whereas at Nether Whitlaw Moss poor-fen has developed from species-poor fen and swamp.

Table 5.21. Vegetation features of Beanrig Moss and Nether Whitlaw Moss. (* combined RFS,PFS,BGS and RARE species)

Vegetation features	*Beanrig*	*Nether Whitlaw*
Vegetation zonation	microtopographical	macrotopographical, 2 zones
Number of total species	88	53
Number of rich-fen species (RFS)	58	30
Number of poor-fen species (PFS)	36	22
Number of bog species (BGS)	11	8
Number of rare species (RARE)	22	7
Number of notable mire species*	66	37
Rarity weighted species-richness	34.95	14.13
Biodiversity score	109	50

Both sites have a hiatus in the peat stratigraphy close to the basal deposits which have been dated as Late Devensian at Beanrig Moss (Webb & Moore 1982). Therefore at both sites the postglacial peat deposits are believed to have been completely stripped. Both sites lie within improved catchments used mainly as permanent pasture. Beanrig Moss is bordered on the Eastern edge by unimproved neutral grassland which is an SSSI. Both sites are drained via open ditch drains.

Essentially Beanrig Moss is a small, shallow basin supporting a range of vegetation in a number of habitats, including Willow carr (*Salix pentandra* and *Salix cinerea*), marginal springs and flushes with microtopographical zonation, grounded vegetation rafts supporting rich-fen communities with extensive local development of ombrotrophic vegetation rich in base-tolerant *Sphagnum* species. In contrast Nether Whitlaw Moss is a relatively large, deep basin with steep sides supporting poor-fen vegetation with Salix and Birch carr in central areas and marginal swamp and rich-fen communities developed as a floating raft in a clear macrotopographical zonation.

It therefore seems likely that at Beanrig Moss the base-rich telluric water still floods the vegetation surface, preventing the encroachment of *Sphagnum* species typical of poor-fen habitats but helps to maintain the present 'hummock-hollow' vegetation mosaic whereas at Nether Whitlaw Moss the isolation of the vegetation surface from telluric water and the absence of strong springs has lead to the direct development of extensive poor-fen. Ultimately, the course of succession at both sites will be likely to lead to the development of bog vegetation when the accumulating peat beneath the raft prevents the flooding of the vegetation surface by telluric water.

Chapter 6: Biodiversity, Conservation Evaluation and Management of the Scottish Borders Fens.

6.1 Introduction

6.1.1 ISLAND BIOGEOGRAPHICAL PRINCIPLES AND CONSERVATION STRATEGY

The publication of the Theory of Island Biogeography (MacArthur & Wilson, 1967) initiated a debate about the distribution of species populations and their conservation. The theory stated that the biota of an island are in a dynamic equilibrium between immigration of new species onto the island and extinction of species already present. Thus at equilibrium small islands and islands far from the mainland should contain fewer species than large islands and islands near to the mainland. The theory was criticised for considering only one source of colonists (the mainland) and ignoring the population density and species identity. These can both be very important because sometimes the presence of a certain species is necessary for the immigration of another and in terms of conservation, specific groups of species are the focus of the research and diversity *per se* may not necessarily be important when attempting to conserve characteristic species groups (Webb & Vermaat 1990). Later studies (Hanski & Gilpin 1991, Harrison & Quinn 1989), used metapopulation dynamics (where sources and sinks are interchangeable), and the incorporation of species identity in examining species distributions (Smith & Charman 1988, Webb & Vermaat 1990, Usher 1980). The focus of the debate soon became the design of nature reserves (size and shape), distribution of species populations (isolation, size, interdependence) and prioritisation of sites for the maximisation of biodiversity, and the conservation of rare and threatened species.

The equation $S = cA^z$ (Preston 1962, May 1975) has been widely used to describe species-area relationships, where S (equilibrium species number) decreases with increasing distance from the mainland or colonising source and is directly proportional to A (island area). The logged power function has been used to construct species area curves where $\ln S = \ln c + z \ln A$. (c and z are constants) (Connor & McCoy 1979).

Loss of natural or semi-natural habitats to urban, commercial or agricultural development has highlighted the problems of conserving the remaining habitats. These sites are often described as terrestrial "habitat islands" and have therefore been the focus for studies of metapopulation dynamics and species area relations in order to determine which features of fragments are important when choosing and designing reserves for the preservation of characteristic and rare species. This debate has mainly concerned the importance of several small versus single large reserves in the conservation of threatened habitats. May (1975) stated that as a rough rule a ten fold decrease in area would lead to a halving of the equilibrium number of species present and concluded that several small areas would support fewer species than a large area of equivalent size. However the conclusion of most of the studies concerning the "single large or several small debate" (S.L.O.S.S.) was that several smaller reserves contain more species than a single large reserve of equivalent total area (Robertson & Quinn 1988; Quinn & Harrison 1988; Higgs & Usher 1980; Jarvinen 1982). More recently research has focused on the systematic selection of networks of reserves to maximise the diversity of biological features, in particular the diversity of characteristic and rare species (Margules *et al.* 1988) and the prioritisation of sites for nature conservation (Pressey *et al.* 1993).

6.1.2 EVALUATION AND PRIORITISATION OF FEN SITES FOR NATURE CONSERVATION

Various schemes exist for the statutory conservation and protection of natural habitats in the UK. Sites can be protected, on the basis of their national and regional importance, through designation as National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSIs). Inclusion in Environmentally Sensitive Area schemes (ESAs) can afford some protection to sites by rewarding landowners and tenants modestly for appropriate management of sites and their catchment. The maintenance of viable populations and overall biodiversity is an important consideration in the evaluation and selection of areas for nature conservation. Constraints of funding and rapid habitat destruction necessitate prioritisation of sites for nature conservation and protection. Systematic methods for the evaluation of sites and the prioritisation of sites for nature conservation on the basis of biodiversity have been recently developed (Williams 1996, Wheeler 1997). Methods for evaluation of rich-fen vegetation on the basis of species rarity and richness were described by Wheeler (1988). Fen species and plant communities have been categorised as characteristic and rare on a national, regional and continental basis (Wheeler 1996). Reserve selection has often been achieved on an *ad hoc* basis, often on the basis of "hotspots" of species richness and rarity, but these methods may not yield a set of reserves which represent all the target species and may result in the over-representation of more widespread species (Williams *et al.* 1996, Pressey 1990, 1994). The principles of complementarity, flexibility, irreplaceablility and efficiency (Pressey & Nicholls 1989, Pressey *et al.* 1993, Vane-Wright 1994) have been used in the systematic selection of networks of areas to represent all species from target species groups.

Systematic methods based on the selection of sets of complementary sites with the greatest combined species richness (complementarity and efficiency) are effective in identifying 'irreplaceable' sites (unique sites which support the only population of a species) and 'flexible' sites (interchangeable sites containing more common species and habitats) which will represent sites (interchangeable sites containing more common species and habitats) which will represent all target species. These methods can also measure the effectiveness of current networks of protected sites in representing species and can identify priority sites for future protection (Williams *et al.* 1996). Other features apart from species richness and rarity are important in the evaluation of sites but these are often difficult to apply consistently (Ratcliffe 1977, Usher 1986). In mire sites the vegetation zonation, structure of vegetation, the surrounding land, the number of characteristic communities and prescence of physical features such as springs, pools, vegetation rafts, runnels and laggs all contribute to the essence and conservation value of a site. The stability and viability of populations are also factors which need to be addressed in the selection of the best sites for conservation management. Until these can be accurately assessed and integrated into systematic selection techniques the techniques presented can only be viewed as a preliminary procedure which can identify potential sets of sites to ensure the maximisation of biodiversity at one point in time (Williams *et al.* 1996, Vane-Wright 1996) which can be used as a *baseline* for the application of other criteria.

In this chapter the conservation importance of the Scottish Borders fens are assessed, using a range of techniques and the relation of species richness to site area, isolation, land management and catchment land use is examined.

6.2 Methods

6.2.1 VEGETATION

The numbers of total species, notable mire species (combined rich-fen species, poor-fen species, bog species and rare fen species), rare species, rich-fen species, poor-fen species and bog species (Wheeler 1988, Wheeler 1997) occurring at each site were calculated.

6.2.2 AREA, ISOLATION AND SHAPE

The area and perimeter of each site were measured using a map-graphics computer package.

The area : perimeter ratio was calculated for each site as an indicator of the shape of the site. The isolation of each site was expressed as average distance to all sites, average distance to the nearest 10 sites and the number of sites within a 5km radius. Correlation coefficients were calculated between isolation, shape and species richness and number of plant communities.

The relationship's between species richness (total species; rich fen species; poor-fen species; bog species and rare fen species) and site area were calculated by regression analyses. Sites which were known to have been substantially modified recently(Borthwickshiels Loch, Cavers Long Moss, Hare Moss, Newhouse Moss, Tocher Lodge Moss), for example in pond creation schemes, were excluded from the area analysis. The relationship between species richness and stand area was also calculated for one plant community, the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, which is widespread in the Scottish Borders fens. Stand area was estimated from sketch maps.

6.2.3 SITE EVALUATION AND CONSERVATION PRIORITISATION

6.2.3.1 Aims

1. To identify sites which are important in a national and regional context
2. To identify which sites would represent all notable mire species 1, 3 and 5 times.
3. To identify "irreplaceable" and "flexible" sites for nature conservation.
4. To compare these results to the currently protected sites in the region (SSSIs and NNRs) and to calculate whether these latter sites represent notable mire species and rare species at least once, and, if not, to calculate which sites should be protected in addition to maintain biodiversity of notable mire species.

The sites were evaluated using the following techniques.

6.2.3.2 Species scores (Wheeler 1988, 1996)

Numbers of rich-fen species (RFS), poor-fen species (PFS), bog species (BGS) and rare fen species (RARE) were calculated for each site and sites were ranked on this basis.

6.2.3.3 Rarity weighted species richness (Wheeler 1988) / Range-size rarity (Usher 1986, Williams 1996)

This rarity score is based on the sum of the inverse frequency of site records for notable mire species in the Scottish Borders fens dataset.

Range-size rarity = $\sum 1 / \text{frequency}_x$

where frequency_x is the number of sites occupied by species x.

6.2.3.4 Fenbase database (Wheeler 1997)

The Fenbase database calculates a 'biodiversity score' and 'target species score' for the evaluation of sites. The biodiversity score (based on the species richness, community number and habitat diversity recorded on the Site Condition form) and target species score (based on a fairly complex algorithm which uses data on the number of rare species and community types together with the extent of the rare community types recorded on the Vegetation form) were calculated for each site and the sites were ranked on this basis. Also sites containing nationally and regionally rare species (Appendix 3) were identified.

6.2.3.5 Worldmap (Williams 1996)

The sites were selected objectively using an iterative algorithm (based on Margules *et al.* 1988) on the basis of the following principles for the maximisation of biodiversity in nature reserves:

- *Complementarity*- the number of new species a new site adds to an existing species list;
- *Irreplacability*-unique sites which support the only population of a species;
- *Flexibility*-a pool of interchangeable sites groups of which would add the same species / habitats to the final selection;
- *Efficiency*- choosing the minimum number of sites and minimum area to conserve the required habitat/species through the maximisation of complementarity;
- *Representation*-the least number of sites on which the species/habitats should occur.

6.2.4 CATCHMENT LAND-USE AND SITE MANAGEMENT

The land-use of the site catchment was recorded using a semi-quantitative scale as defined in chapter 4. This was correlated with habitat type and species richness at each site. The species richness of grazed and ungrazed sites in similar catchments was compared.

6.3 Results

6.3.1 SPECIES TOTALS

In total 210 species were recorded in the survey of the fens of the Central Scottish Borders. These were further categorised into notable wetland species (121), rich-fen species (95), poor-fen species (60), bog species (23) and rare species (39). In total 24 plant communities were recorded. Lists of nationally and regionally rare species, and notable wetland plant communities are presented in Appendix 3.

A large proportion of the total recorded species and notable wetland species tended to occur on only few sites, whereas a smaller proportion occurred on a larger number of sites (figures 6.1 & 6.2). This effect was weaker for notable mire species than for all species (figure 6.3) probably because notable mire species are more characteristic of fens so are likely to be more widespread in this habitat. One relatively large site (Wester Branxholm Loch, 9.84 ha) contained the largest proportion of the recorded species in all categories. This indicates that there is a high degree of "nestedness" within the data set where one site contains most of the recorded species and the other sites contain subsets of the total. This is not surprising in a data set of this type where many sites have overlaps in the habitats and species they contain.

6.3.2 SPECIES - AREA / ISOLATION RELATIONS

The largest site in the data set was Adderstonelee Moss (12.2 ha), and the smallest was Whitehaughmoor Moss middle basin (0.07 ha) (table 6.1). Only 11 sites out of 63 were larger than 5 ha in extent. These were Adderstonelee Moss, Ashkirk Loch, Blind Moss, Branxholm Wester Loch, Dry Loch, Lilliesleaf Moss, Murder Moss, Shielswood Loch, Tandlaw Moss, Whitmuir Moss and Whitmuirhall Loch.

Site area was positively correlated with the number of communities present, the number of notable wetland species, rich-fen species and total species (table 6.2).The index of shape (area/perimeter) was significantly positively correlated with the number of plant communities, total species richness, notable mire species richness, rich-fen species richness, bog species richness and rare fen species richness. The number of communities was significantly correlated with the number of species in all categories.

Table 6.2 . Correlation coefficients of recorded species with the area, shape (area:perimeter ratio) and number of plant communities at each site. *** $p<0.001$; **$p<0.01$, *$p<0.05$ (d.f 61).

	total species	*notable mire species*	*rich-fen species*	*poor-fen species*	*bog species*	*rare fen species*	*plant communities*
area	0.389**	0.360**	0.347**	0.297*	0.268	0.301*	0.443***
shape	0.357**	0.314*	0.284*	0.274	0.300*	0.250*	0.315*
plant communities	0.572***	0.573***	0.588***	0.512***	0.379**	0.514***	1

Generally there was a positive relationship between species richness and site area (figures 6.4 a,b) although this was not significant for bog species richness and rare fen species richness.

The regression equations for each species-richness category and site area were:

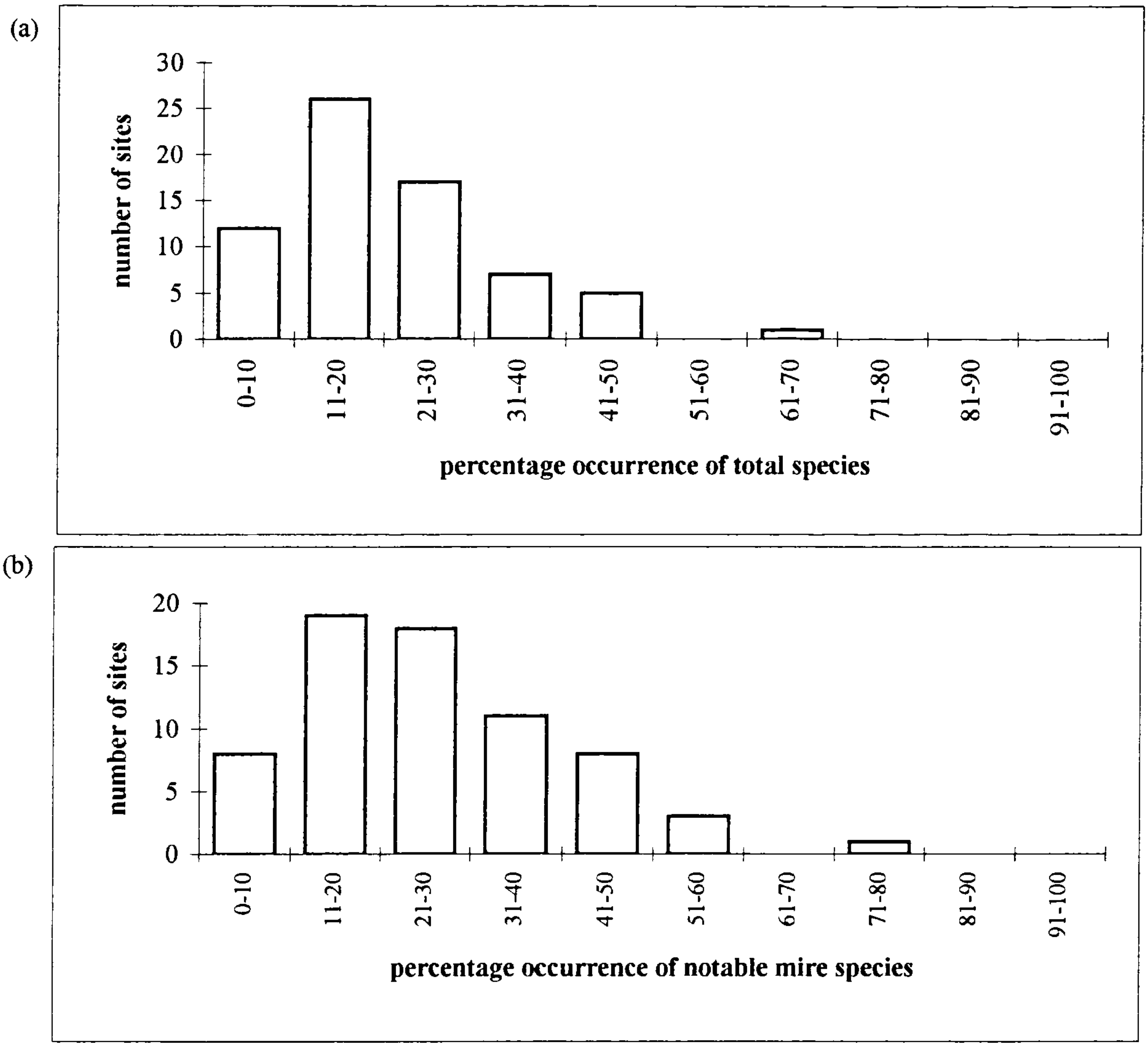


Figure 6.1. The proportion of the (a) total species (n = 209) and (b) notable mire species (n = 121) occurring on Scottish Borders fens. A large proportion of the recorded species occur on just one site (Branxholm Wester Loch).

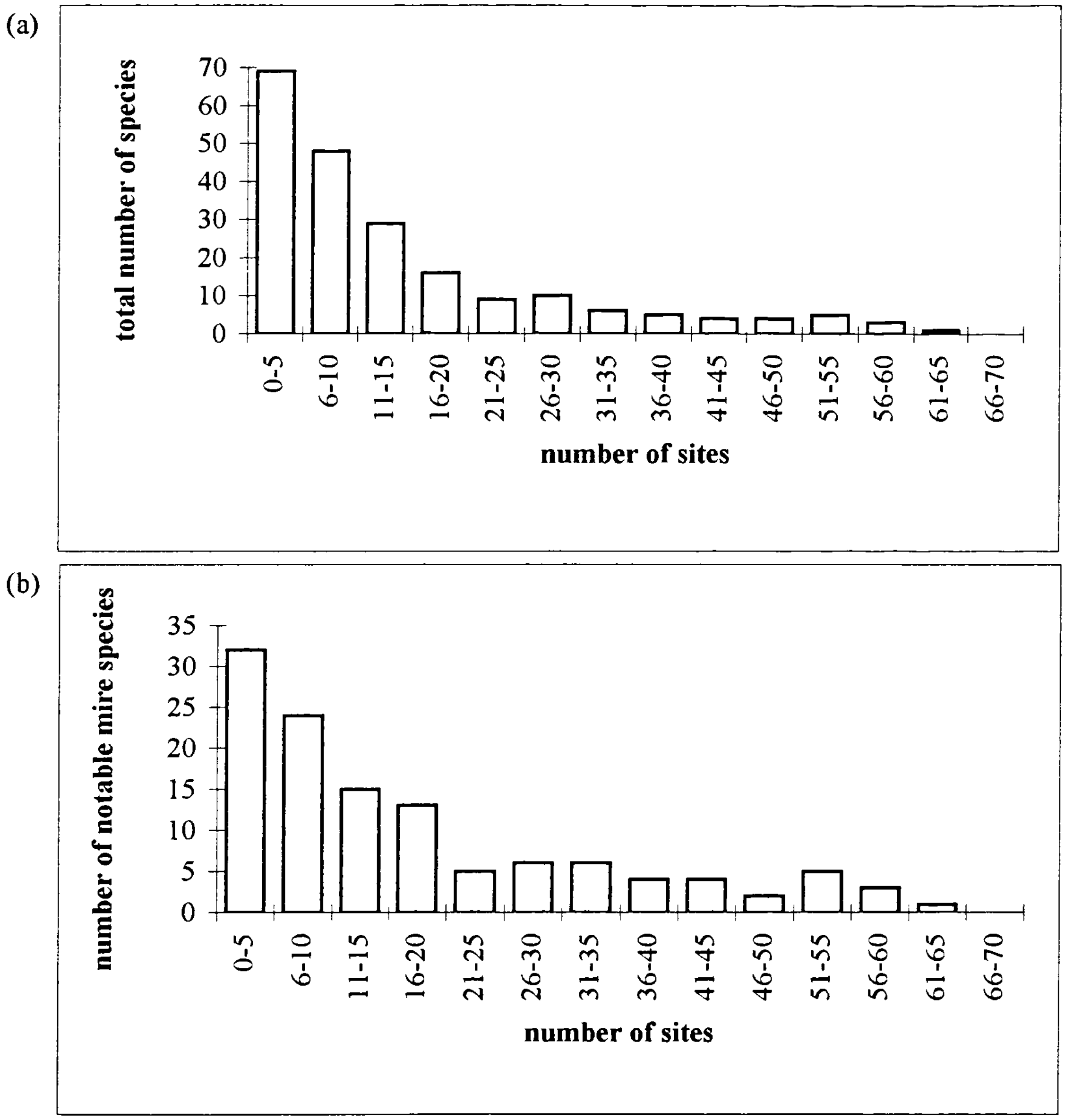


Figure 6.2. Distribution of (a) all species (n = 209) and (b) notable mire species (n = 121) in the Scottish Borders fens. Many plant species occur on only a few sites.

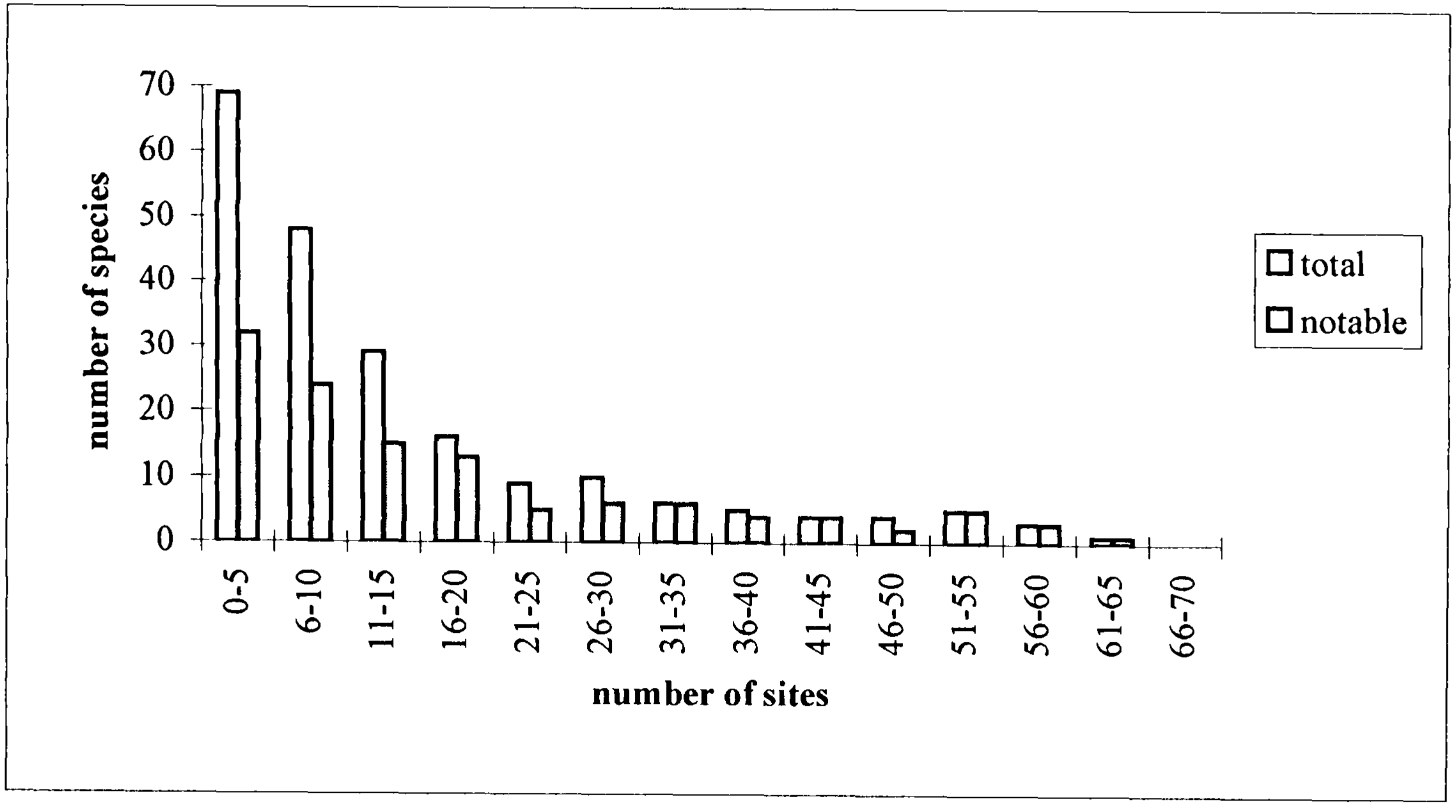


Figure 6.3. Distribution of all species (n = 209) and notable mire species (n = 121) in the Scottish Borders fens. Many plant species occur on only a few sites, although the distribution of notable mire species is more even than that of all species.

Table 6.1. Area, altitude, catchment management score and isolation of the Scottish Borders fens.

Site name	*NGR NT*	*Site area (ha)*	*area/ perimeter*	*altitude (m O.D)*	*Catchment Management Score*	*Average distance to all sites (km)*	*Average distance to nearest 10 sites (km)*	*Number of sites within a 5 km radius*
Adderstonelee Moss	533 119	12.24	73.8	235	5	11.4	3.5	7
Ashkirk Loch	476 193	5.02	44.4	270	3	5.8	1.6	30
Beanrig Moss	517 293	1.35	27.2	245	5	9.9	2.2	18
Bees Wood Moss	447 232	0.117	8.4	310	3	7.2	2.9	19
Berry Moss	491 250	1.875	29.8	250	11	6.8	1.4	31
Bitchlaw Moss	525 121	0.28	17.0	270	2	10.3	3.1	9
Blackcraig Moss	502 208	2.66	23.1	270	12	6.1	2.1	30
Blackpool moss	517 290	3.38	42.9	240	11	9.9	2.2	18
Blind Moss	458 183	5.22	29.3	285	3	6.6	1.5	28
Boghall Moss	491 186	2.09	30.6	260	13	6.1	1.6	27
Boosmill Hill Moss	502 236	0.12	8.0	210	11	6.5	2.3	29
Borthwickshiels Loch	425 153			260	11	9.4	3.4	14
Branxholm Wester Loch	422 110	9.84	75.3	270	2	12.0	5.3	5
Brown Moor Heights	458 247	1.13	27.8	295	1	7.0	2.5	25
Buckstruther Moss	540 120	2.92	35.9	235	6	11.3	3.6	6
Cavers Long Moss	543 146			205	7	10.1	3.7	7
Clerklands moss	494 253	1.65	27.6	235	11	6.8	1.4	31
Curdyhaugh Moss	504 282	0.5	15.9	245	3	8.8	1.3	22
Dry Loch	483 266	6.24	48.2	200	10	7.3	1.4	27
Dunhog Moss	474 247	3.03	34.5	285	7	6.4	2	33
Fluther Moss	548 123	0.32	16.0	220	12	11.3	3.6	6
Greenside Moss	518 258	1.1	20.9	190	11	7.4	2.2	25
Groundistone Moss	498 195	3.84	32.2	265	13	5.9	1.4	27
Haining Moss	467 273	3.17	30.8	185	11	8.2	2.5	25
Hall Moss	489 197	1.206	21.7	295	5	5.7	1.4	29
Harden Moss	449 164	2.59	39.2	290	2	7.7	2.1	22
Hare Moss	468 247			265	4	6.7	2.3	29
Hartwoodburn Moss	466 269	0.824	23.5	175	5	7.6	2.3	26
Highchesters Moss	413 145	1.204	23.0	200	7	10.6	4.5	6
Hummelknowes Moss	515 127	2.83	32.4	190	5	9.9	3.4	12
Huntley Moss	413 248	0.33	12.8	155	11	9.6	4.5	6
Hutlerburn Loch	420 253	4.43	47.9	330	2	9.2	3.8	8
Kippilaw Moss	493 154	0.76	17.6	195	11	7.5	2.9	29
Ladywoodedge Moss	488 256	2.26	29.3	245	11	6.8	1.5	32
Lilliesleaf Moss	539 251	8.04	45.6	140	13	8.7	3.6	17
Lionfield Moss	485 161	0.38	14.2	215	4	6.7	1.4	26
Little Moss	540 144	0.71	23.7	175	11	10.1	3.7	7
Long Moss	478 185	2.74	33.8	290	1	5.9	1.2	25
Mabonlaw Moss	455 167	1.64	22.9	295	2	7.2	1.6	25
Muirfield Moss	504 204	3.92	23.4	260	2	6.1	2.1	30
Murder Moss	504 285	8.88	35.4	245	11	8.8	1.3	22
Nether Whitlaw Moss	508 294	4.23	38.2	275	11	9.6	1.7	19
Newhouse Moss	518 234			165	11	6.8	2.7	25
Pickmaw Moss	493 281	0.799	13.7	270	11	8.6	1.4	23
Riddellshiel Loch	501 253	1.49	29.2	235	11	7.1	1.6	30
Rotten Moss	460 170	0.516	18.1	280	2	6.5	0.9	27
Seacroft Moss	478 104	1.23	19.7	230	11	11.1	4.8	6
Selkirk Hill Moss	486 285	0.62	16.8	205	2	8.6	1.6	22
Selkirk Pot Loch	478 293	0.767	17.8	170	7	9.5	2.6	20
Selkirk Racecourse Moss	498 276	2.03	20.9	270	2	7.9	1.2	25
Shielswood Loch	453 191	5.79	57.6	275	2	6.4	2.2	30
St Leonards Moss	483 107	2.42	35.3	225	10	11.1	4.7	6
Stoneyford Moss	486 204	0.64	11.4	240	2	5.7	1.4	34
Stouslie Pool	490 170	0.26	17.3	250	2	6.4	1.6	26
Synton Couses Loch	483 224	0.14	7.0	225	7	5.9	2.4	38
Synton Loch	483 206	3.19	26.4	240	2	5.7	1.4	34
Tandlaw Moss	490 177	5.33	56.1	235	11	6.4	1.6	26
Tathyhole Moss	475 218	1.29	26.2	205	11	5.8	2.2	37
Threephead Moss	450 174	0.828	14.4	295	2	6.8	1.4	25
Tocher Lodge Moss	438 231			295	2	7.8	3.1	13
Todshawhill Moss	452 122	1.299	25.8	200	9	9.9	4.1	16
Whitehaughmoor Moss E	474 176	0.331	13.7	270	1	6.3	1.1	27
Whitehaughmoor Moss M	473 178	0.073	6.6	285	1	6.3	1.1	27
Whitehaughmoor Moss W	471 176	0.58	16.9	285	4	6.3	1.1	27
Whitmuir Moss	492 269	5.8	61.1	250	11	7.3	1.3	26
Whitmuirhall Loch	497 272	8.89	47.4	245	8	7.9	1.2	25
Woolaw Loch	461 173	0.387	13.3	300	3	6.5	0.9	27
Woolaw Moss	465 172	1.73	28.8	270	2	6.5	0.9	27

Total species richness = 1.57 + 0.197 area $R^2 = 17.1\%$ p = 0.001

Notable mire species = 1.42 + 0.178 area $R^2 = 14.0\%$ p = 0.002

Rich-fen species = 1.40 + 0.158 area $R^2 = 13.0\%$ p = 0.004

Poor-fen species = 1.17 + 0.175 area $R^2 = 9.9\%$ p = 0.012

Bog species = 0.544 + 0.204 area $R^2 = 6.1\%$ p = 0.064 (not significant)

Rare fen species = 0.652 + 0.153 area $R^2 = 4.0\%$ p = 0.140 (not significant)

Even where the relationship between site area and species richness was significant ($p<0.05$) much of the variation in species richness in all categories was not accounted for by the site area. There was a trend for more species to occur in larger sites but there were many exceptions where larger sites were species-poor (e.g. Lilliesleaf Moss) and smaller sites were species-rich (e.g. Whitehaughmoor Moss east basin). This relationship may be largely a result of the tendency for large sites to support a wider range of habitats and plant communities than small sites (table 6.2) therefore increasing the site species-richness through cumulative species-richness of different habitats and plant communities. Differences in sampling effort at small and large sites may also have some impact on the numbers of species recorded as larger sites are often less well known than smaller sites (Usher 1979).

Numbers of bog species showed no significant correlation to area but were significantly greater on sites with a large area to perimeter ratio where the centre of the site is further from the boundaries (correlation coefficient $r=0.300$, $p<0.05$).

The effect of the positive relationship between the number of plant communities and site area on species - area relations can be eliminated by analysing the species - area relationship of one plant community, where the actual area occupied by a particular plant community on each site where it occurs (the stand area), is measured and related to the species-richness of that plant community at each site. The *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community is widespread in the Scottish Borders fens. Regression equations for species richness and stand area of the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community are:

Total species richness = 1.46 + 0.176 area of stand $R^2 = 21.4\%$ p = 0.015

Notable mire species = 1.38 + 0.182 area of stand $R^2 = 27.9\%$ p = 0.005

(a)

(b)

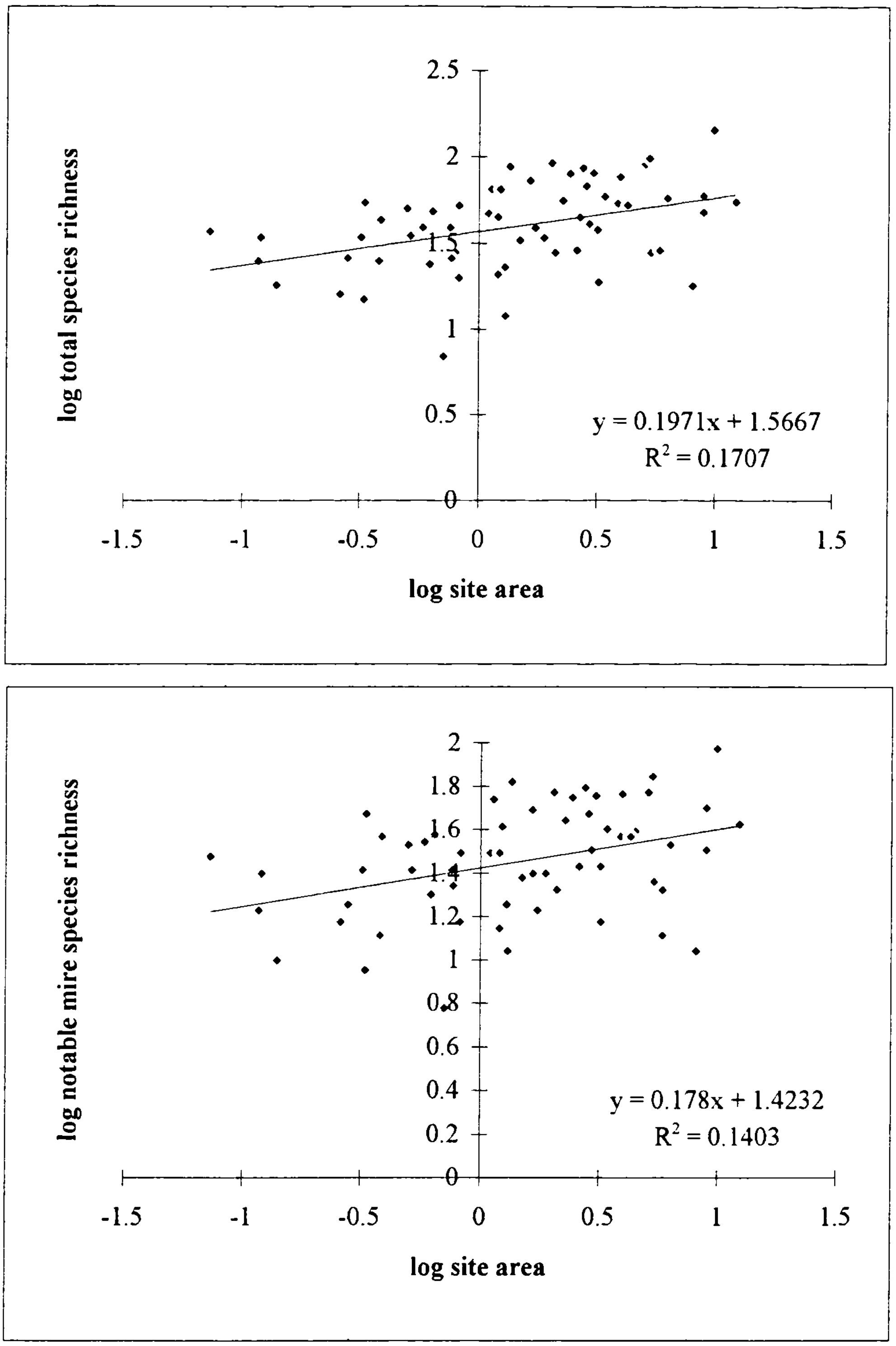


Figure 6.4. The relationship between site area and (a) total species richness and (b) notable mire species richness in 62 Scottish Borders fens.

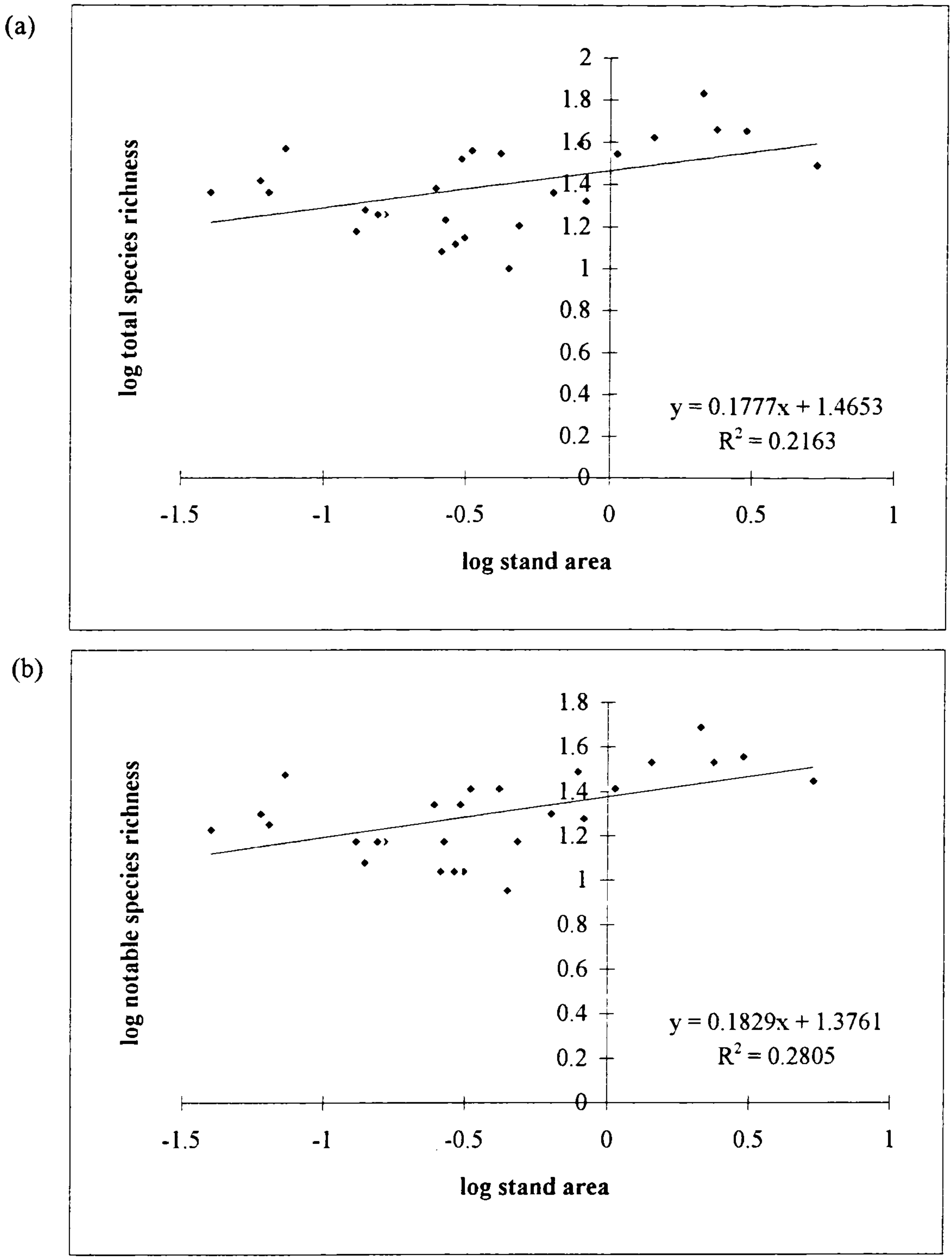


Figure 6.5. The relationship between stand area of the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community and (a) total species richness and (b) notable mire species richness in 26 Scottish Borders fens.

Within stands of the *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community the number of notable mire species is more strongly related to stand area than the total number of species (figures 6.5 a,b). Also, in this plant community, the stand area accounts for a larger proportion of the variation in species richness than does the site area for variation in site species richness.

Isolation was calculated using three methods: the average distance to all other sites, the average distance to the nearest 10 sites and the number of sites within a 5 km radius. The sites showed a range of isolation, the mean scores were:

- average distance to all sites 7.9 km (range 5.7-12.0 km)
- average distance to nearest 10 sites 2.3 km (range 0.9-5.3 km)
- number of sites within a 5 km radius 22.3 (range 5-38)

There was no significant correlation between isolation of sites and species richness in any category. The most isolated sites were Branxholm Wester Loch, Buckstruther Moss, Adderstonelee Moss, St Leonard's Moss, Fluther Moss, Fluther Moss, Bitchlaw Moss, Little Moss and Cavers Long Moss (table 6.1). The average distance from these sites to all others within the study area was greater than 10 km, the average distance to the nearest 10 sites was greater than 3 km and there were less than 10 sites within a 5 km radius. Sites with 30 or more sites within a 5 km radius were Ashkirk Loch, Blackcraig Moss, Clerklands Moss, Dunhog Moss, Ladywoodedge Moss, Muirfield Moss, Riddellshiel Loch, Shielswood Loch, Stoneyford Moss, Tathyhole Moss. There was no significant difference between the species richness of the most and least isolated sites ($p>0.05$) (table 6.3).

Table 6.3 . Species richness of the most and least isolated sites within the Borders fens study area.

site	*Site area (ha)*	*Average distance to all sites (km)*	*Average distance to nearest 10 sites (km)*	*Notable mire species*	*Rich-fen species*	*poor-fen species*	*Bog species*	*Rare fen species*	*Total species richness*
Most isolated sites (<10 sites within a 5 km radius)									
Branxholm Wester Loch	9.84	12.0	5.3	94	74	52	20	28	144
Buckstruther Moss	2.92	11.3	3.6	32	25	24	10	2	41
Fluther Moss	0.32	11.3	3.6	26	26	15	2	3	34
Highchesters Moss	1.20	10.6	4.5	14	14	7	0	0	21
Huntley Moss	0.33	9.6	4.5	9	9	4	0	0	15
Seacroft Moss	1.23	11.1	4.8	41	40	19	5	5	65
St Leonards Moss	2.42	11.1	4.7	56	55	28	4	13	80
Adderstonelee Moss	12.2	11.4	3.5	42	41	23	4	11	55
Cavers Long Moss		10.1	3.7	12	12	8	1	0	14
Little Moss	0.71	10.1	3.7	6	6	2	0	0	7
Hutlerburn Loch	4.43	9.2	3.8	39	27	31	15	9	54
Bitchlaw Moss	0.28	10.3	3.1	18	18	11	1	2	26
			average	**32.4**	**28.9**	**18.7**	**5.2**	**6.1**	**46.3**
Least isolated sites (>30 sites within a 5 km radius)									
Ashkirk Loch	5.02	5.8	1.6	59	55	31	7	17	91
Blackcraig Moss	2.66	6.1	2.1	28	28	14	0	2	45
Muirfield Moss	3.92	6.1	2.1	58	57	29	4	20	77
Riddellshiel Loch	1.49	7.1	1.6	24	24	10	1	6	33
Shielswood Loch	5.79	6.4	2.2	21	21	10	1	1	29
Berry Moss	1.88	6.8	1.4	25	25	13	2	3	34
Clerklands moss	1.65	6.8	1.4	25	25	15	2	1	39
Ladywoodedge Moss	2.26	6.8	1.5	44	43	19	2	8	56
Dunhog Moss	3.03	6.4	2	57	49	29	9	9	81
Stoneyford Moss	0.64	5.7	1.4	38	37	21	4	6	48
Synton Loch	3.19	5.7	1.4	15	15	8	0	3	19
Tathyhole Moss	1.29	5.8	2.2	18	18	9	0	0	23
Synton Courses Loch	0.14	5.9	2.4	10	10	5	0	0	18
			average	**32.5**	**31.3**	**16.4**	**2.5**	**5.8**	**45.6**

6.3.3 LAND USE AND SITE MANAGEMENT

Catchment management score was negatively correlated to altitude (r = -0.506, d.f. 66, $p<0.001$), indicating that, in general, agricultural land-use was more intensive in more lowland areas.

The Catchment Management Score was also significantly negatively correlated with the total species richness (r = -0.309, d.f.66, $p<0.02$), rare fen species (r = -0.439, d.f.66, $p<0.001$), bog species (r = -0.406, d.f.66, $p<0.01$), poor-fen species (r = -0.429, d.f.66, $p<0.01$), and rich-fen species ($r = -0.307$, d.f.66, $p<0.05$). Therefore the most species rich vegetation was likely to occur in areas with low intensity catchment management.

Site management in the Scottish Borders fens usually takes the form of grazing by sheep and or cattle. In the past sites have been mown for animal fodder and bedding but this practice has long ceased. The reedbeds on the Whitlaw Mosses are mown yearly for conservation management to open up the herbaceous vegetation, to weaken the dominance of *Phragmites australis* and to remove nutrients from the sites (Scottish Natural Heritage 1991). Most of the grazed sites in the Borders have a low catchment management score of less than 5 and mostly 1 or 2. Many sites are fenced off and unmanaged. A total of 12 sites are grazed (Brown Moor Heights, Long Moss, Whitehaughmoor Moss (middle basin), Hutlerburn Loch, Mabonlaw Moss, Muirfield Moss, Selkirk Racecourse Moss, Stoneyford Moss, Threephead Moss, Woolaw Moss, Blind Moss and Hall Moss). The grazed sites contained more species in all categories than contrasting ungrazed sites with low catchment management scores (figure 6.6) indicating the importance of site management for the maintenance of species richness.

6.3.4 EVALUATION

6.3.4.1 Species Richness Scores

The sites were ranked according to their species richness (split into 6 categories, total species, notable mire species, rich-fen species, poor-fen species and rare fen species). The top ten ranked sites within each category were combined to produce a list of the sites representing the greatest overall species and plant community richness. This analysis yielded 17 sites (table 6.4). Wester Branxholm Loch was ranked first in all species richness categories because of the range of distinct plant communities it contains, and their associated species richness. Ashkirk Loch supported the most plant communities but this is due to the range of species-poor and swamp communities present.

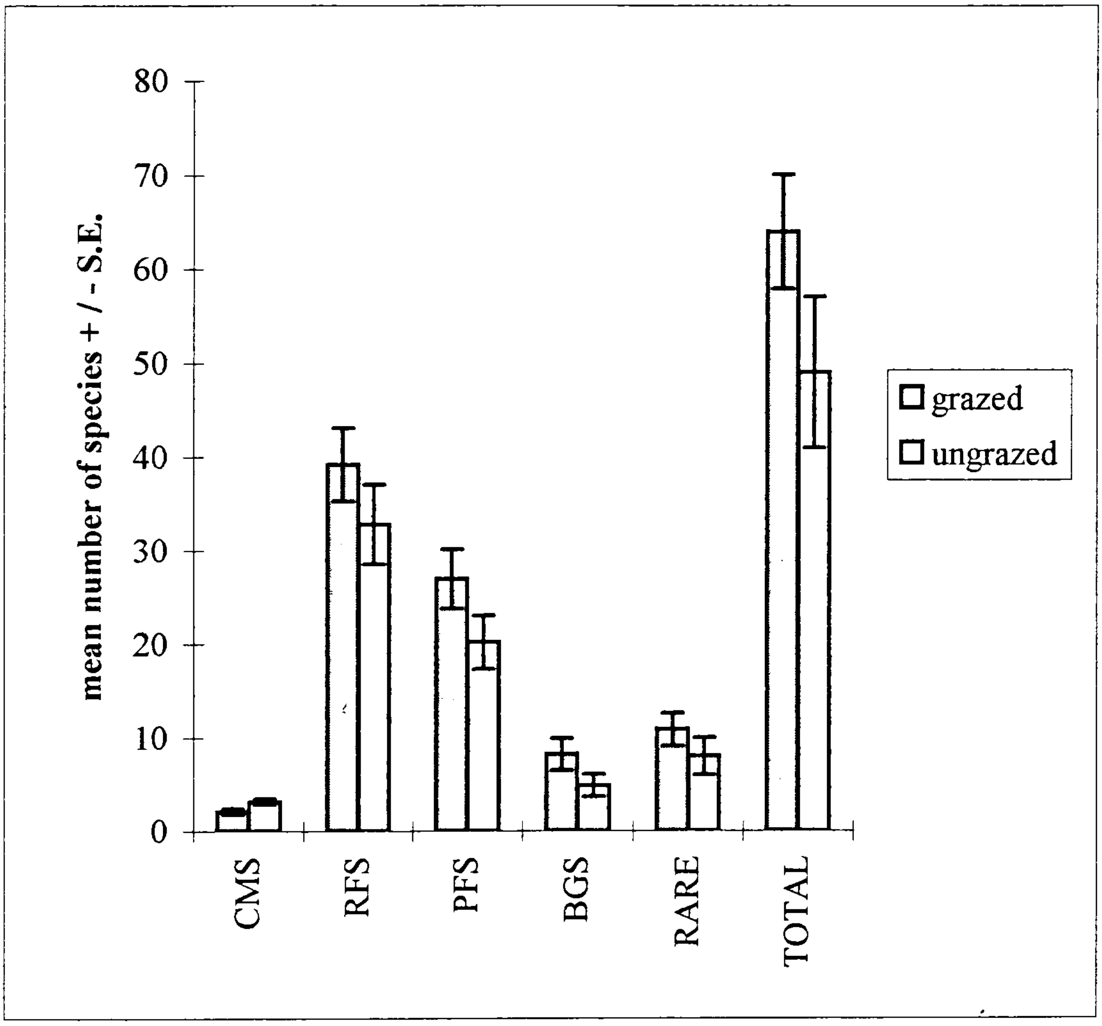


Figure 6.6. Species richness of some grazed (n = 12) and ungrazed (n = 17) Scottish Borders fens with a catchment management score (CMS) of 5 or less. There is no statistical significance between the species-richness of grazed and ungrazed sites in any species category.
RFS - Rich-fen species; PFS - Poor-fen species; BGS - Bog species; RARE - Rare fen species; TOTAL - Total species-richness.

Table 6.4. The most species-rich sites and their associated species richness and number of plant communities resulting from the combination of the top ten ranked sites in each category of species richness: total species, notable mire species, rich-fen species, poor-fen species and rare fen species.

	Plant communities	*Notable mire species*	*Rich-fen species*	*Poor-fen species*	*Bog species*	*Rare species*	*Total species*
Ashkirk Moss	8	59	55	31	7	17	91
Beanrig Moss	4	66	58	36	11	22	88
Blind Moss	7	70	54	45	17	17	98
Branxholm Wester Loch	7	94	74	52	20	28	144
Brown Moor Heights Moss	4	55	42	40	15	13	65
Buckstruther Moss	2	32	25	24	10	2	41
Dunhog Moss	4	57	49	29	9	9	81
Groundistone Moss	6	37	28	26	11	2	54
Hutlerburn Moss	5	39	27	31	15	9	54
Long Moss	5	62	51	38	16	14	87
Mabonlaw Moss	6	49	43	32	9	10	73
Muirfield Moss	6	58	57	29	4	20	77
Murder Moss	7	50	47	23	4	10	60
Selkirk Racecource Moss	4	59	57	25	4	20	92
St Leonards Moss	6	56	55	28	4	13	80
Whitehaughmoor Moss, east basin	3	47	42	26	5	17	54
Woolaw Loch	3	37	30	26	9	7	43

6.3.4.2 Fenbase Evaluation

The biodiversity and target species scores for each site and numbers of nationally and regionally rare species recorded for each site in the Fenbase database (Borders basin fen survey) are presented in table 6.5. Of a possible 68 sites, 29 sites contained 1 or more regionally rare species and 47 sites contained 1 or more nationally rare species. The sites were ranked by biodiversity score. Branxholm Wester Loch had the highest biodiversity score, followed by Beanrig Moss. 27 sites had scores of 50 or above. 13 sites had scores above 64, the value for Clack fen (table 6.5) but no site matched the score for Catfield and Irstead Fens, Norfolk (table 6.6). The scores for the Scottish Borders fens are high, considering the small size of most of the sites.

Table 6.6. Fenbase biodiversity and target species scores of a range of contrasting British fen sites (Wheeler 1988, 1997).

Site	*Biodiversity score*	*Target species score*
Catfield and Irstead Fens, Norfolk	137	19
Beanrig Moss, Selkirk	86	11
Wheatfen, Norfolk	72	9
Clack Fen, Bucks	64	3
Drabblegate Common, Norfolk	12	0

Table 6.5. Species richness, rarity and biodiversity and target species scores of Scottish Borders fens.

Site	*Notable mire species*	*Range size rarity*	*Fenbase Biodiversity score*	*Fenbase Target species score*	*Nationally rare species*	*Locally rare species*
Adderstonelee Moss	42	17.87	62	3	3	0
Ashkirk Loch	59	22.31	69	5	7	2
Beanrig Moss	66	34.95	109	8	13	4
Beeswood Moss	17	2.25	27	0	2	0
Berry Moss	25	4.97	38	0	1	0
Bitchlaw Moss	18	2.46	32	0	1	0
Blackcraig Moss	28	7.96	47	0	1	0
Blackpool Moss	40	10.24	61	4	4	1
Blind Moss	70	36.33	77	5	6	0
Boghall Moss	21	3.11	28	0	0	0
Boosmill Moss	25	4.8	30	2	0	0
Borthwickshiels Loch	20	4.1	35	0	1	0
Branxholm Wester Loch	94	60.24	111	8	11	3
Brown Moor Heights	55	24.71	84	7	5	1
Buckstruther Moss	32	10.84	49	0	1	0
Cavers long Moss	12	1.61	14	0	0	0
Clerklands Moss	25	4.11	37	0	0	0
Curdyhaugh Moss	34	9.2	51	0	1	0
Dry Moss	34	6.1	56	0	0	0
Dunhog Moss	57	20.57	79	2	3	1
Fluther Moss	26	4.06	34	0	1	0
Greenside Moss	31	7.15	54	3	4	2
Groundistone Moss	37	13.01	19	1	0	0
Haining Moss	27	6.17	40	0	2	0
Hall Moss	31	7.38	50	1	5	1
Harden Moss	27	8.09	29	0	2	0
Hare Moss	19	4.11	21	0	0	0
Hartwoodburn Moss	15	1.97	21	1	1	0
Highchesters Moss	14	2.07	20	0	0	0
Hummelknowes Moss	47	11.1	76	5	2	1
Huntley Moss	9	1.76	15	0	0	0
Hutlerburn Loch	39	22.54	62	5	2	2
Kippilaw Moss	26	4.7	47	2	4	0
Ladywoodedge Moss	44	13.15	66	4	5	2
Lilliesleaf Moss	11	1.48	13	0	0	0
Lionfield Moss	13	2.22	18	0	0	0
Little Moss	6	0.79	6	0	0	0
Long Moss	62	24.3	72	5	4	1
Mabonlaw Moss	49	14.83	77	5	2	0
Muirfield Moss	58	20.98	84	6	7	3
Murder Moss	50	16.38	55	4	4	1
Nether Whitlaw Moss	37	14.13	50	4	4	2
Newhouse Moss	8	1.43	11	0	0	0
Pickmaw Moss	22	5.82	30	1	2	1
Pot Loch	22	6.19	30	1	3	1
Riddelshiel Loch	24	6.63	37	2	3	2
Rotten Moss	26	4.98	36	0	1	0
Seacroft Moss	41	11.07	71	3	1	1
Selkirk Hill Moss	20	3.55	29	1	3	1
Selkirk Racecourse Moss	59	20.17	63	6	6	3
Shielswood Moss	21	3.51	30	0	1	0
St Leonards Moss	56	16.43	66	4	2	1
Stoneyford Moss	38	11.22	50	0	2	0
Stouslie Pool	15	1.89	16	0	0	0
Synton Courses Loch	10	3.7	20	0	0	0
Synton Loch	15	2.65	20	0	1	0
Tandlaw Moss	23	4.75	28	1	2	1
Tathyhole Moss	18	4.94	22	0	0	0
Threephead Moss	31	9.4	57	3	0	1
Tocher Lodge Moss	9	1.19	15	0	0	0
Todshawhill Moss	11	1.49	12	0	0	0
Whitehaughmoor Moss East	47	23.85	64	5	10	3
Whitehaughmoor Moss Middle	30	6.63	44	2	3	1
Whitehaughmoor Moss West	35	6.34	45	2	1	1
Whitmuir Moss	13	2.87	30	0	0	0
Whitmuirhall Loch	32	12.47	39	2	2	2
Woolaw Loch	37	11.73	50	2	4	0
Woolaw Moss	17	2.88	46	0	0	0

6.3.4.3 Vegetation zonation

The zonation of vegetation on a large, site scale (macrotopographical) and a small, hummock-hollow scale (microtopographical) is an important feature of fen sites. In sites which have developed hydroserally these zonations are often interpreted as phase in a successional sequence, although this is not always the case as the occurrence of particular species and plant communities can be influenced by a variety of factors which may be prevalent in different areas of a site. The zones of vegetation may therefore represent different environments and sites showing distinct zonation may therefore support a wider range of plant communities than those which do not. Where microtopographical zonation is present this often adds another structural dimension to a plant community, increasing the species richness (Wheeler 1980b). It is contentious whether plant communities commonly found as small scale mosaics of hummocks and hollows should be considered as one or more distinct plant communities. Several sites in the Scottish Borders exhibit distinct zonation (table 6.7).

Table 6.7. Sites showing distinct vegetation zonation. ✓ indicates distinct zonation; + indicates indistinct zonation.

	Zonation	
Site	*Macrotopographical*	*Microtopographical*
Long Moss	✓	✓
Branxholm Wester Loch	✓	✓
Selkirk Racecource Moss	✓	✓
Kippilaw Moss	✓	
Brown Moor Heights	✓	
Ashkirk Loch	✓	
Nether Whitlaw Moss	✓	
Greenside Moss	✓	
Hutlerburn Loch	+	
Dunhog Moss	+	
Blind Moss	+	✓
Beanrig Moss		✓
Mabonlaw Moss		✓
Threephead Moss		✓
Woolaw Loch		✓
Whitehaughmoor Moss (E)		✓

6.3.3.4 Prioritising sites for the maximisation of biodiversity

The sites exhibit a high degree of nestedness where one site contains a large proportion of the total species in the data set (Branxholm Wester Loch). Table 6.8 summarises the nested distribution of notable mire species in Scottish Borders fens sites.

Table 6.8. Matrix showing the 'nestedness' of the Scottish Borders fens on the basis of notable mire species richness.
X represents the occurrence of a species on a site. The sites are ranked from left to right in the order of decreasing species richness.
The species are ranked from top to bottom in the order of decreasing number of occurrences in the Scottish Borders fens.
The sites and their notable mire species richness and the species and their number of occurrences are listed overleaf.

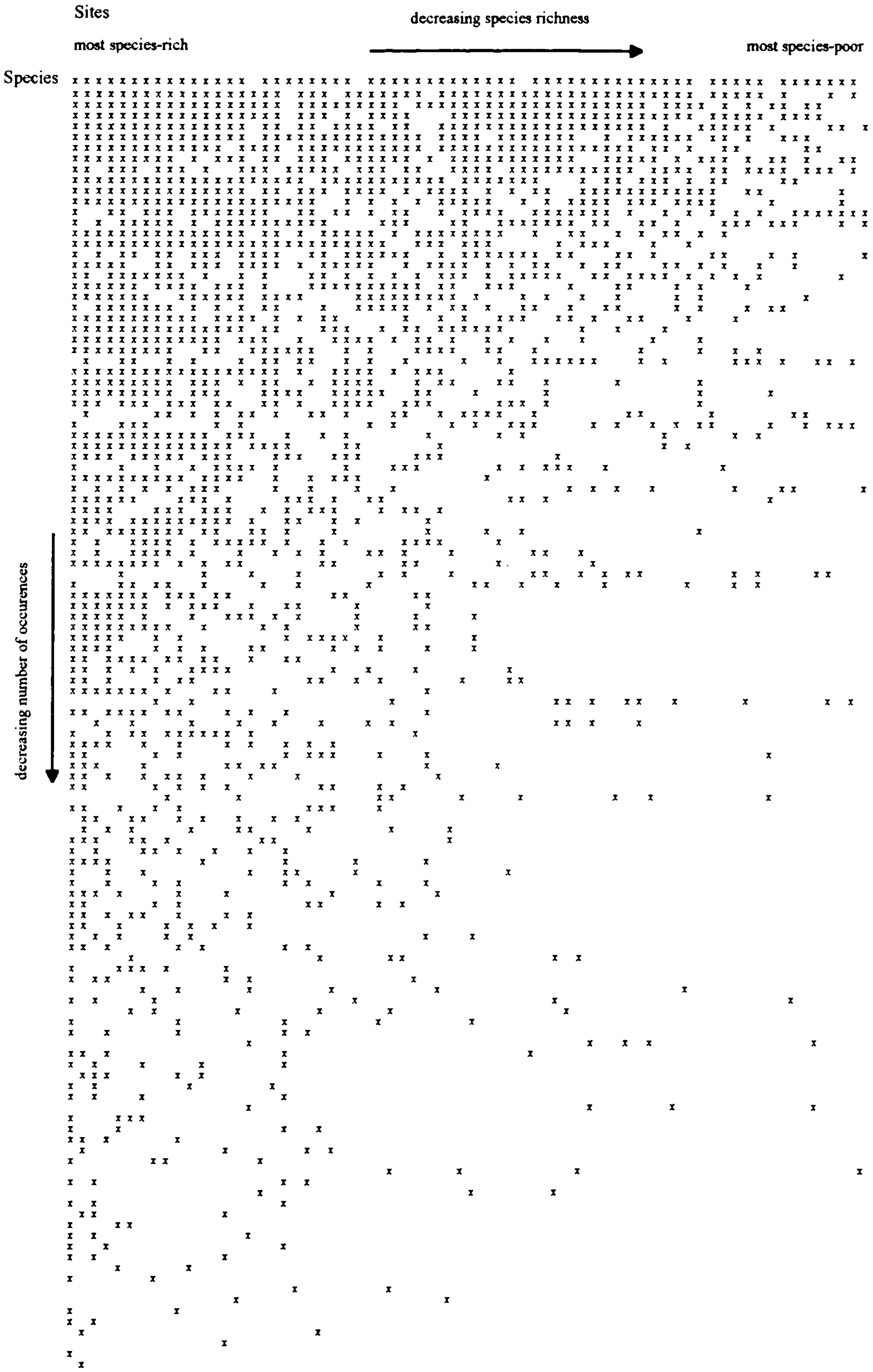


Table 6.8 cont.

Notable mire species	*No. of occurences (out of a possible 68)*
Carex rostrata	62
Equisetum fluviatile	58
Calliergon cuspidatum	57
Galium palustre	56
Caltha palustris	53
Potentilla palustris	53
Epilobium palustre	52
Filipendula ulmaria	51
Juncus effusus	51
Menyanthes trifoliata	49
Juncus acutiflorus	48
Carex nigra	45
Myosotis scorpioides	45
Mentha aquatica	43
Plagiomnium rostratum	41
Eriophorum angustifolium	39
Salix cinerea	39
Cirsium palustre	38
Ranunculus flammula	38
Lychnis flos-cuculi	35
Equisetum palustre	34
Angelica sylvestris	33
Calliergon giganteum	32
Carex diandra	32
Carex panicea	31
Juncus articulatus	30
Sparganium erectum	30
Carex lepidocarpa	28
Galium uliginosum	28
Molinia caerulea	27
Valeriana dioica	26
Calliergon cordifolium	24
Carex disticha	24
Potamogeton polygonifolius	24
Bryum pseudotriquetrum	23
Drepanocladus revolvens	22
Carex paniculata	20
Pedicularis palustris	20
Phragmites australis	20
Viola palustris	20
Aulacomnium palustre	19
Campylium stellatum	19
Carex echinata	19
Dactylorhiza purpurella	19
Dactylorhiza fuchsii	18
Rhizomnium pseudopunctatum	18
Eleocharis palustris	17
Veronica scutellata	17
Scorpidium scorpioides	16
Carex hostiana	15
Carex lasiocarpa	15
Carex pulicaris	15
Sphagnum recurvum	14
Sphagnum subnitens	14
Carex dioica	13
Climacium dendroides	13
Dryopteris carthusiana	13
Parnassia palustris	12
Phalaris arundinacea	12
Pinguicula vulgaris	12
Ranunculus lingua	12
Sagina nodosa	12
Drosera rotundifolia	11
Sphagnum palustre	11
Dactylorhiza incarnata	10
Juncus bulbosus	10
Sphagnum squarrosum	10
Alnus glutinosa	9
Carex curta	9
Cratoneuron commutatum	9
Myosotis laxa caespitosa	9
Triglochin palustris	9
Aneura pinguis	8
Erica tetralix	8
Fissidens adianthoides	8
Sphagnum capillifolium	8
Sphagnum contortum	8
Sphagnum fimbriatum	8
Utricularia minor	8
Hydrocotyle vulgaris	7
Salix repens agg	7
Sphagnum papillosum	7
Cicuta virosa	6
Eriophorum latifolium	6
Philonotis calcarea	6
Philonotis fontana	6
Salix pentandra	6
Scutellaria galericulata	6
Calliergon stramineum	5
Eriophorum vaginatum	5
Iris pseudacorus	5
Narthecium ossifragum	5
Selaginella selaginoides	5
Sphagnum auriculatum	5
Corallorhiza trifida	4
Eleocharis quinqueflora	4
Epilobium hirsutum	4
Juncus alpino-articulatus	4
Mylia anomala	4
Polytrichum alpestre	4
Sphagnum teres	4
Stellaria alsine	4
Typha latifolia	4
Vaccinium oxycoccos	4
Carex acutiformis	3
Carex limosa	3
Homalothecium nitens	3
Potamogeton coloratus	3
Pyrola rotundifolia	3
Sphagnum magellanicum	3
Sphagnum warnstorfii	3
Calamagrostis stricta	2
Carex appropinquata	2
Carex vesicaria	2
Epilobium parviflorum	2
Odontoschisma spahgni	2
Pellia endiviifolia	2
Sphagnum cuspidatum	2
Cinclidium stygium	1
Sphagnum imbricatum	1
Sphagnum fuscum	1

Sites	*No. of notable mire species*
Branxholm Wester Loch	94
Blind Moss	70
Beanrig Moss	66
Long Moss	62
Ashkirk Loch	59
Selkirk Racecourse Moss	59
Muirfield Moss	58
Dunhog Moss	57
St Leonards Moss	56
Brown Moor Heights	55
Murder Moss	50
Mabonlaw Mabonlaw	49
Hummelknowes Moss	47
Whitehaughmoor Moss E	47
Ladywoodedge Moss	44
Adderstonelee Moss	42
Seacroft Moss	41
Blackpool Moss	40
Hutlerburn	39
Stoneyford Moss	38
Groundistone Moss	37
Nether Whitlaw Moss	37
Woolaw Loch	37
Whitehaughmoor Moss W	35
Curdyhaugh Moss	34
Dry Loch	34
Buckstruther Moss	32
Whitmuirhall Loch	32
Greenside Moss	31
Hall Moss	31
Threephead Moss	31
Whitehaughmoor Moss M	30
Blackcraig Moss	28
Haining Moss	27
Harden Moss	27
Fluther Moss	26
Kippilaw Moss	26
Rotten Moss	26
Berry Moss	25
Boosmill Moss	25
Clerklands Moss	25
Riddelshiel Moss	24
Tandlaw Moss	23
Pickmaw Moss	22
Pot Loch	22
Boghall Moss	21
Shielswood Loch	21
Borthwickshiels Loch	20
Selkirk Hill Moss	20
Hare Moss	19
Bitchlaw Moss	18
Tathyhole Moss	18
Beeswood Moss	17
Woolaw Moss	17
Hartwoodburn Moss	15
Stouslie Pool	15
Synton Moss	15
Highchesters Moss	14
Lionfield Moss	13
Whitmuir Moss	13
Cavers Long Moss	12
Lilliesleaf Moss	11
Todshawhill Moss	11
Synton Courses Moss	10
Huntley Moss	9
Tocher Lodge Moss	9
Newhouse Moss	8
Little Moss	6

"Hotspots" of species richness and rarity -weighted species richness / range-size rarity (the top ~5% of total sites, based on Prendergast *et al.* 1993) are Wester Branxholm Loch, Blind Moss and Beanrig Moss. Out of a total of 68 sites a combination of 8 sites represents all notable mire species at least once. Branxholm Wester Loch, Blind Moss and Whitehaughmoor Moss are "irreplaceable" sites because they are the only locations of certain species (*Sphagnum fuscum*, *Sphagnum imbricatum* and *Cinclidium stygium* respectively) within the study area. 26 sites are required for the representation of all notable wetland species three times and 36 sites are necessary for five representations (table 6.9).

Table 6.9. Near-minimum-area set for 1,3 and 5 representations of notable mire species (combined number of RFS, PFS, BGS and RARE species). "Hotspots" of species richness are indicated in **bold** type. Flexible sites at each step are indicated in *italics*.

Site	*Notable mire Species Richness*	
Wester Branxholm Loch	96	
Blind Moss	70	
Ashkirk Loch	59	
Whitehaughmoor Moss E.	47	
Ladywoodedge Moss	44	1 representation
Adderstonelee Moss	42	8 sites
Seacroft Moss	41	2 irreplaceable
Whitmuirhall Loch	32	6 flexible
Beanrig Moss	66	
Long Moss	62	
Selkirk Racecourse Moss	59	
Dunhog Moss	57	
Brown Moor Heights	55	
Murder Moss	50	
Hutlerburn Moss	39	
Stoneyford Moss	38	
Nether Whitlaw Moss	37	
Woolaw Loch	37	
Blackcraig Moss	28	
Haining Moss	27	
Harden Moss	27	
Riddelshiel Loch	23	3 representations
Pickmaw Moss	22	26 sites
Pot Loch	22	23 irreplaceable
Synton Courses Loch	10	3 flexible
Muirfield Moss	58	
St Leonards Moss	56	
Mabonlaw Moss	49	
Blackpool Moss	40	
Groundistone Moss	37	
Curdyhaugh Moss	34	
Buckstruther Moss	33	
Boosmill Moss	25	5 representations
Borthwickshiels Loch	20	36 sites
Hare Moss	19	36 irreplaceable
Tathyhole Moss	19	0 flexible

Sixteen of the fen sites included in this study are currently protected as reserves, either as Sites of Special Scientific Interest (SSSI) and/or National Nature Reserves (NNR). These sites represented 97.5% of the total (notable mire species) biodiversity of the data set (table 6.10).

Table 6.10. 16 currently protected sites accounting for 97.5% of notable wetland species.

Site	*Notable mire species richness*
Wester Branxholm Loch (SSSI)	96
Blind Moss (SSSI)	70
Beanrig Moss (NNR)	66
Long Moss (SSSI)	62
Ashkirk Loch (SSSI)	59
Selkirk Racecourse Moss (SSSI)	59
Dunhog Moss (SSSI)	57
Brown Moor Height (pSSSI)	55
Murder Moss (NNR)	50
Hummelknowes Moss (SSSI)	47
Adderstonelee Moss (SSSI)	42
Blackpool Moss (NNR)	40
Buckstruther Moss (SSSI)	3
Whitmuirhall Moss (SSSI)	32
Nether Whitlaw Moss (NNR)	37
Kippilaw Moss (SSSI)	26

Using these sixteen sites as a starting point for the site selection procedure, three additional sites were required to represent all notable mire species at least once, 13 additional sites were required for three representations and 22 additional sites were required for 5 representations (Table 6.11).

Table 6.11. Sites required in addition to the 16 currently protected sites (table 6.10) for 1, 3 and 5 representations of notable wetland species. Flexible sites are indicated by *italics*.

Site	
Whitehaughmoor Moss E.	1 representation (16+3 sites)
Seacroft Moss	1 irreplaceable site
Ladywoodedge Moss	2 flexible sites
Haining Moss	
Harden Moss	
Pickmaw Moss	
Riddelshiel Loch	
Hutlerburn Loch	
Stoneyford Moss	
Blackcraig Moss	
Pot Loch	3 representations (16+13 sites)
Synton courses Loch	10 irreplaceable sites
Woolaw Loch	3 flexible sites
Curdyhaugh Moss	
Groundistone Moss	
Borthwickshiels Loch	
Hare Moss	
Boosmill Moss	
Muirfield Moss	
Mabonlaw Moss	5 representations (16+22 sites)
Tathyhole Moss	22 irreplaceable sites
St Leonards Moss	0 flexible sites

It should be stressed that these techniques select sites on the basis of presence and absence of species with no regard to the plant communities or population size and should be regarded as a template for reserve network selection to ensure the representation of biodiversity as a baseline. The analyses presented are the most basic as the techniques are still being developed with the aim of incorporating other important site features. Notable mire plant species recorded in this study are the only species group taken into account in these analyses and a different network of sites may be important for maintaining other species groups, for example birds and invertebrates.

6.4 Discussion

The objectives of this part of the study were to evaluate fen sites within the study area on the basis of their species richness, to identify groups of sites which would represent the biodiversity of notable mire species a number of times and to examine the impact of area, area : perimeter ratio, isolation, site management and the intensity of catchment land-use on site species richness.

6.4.1 EVALUATION AND PRIORITISATION OF SITES FOR NATURE CONSERVATION

The use of evaluation and site prioritisation procedures based on species richness requires some caution. They rely on the assumption that an equally good inventory of species has been made for all sites, which is not always the case, as some sites frequently receive more attention than others (Usher 1979, Bond *et al.* 1988). These techniques also only provide a snapshot of the current resource and require updating through monitoring of species distributions.

There are two approaches to the objective prioritisation of sites:

1. selecting a set of sites which fulfil the desired criteria (e.g. representing the total species biodiversity, all sites with a score above a certain value)
2. choosing a quota of sites (e.g. selecting 20 sites).

The analyses presented were mainly concerned with the first approach. The biodiversity analyses identified groups of sites which could represent the total species richness of the fens a specified number of times and these proved a more satisfactory technique for prioritising sites than simple ranking procedures because they selected groups of sites, based on established criteria, rather than simply listing all sites. A number of species-poor sites which in simple ranking operations would be at the end of the list (Tathyhole Moss, Borthwickshiels Loch), and certainly not in the top twenty or thirty places, were included in the biodiversity selection as well as those with high species richness (Branxholm Wester Loch, Blind Moss). This indicates that the groups of sites selected in the biodiversity analyses contain a more representative range of vegetation types, not just the richest examples.

The data set from the Borders fens is strongly nested so one site contains almost all the species in the data set. In a perfectly nested data set one site contains all the species and other sites contain a subset of the entire species complement. In this situation the issue in prioritisation on the basis of biodiversity becomes the representation of particular species. Largely for this reason the sixteen currently protected sites account for 97.5 % of the total notable mire species richness but they do not include a number of sites with important species populations, notably Whitehaughmoor Moss. Other sites support extensive examples of rare plant communities (e.g. small sedge species-rich flushes with abundant *Eriophorum latifolium* at Muirfield Moss) but this is only included in the group of sites required to represent all notable mire species 5 times because the species population sizes are not accounted for in the analyses presented. The number of representations of a species required to ensure adequate protection is not known and selection of sites on the basis of biodiversity cannot identify the most threatened populations and the functioning metapopulations. There is rather little detailed knowledge about the processes of colonisation, establishment requirements and autecology of wetland plant species in natural habitats and although metapopulation dynamics have been demonstrated to be important in the conservation of some species groups, e.g. invertebrates, their significance to the maintenance of populations of long lived perennial plant species is little understood, and probably negligible in influencing changes in species composition compared to other factors (e.g. habitat destruction, vegetation management) (Gibson 1986).

The use of ranking operations in site prioritisation requires the setting of arbitrary criteria and cut-off points (e.g. the determination of "standard" scores with which to compare the ranked scores, the top 10%) for the selection of a group of priority sites. The biodiversity scores for the Borders fens showed that these sites compare well with some important sites in the Norfolk Broads, which are usually much larger than the Borders fen sites indicating the exceptional richness of some of these sites relative to their size.

"Hotspots" of species richness have been defined in some bird studies as the top 5 % of sites (Prendergast *et al.* 1993). In this study of the Scottish Borders fens this corresponds to about 3 sites (Branxholm Wester Loch, Blind Moss, Beanrig Moss). The biodiversity analyses presented here show that at least 8 (~11%) sites are required to represent all species at least once, and 36 (>50%) are required to represent all notable mire species 5 times.

One goal of conservation is to maximise the biodiversity and representation of notable and rare species in a region through the selection and protection of reserves, and subsequent management of sites and site catchments to maintain and create habitats which will support viable species populations.

However in evaluating fens and prioritising areas for nature conservation other qualities of a desirable *site* also need to be defined if the selection is to be made objectively, and this involves the setting of additional more complex criteria as well as maintaining species biodiversity. Fens have been classified on the basis of their hydrology, situation, hydrochemistry and the vegetation they contain. Therefore fens are currently protected on an "ad hoc" basis as *sites* taking account of the vegetation, zonation of vegetation, peat deposits, and in recent years including part or all of the catchment as a buffer zone. The use of factors other than species richness, rarity and size (e.g. Ratcliffe 1977) in assessing the quality of sites and in reserve selection has been difficult to quantify and applied inconsistently to sites (Usher 1985, Wheeler 1988). The use of a range of criteria in producing a numerical score representing the conservation importance of a site also relies on the aggregation of the different criteria, the importance of which may vary between sites (Usher 1985). Moreover the goals of conservation of fen sites are often difficult to define and quantify and it is not clear how the conservation importance or "quality" of sites can be determined and compared on a truly objective basis.

6.4.2 SITE SIZE, ISOLATION AND EDGE EFFECTS

In the Borders fens larger sites tend to support more plant communities types and more species. This relationship would be expected because larger sites generally provide more habitats and a larger possible area for colonisation of species than smaller sites (Usher 1991). However area accounts for only a small amount of the variation in species richness in the Scottish Borders fens and many sites deviate from the regression line indicating that many sites are more species-rich and more species-poor than would be expected on the basis of area alone (Usher 1985).

The relationship between stand area and species richness within one plant community (*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community) is stronger than that between *site* area and *site* species richness in the Scottish Borders fens. Notable mire species richness (indicating the number of 'characteristic' mire species) is more strongly related to stand area than total species richness suggesting that the relationship between species richness and area cannot be simply explained by the tendency of large areas to support more habitats than small areas.. Usher (1980) also found that the number of species 'typical' or 'characteristic' of limestone pavements was more strongly related to habitat area than the total number of species. He suggested that this was because larger areas contain more niches than smaller areas and there is a higher chance of colonisation by species in larger areas.

In the Scottish Borders fens rare species occur on sites of all sizes and no species are excluded from small sites. This was also the case in a study of remnant prairies and forests in the U.S.A (Simberloff & Gotelli 1984) although these sites had only been remnants for a short time and the species-area relationship represents a static measure of a dynamic community (Usher 1979 & 1985).

Because area usually accounts for only a small amount of the variation in species richness in different sites the importance of critical minimal areas for conservation of plant communities has not been widely studied (McCoy, 1983; Helliwell 1976). Instead the focus has been on the conservation of individual sites and species.

Little is known about the importance of area *per se* for the conservation of species but there is substantial evidence to suggest that although species-area relations can be a useful guide for the selection of sites that are the most diverse or typical or which contain the most rare species they are probably insufficient to provide more than a snapshot of a community at a particular time and should not therefore be relied upon as an exclusive guide for conservation management (Usher 1985). The importance of a thorough knowledge of the autecology of endangered species and the consideration of the value of individual sites cannot be underestimated.

Shape has been considered as important in the minimisation of edge effects in the conservation of specific species groups (Smith & Charman 1988) and it was largely believed that circular sites, with the smallest edge:area ratio, would be most suitable as reserves for species conservation (Diamond 1975), minimising the risk of nutrient enrichment, damage by livestock, drying out and invasion by other species. The impact of edge effects on vegetation composition is largely dependent on the surrounding land-use. In this study of the Scottish Borders fens the intensity of catchment land-use was significantly negatively related to the species richness of the vegetation so sites surrounded by intensively farmed land contained fewer species than those surrounded by unimproved land. The designation of buffer zones, the water catchment in the case of fen sites, is perceived to be a practical solution to the protection of sites threatened by edge effects. In the current study shape was crudely characterised by the area : perimeter ratio where long, thin sites or sites with an irregular boundary have relatively small area : perimeter ratios and sites which are approximately circular and those with regular boundaries have relatively large area : perimeter ratios. Blouin & Connor (1985) used a more complicated index of shape and found no significant relationship between shape and total species diversity.

In the Scottish Borders fens there was no significant relationship between bog species richness and site area but there was a positive and significant correlation between bog species richness and area : perimeter ratio. Therefore sites which had a larger area : edge ratio contained more bog species than those with a small area : edge ratio. This was also found in a study of the distribution of ombrothrophic bog vegetation in Northumberland by Smith and Charman (1988). Characteristic bog species thrive in areas isolated from groundwater, conditions which are more likely to occur near the centre of basin fen sites, away from inputs of runoff and telluric water. In sites with a large area : edge ratio the extent of the central habitat is reduced, and reserves with long perimeters relative to site area may have proportionately fewer species characteristic of the central area (Williamson 1975, Margules et al 1982).

In the current study all species richness categories except poor-fen species were significantly correlated with area : perimeter ratio, probably due to the impact of surrounding land-use on vegetation composition in sites affected by nutrient enrichment, but the relationship was weaker for rich-fen and rare-fen species. This may be because not all sites are affected by nutrient enrichment from runoff from the surrounding land and some species may be favoured by conditions nearer the edges of sites especially in areas of spring discharge, or where central areas of the site are colonised by bog and the rich fen and poor-fen species are concentrated nearer the edge.

Isolation of sites has been regarded as undesirable in nature conservation strategies (see Usher 1991) because immigration rates of species have been assumed to be lower in more isolated sites (MacArthur & Wilson 1967). There is little evidence on the effect of immigration and isolation in maintaining species numbers in sites. Moore (1962) found that in the case of certain species of birds and reptiles a distance of 5km was effective in preventing recolonisation of fragments of Dorset heathland and Hooper (1971) suggested that much smaller distances may be effective in preventing recolonisation of fragments of woodland by higher plant species, probably due to small dispersal distances of seeds and the prevention of propagation by vegetative reproduction. Many characteristic fen species are long-lived perennials so the impact of immigration on maintaining their populations is likely to be negligible. The degree of isolation of fen sites in the Scottish Borders showed no relationship to their species richness, and there were no significant differences between the mean species richness of the most and least isolated fen sites. There are no truly isolated sites in the Borders fens because most sites occur in clusters and the nearest site is usually within 1-2km. Also some 'fen' species occur in other habitats, for example stream margins. In addition a number of very small hollows were not included in this study and may be sources of potential colonists.

6.4.3 IMPACT OF VEGETATION MANAGEMENT ON SPECIES RICHNESS

The effects of natural immigration and extinction rates and therefore species turnover have been found to be negligible compared to the effects of management in changing community composition (Gibson 1986). In semi-natural habitats land management, and catchment management are as important as biogeographical conditions (e.g. area, isolation) in influencing the occurrence of conservationally important species and plant communities and species richness of sites (Helliwell 1976, Wheeler 1983, Bond *et al.* 1988). In this study managed (grazed) sites contained more species than those which were unmanaged. In natural systems species turnover (extinction and invasion) is inevitable, especially during spontaneous succession. The Scottish Borders fens have traditionally been used as summer grazing for cattle and sheep and in the past the vegetation was cut where the water was too deep for the grazing of livestock.

A lack of management or change of surrounding land management can quickly lead to dereliction and loss of species and renewed management may only encourage the growth of species which are already struggling, not those which have already perished. The cessation of grazing of the fen at Ashkirk Loch since the recent forestry development has already led to the colonisation of the fen surface by *Salix* seedlings. Summer mowing of dense *Phragmites australis* reedbeds at Murder Moss and Blackpool Moss has noticeably increased the cover of associated species *Filipendula ulmaria* and *Caltha palustris* and bryophytes *Calliergon* spp., although there has been no noticeable recovery in the populations of rare species in these areas. There are many documented cases of site dereliction, through cessation of management, especially in areas where management by mowing was traditional, for example the Norfolk Broads (Wheeler & Shaw 1995a).

Hydroseral succession is a feature of many fen sites, especially in the Borders fens where the vegetation at many sites has developed through the hydroseral colonisation of former peat cuttings and marl workings. Some species appear to be dependent upon particular phases in a successional sequence (e.g. *Liparis loeselii*, Giller & Wheeler 1986). The only way to conserve such species may be through the re-excavation of peat cuttings to re-initiate the vegetation succession (Wheeler & Shaw 1995a). The vegetation composition of a site is dependent on many factors unique to individual sites (e.g. management history) which often account for more of the variation found than measured variables (McCune & Allen 1985). Hence the continuation of vegetation management in fen sites for the maintenance of species richness is therefore of major importance in conservation.

Chapter 7: General Discussion

7.1 Controls on vegetation composition

The fen habitat encompasses a wide range of plant communities occurring under a range of environmental conditions. At present rather little is known about the specific establishment requirements, comparative ecology and competitive interactions of typical wetland plant species so the exact constraints on the species composition of fen vegetation remain uncertain. This study has shown that the influences of soil and water chemical conditions, water movement, management history and vegetation succession are of primary importance to the vegetation composition of the Scottish Borders fens .

7.1.1 SUBSTRATUM CHEMICAL CONDITIONS

7.1.1.1 Base status

The Scottish Borders fens occur over a wide range of water base-richness. In some plant communities, with well developed vegetation mosaics, there is a striking vertical variation in base-richness. But at depth there is little variation in the base-richness of the fen water between sites in general. The base-richness of the interstitial water (at the rooting zone of the vegetation) corresponds to the primary axis of floristic variation in the Scottish Borders fens (chapter 4). This was also found for British fens (Shaw & Wheeler 1991). Variation in base-richness was the basis for the early categorisation of fen vegetation into rich-fen and poor-fen (Du Rietz 1949, 1954) where rich and poor fens were separated by the 'calciphyte plant limit' (a floristic boundary based on the presence of plants believed to be indicators of base-rich conditions). However it proved difficult to relate this division of poor-fen and rich-fen vegetation to *specific* chemical conditions so the chemical distinction between rich and poor fen was regarded as a relative one where at any one site the rich-fen vegetation occupied more base-rich conditions relative to the poor-fen vegetation. The split between rich and poor fen vegetation was regarded by Sjors (1950) as an arbitrary sub-division on a continuous gradient of floristic and base-richness variation. In the Scottish Borders poor-fen vegetation was the most chemically-distinct vegetation type with lower concentrations of calcium and lower pH than rich-fen vegetation types. This is probably largely because poor-fen vegetation is characterised by abundant *Sphagnum* spp. which have been shown to reduce the pH of water through active exchange of hydrogen ions (Clymo 1963). Shaw and Wheeler (1991) observed that poor-fen vegetation tended to have a pH less than 5.5 and rich-fen greater than pH 5.5. This was largely due to the association of more acidic water with plant communities characterised by plentiful *Sphagnum*.

7.1.1.2 Fertility

The fertility of fen soils is primarily determined by the availability of growth-limiting nutrients, especially nitrogen and phosphorus. A more realistic assessment of the comparative soil fertility of fens can be obtained using phytometric procedures than by simple measurements of nutrient concentrations (Wheeler *et al.* 1992). The peat fertility of the Scottish Borders fens corresponds to the secondary axis of floristic variation, which is orthogonal to (and therefore largely independent of) the base-richness gradient (chapter 4). Phytometric fertility and concentrations of phosphate anions in interstitial water show no significant ($p<0.05$) correlation with pH, suggesting that pH has little value as an indicator of the nutrient status of fens. However pH is significantly correlated with nitrate concentrations and peat fertility is significantly correlated with water calcium concentration, probably because of the application of lime to surrounding agricultural land. Some of the greatest peat fertility values in the Scottish Borders fens were recorded from the inflows and edges of sites surrounded by land used intensively for agriculture.

As a general rule, in British fens and in the Scottish Borders fens, plant communities which are most species-rich and those which contain most rare species are confined to low fertility environments (Wheeler 1988, Shaw & Wheeler 1991). The species-richness of vegetation in the Scottish Borders fens was significantly negatively correlated with fertility and calcium concentrations. The plant communities associated with the lowest average peat fertility were the species-rich small sedge flush community, the mixed sedge rich fen community, *Molinia caerulea* wet grassland and the *Carex diandra - Sphagnum contortum* community. Enrichment by agricultural nutrients is detrimental to such species-rich communities (Wheeler 1993).

7.1.2 WATER LEVELS AND WATER MOVEMENT

Wheeler (1993) found that the number of characteristic fen species within fen vegetation is not correlated with water table and that most fen phanerophytes can be grown in garden conditions without supplementary watering. The restriction of some fen plants to waterlogged sites may be due more to their competitive exclusion from drier sites than to their requirement for waterlogged conditions (Ellenberg 1954). Microtopographical zonation occurs within some plant communities in the Scottish Borders fens where different components of the vegetation occur as a small scale mosaic of hummocks and hollows, occupying areas subject to contrasting water conditions.

The effect of water movement on the ecology of fens has proved difficult to study although its potential significance has been emphasised by some workers (e.g. Kulczynski 1949). Water flow may help to supply nutrients to plants in soakways (Ingram 1967). It may also lead to better aeration of the substratum. In British fens soligenous fen soils have higher redox potentials than other fen soils (Shaw & Wheeler 1991). This may explain the occurrence of typically dryland plants (e.g. *Briza media*) in spring-fed fens. The distribution of typical fen plants within fens may be attributable to the aeration of the substratum as some species are intolerant to strongly reducing soil conditions (e.g. *Molinia caerulea* (Webster 1962)) and typical fen plants show considerable variation in their tolerance of high concentrations of reduced iron (Snowden &Wheeler 1993). Most of the Scottish Borders fens have inflows and outflows, and many sites appear to be fed by marginal springs discharging into the basin so these systems are topogenous (developed in basins) but there is some water movement through them. These fens have been classified as 'percolating fens' (Succow & Lange 1984). The importance of the marginal springs to the hydrodynamics of these Scottish Borders sites has not been quantified.

7.1.3 MANAGEMENT HISTORY AND HYDROSERAL SUCCESSION

The present vegetation of the Borders fens has developed through:

- Unmodified succession since the Late glacial;
- The re-vegetation of peat cuttings;
- The re-vegetation of areas which have been recently modified in pond-creation schemes.

7.1.3.1 Extraction of peat and marl

Former peat and marl cuttings have re-vegetated in two different ways:

1. Where drainage has remained effective the vegetation has colonised the base of the peat cutting, often several metres beneath the former peat surface. Fen meadow and rush pasture are frequently found in these areas, and swamp and species - poor fen vegetation in areas with standing water, which are unmanaged and subject to nutrient enrichment. In areas where there are strong springs the substratum has been colonised by species-rich small sedge flush vegetation.
2. Where the drains are blocked or ineffective the vegetation has developed as a quaking raft over fluid mud. Rafts support vegetation ranging from species-poor communities to *Carex rostrata* based rich-fen to poor-fen with abundant *Sphagnum* species. One former peat cutting supports embryonic raised bog vegetation with *Sphagnum papillosum* and *Eriophorum vaginatum*.

7.1.3.2 Hydroseral succession and the occurrence of Sphagnum *- rich vegetation*

Many fen sites in the Scottish Borders fens have developed hydroserally, through the colonisation of open water. The pathways of hydroseral succession in British fens have been described by Walker (1970). Bog vegetation is usually the climax community resulting from autogenic hydroseral succession in fens. Un-modified stratigraphic sequences in the Scottish Borders fens show the succession of open water → aquatic communities → fen → bog. In many of the Scottish Borders fens hydroseral succession has also taken place over former peat and marl cuttings within the last 200 years. A range of plant communities occur in former peat and marl cutting in the Scottish Borders fens but the development of *Sphagnum* rich vegetation is of particular interest.

The occurrence of *Sphagnum* coincides with base-poor surface water (chapters 4 & 5). However, in these areas at depth the water is not consistently different from that at sites which do not contain *Sphagnum*. This is true at sites believed to be former peat cuttings and also beneath the bog vegetation in undisturbed peat at Long Moss. The occurrence of *Sphagnum* dominated communities is therefore not simply a function of less base-rich groundwater but a developmental phase controlled by other factors. Potentially all sites in the Scottish Borders fens could probably develop *Sphagnum* rich vegetation.

Different species of *Sphagnum* characterise different communities. The two most widespread *Sphagnum* communities in the Scottish Borders fens are the *Carex diandra - Sphagnum contortum* community and the *Carex rostrata - Sphagnum recurvum* community. The former community is encountered in small sites which appear to be subject to strong inputs from marginal springs and where the raft is 'grounded' so the distance from the vegetation surface to 'solid' peat is usually less than 150 cms and the vegetation surface may be subject to periodic flooding by base-rich waters from beneath the raft (Whitehaughmoor Moss, Woolaw Loch, Beanrig Moss, Wester Branxholm Loch. Brown Moor Heights). The *Carex rostrata - Sphagnum recurvum* community is commonly found in larger sites, or nearer the centre of sites in areas which do not appear to have strong inputs from marginal springs. In these areas the vegetation is developed as a "floating" raft where the solid substratum lies more than 150 cms beneath the vegetation surface (Nether Whitlaw Moss, Greenside Moss, Buckstruther Moss, Brown Moor Heights, Groundistone Moss, Hutlerburn Loch). It therefore appears that basin topography, combined with the influence of marginal springwater and frequency of periodic flooding are the main factors determining the development of *Sphagnum* vegetation types in these systems. Except where there are major external inputs of nutrients which exert an effect on the vegetation, the differences in chemistry detected between vegetation types appear to occur as a *result* of the vegetation development, in particular the development of *Sphagnum* rich communities, rather than the chemical conditions being a controlling factor in the development of different vegetation types. Basin shape and the influence of marginal springs may also have been of primary importance in determining the vegetation development in the post-glacial period, leading to the differences in peat types and stratigraphic sequences presently found in undisturbed and residual peat deposits in the Scottish Borders fens (chapter 3).

The pattern of hydroseral succession in the Scottish Borders fens where peat formation is most rapid in central areas contradicts some widely accepted models of hover colonisation and littoral colonisation. The mechanisms of *initiation* of raft formation and central thickening do not appear to be satisfactorily explained by existing theories (chapter 5). Greater fluctuation of the water table *relative to the vegetation surface* at the edges of the site, where the raft is firmly anchored to the edge, than in the centre of the site may be responsible (through differential rates of decomposition) for the pattern of raft thickening at the centre of sites described from Scottish Borders fen sites (chapter 5). Once this pattern is established then positive feedback processes may be expected to re-enforce the faster development of the central area through isolation from telluric water, diversion of water flow by the central peat plug, etc.. (Kulczynski 1949, Moore & Bellamy 1974).

7.1.4 MANAGEMENT OF FEN SITES FOR NATURE CONSERVATION

Important factors in the maintenance of the conservation interest of the Scottish Borders fens are the management of fen sites (by grazing) and the management of fen catchments to prevent further nutrient enrichment (chapters 4 & 6).

The past extraction of peat and marl has been important in determining the present vegetation at most fen sites in the Scottish Borders. Successional sequences can be reinitiated by the re-excavation of peat-cuttings and, elsewhere, this form of management is potentially important for the conservation and restoration of some rich-fen plant communities and species (e.g. *Liparis loeselii*) which are confined to a particular phase in the hydrosere (Wheeler 1993). The range of vegetation types present in the Scottish Borders fens today indicate the potential of the methods of drainage and peat cutting for the manipulation of vegetation. Bog vegetation, often regarded as a successional "climax" community with abundant *Sphagnum papillosum* and *Eriophorum vaginatum,* has developed at one site, abandoned in the 1830s. However the communities present in the Borders fens have also been affected by other factors such as nutrient enrichment and grazing / mowing and the initial conditions for the re-vegetation of peat cuttings is often unknown as are the actual processes of raft formation. The size and depth of peat cuttings were found to be important in determining the vegetation which colonised abandoned peat-cutting in Irish Bogs (White 1930). Trials investigating the roles of methods of drainage and re-flooding, the size of peat pits and the practices of returning the turf to the cutting (shoeing the moss) in the re-vegetation of peat-cuttings would be useful in monitoring the potential of this method for fen vegetation restoration. Vegetation rafts often establish over former peat cuttings and sometimes these rafts contain species characteristic of soligenous flushes occurring on solid peat substrata (Wheeler 1993). These species are often scarce and a target for species conservation (Wheeler 1988). Their occurrence may be due to the maintenance of a constant water table at the vegetation surface through the hydrostatic environment of a vegetation raft (Giller & Wheeler 1986). This may be similar to the environment at the vegetation surface in a habitat subject to continuous telluric discharge.

7.1.5 EXTERNAL VERSUS INTERNAL CONTROLS ON VEGETATION DEVELOPMENT

The template for vegetation development is the initial state of the site prior to colonisation and primary succession. In sites which have been disturbed by peat and / or marl extraction this state is that at abandonment. This template may be altered through time, the water regime may change, for example the site may become wetter as drains become blocked, and the environment may be altered by colonising species through the alteration of the vegetation structure (microtopography) (Van Wirdum 1991) or the alteration of the chemical environment at the vegetation surface favouring the establishment of particular species (Glime *et al.* 1982).

Therefore variation in chemistry and vegetation structure within sites can be caused by internal factors, (e.g. discharge of springs, mineralization rates, nitrogen fixation by roots of leguminous plants, increase in deposition of litter) and external factors (e.g., increased nutrient inputs near site boundaries and inflowing drains, fouling by animals (e.g. seagull populations, ducks), site management (mowing or grazing)).

7.2 Conservation Importance of the Scottish Borders fens

The Scottish Borders fens are characterised by a number of features seldom found in combination elsewhere in Britain. These include:

- Wide range of characteristic and rare fen vegetation types and habitats;
- Populations of nationally rare and nationally scarce plant species including Red Data Book species; *Calamagrostis stricta* and *Hierochloë odorata* and abundant populations of the nationally scarce sedge *Carex diandra*;
- Examples of clear macrotopographical and microtopographical vegetation zonation;
- Quaking rafts of vegetation;
- Documented management histories;
- Peat deposits showing continuous and truncated sequences since initiation during the late-glacial period (Webb & Moore 1982, Tight 1987);

- Basal deposits from the Late Devensian, Allerød interstadial (Webb & Moore 1982);
- Concentration of sites in a small area and the existence of "complexes" of sites.

7.2.1 CONSERVATION GOALS

The goals of conservation should include the protection of a range of sites selected to be representative of all aspects of the ecology of the Scottish Borders fens. This requires the conservation of sites which represent the full range of:

- Wetland habitats with examples of each type in different and comparable situations;
- Baseline water chemistry from base-rich to base-poor and including examples along a gradient of nutrient enrichment;
- Documented management history and / or evidence of this;
- unmodified postglacial peat deposits;
- Distinct vegetation zonation (microtopographical and macrotopographical);
- Plant species characteristic of wetland plant communities and nationally and locally rare species;
- Animal species characteristic of wetlands and nationally and locally rare species;
- Catchment land-use;

Table 7.1 summarises the vegetation resource, the physical features and the management history documentation for each site included in the general survey. In terms of selecting sites to represent fully and understand all aspects of the ecology of the Scottish Borders fens (within the scope of this survey) the following rationale is suggested:

1. Select all sites with a recorded management history (with examples containing structures relating to their management history, e.g. stone drains, and associated stonework);
2. Select all sites containing unmodified peat profiles;
3. Select all sites containing rare species and rare communities;
4. Select all sites showing distinct micro- and macro- topographical vegetation zonation;
5. Check the set of sites for representation of biodiversity (use the set for 5 representations of notable wetland species as a template) and for representation of catchment land use and catchment management scores.

On this basis a set of at least 48 out of 68 sites is required. It must be emphasised that this takes no account of other species groups for example birds, invertebrates for which different factors

Table 7.1. Summary of the features of the Scottish Borders fens. Sites in italics are those required to represent all notable mire species at least 5 times including 16 sites already designated as nature reserves. * denotes sites required in combination to represent all aspects of the ecology of the Scottish Borders fens.

		Plant species		*Vegetation*						*Features*				
Site name	*Located within E.S.A. boundary*	*Nationally rare species*	*Regionally rare species*	*Rich fen*	*Poor fen*	*Bog*	*Species-poor fen*	*Carr*	*Rare plant communities*	*Distinct Zonation*	*Up-welling springs (well-eyes)*	*Springs*	*Un-modified stratigraphy*	*Recorded History*
*Adderstonelee Moss SSSI**		✓		✓			✓	✓	✓			✓		
*Ashkirk Loch SSSI**	✓	✓	✓	✓			✓		✓	✓	✓	✓		
*Beanrig Moss NNR**	✓	✓	✓	✓				✓	✓	✓		✓		
Beeswood Moss	✓						✓							
Berry Moss	✓							✓						
Bitchlaw Moss				✓			✓							
Blackcraig Moss	✓			✓			✓							
*Blackpool Moss NNR**	✓	✓	✓	✓			✓	✓						✓
*Blind Moss SSSI**		✓		✓		✓	✓		✓	✓		✓	✓	✓
Boghall Moss*	✓						✓				✓	✓		
Boosmill Moss	✓			✓			✓							
*Borthwickshiels Loch**							✓							✓
*Branxholm Wester Loch SSSI**		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	
*Brown Moor Heights pSSSI**	✓	✓	✓	✓		✓			✓	✓		✓	✓	
*Buckstruther Moss SSSI**					✓				✓					
Cavers Long Moss				✓			✓							
Clerklands Moss	✓						✓							
*Curdyhaugh Moss**	✓			✓			✓							✓
Dry Moss	✓						✓							
*Dunhog Moss SSSI**	✓	✓	✓	✓			✓	✓	✓	✓				
Fluther Moss				✓			✓							
Greenside Moss*	✓	✓	✓	✓	✓		✓		✓	✓				
*Groundistone Moss**	✓				✓	✓	✓	✓	✓					✓
Haining Moss	✓							✓						
Hall Moss*	✓	✓	✓	✓					✓					✓

table 7.1 cont.

Site name	Located within E.S.A. boundary	Plant species: Nationally rare species	Plant species: Regionally rare species	Vegetation: Rich fen	Vegetation: Poor fen	Vegetation: Bog	Vegetation: Species-poor fen	Vegetation: Carr	Vegetation: Rare plant communities	Features: Distinct Zonation	Features: Up-welling springs (well-eyes)	Features: Springs	Features: Un-modified stratigraphy	Features: Recorded History
*Harden Moss**							✓							✓
Hare Moss	✓						✓							
Hartwoodburn Moss*	✓		✓				✓							
Highchesters Moss							✓							
*Hummelknowes Moss SSSI**			✓	✓			✓	✓	✓		✓	✓		
Huntley Moss*							✓							✓
*Hutlerburn Loch**			✓	✓	✓	✓			✓	✓			✓	
*Kippilaw Moss**		✓		✓			✓	✓	✓	✓				
*Ladywoodedge Moss**	✓	✓	✓	✓					✓		✓			
Lilliesleaf Moss	✓						✓	✓						
Lionfield Moss							✓							
Little Moss							✓	✓						
*Long Moss SSSI**	✓	✓	✓	✓		✓	✓		✓	✓			✓	✓
*Mabonlaw Moss**				✓					✓	✓				✓
*Muirfield Moss**	✓	✓	✓	✓					✓			✓		
*Murder Moss NNR**	✓	✓	✓	✓			✓	✓	✓		✓	✓		✓
*Nether Whitlaw Moss SSSI**	✓	✓	✓		✓		✓	✓	✓	✓				✓
Newhouse Moss	✓						✓							
*Pickmaw Moss**	✓		✓				✓							
*Riddellshiel Moss**	✓	✓	✓	✓			✓							
Rotten Moss*	✓			✓				✓						
*Sea Croft Moss**			✓	✓			✓		✓					
Selkirk Hill Moss*	✓	✓	✓				✓							
*Selkirk Pot Loch**	✓	✓	✓				✓							✓
*Selkirk Race Course Moss SSSI**	✓	✓	✓	✓			✓	✓	✓	✓		✓		
Shielswood Loch				✓			✓							

table 7.1 cont.

Site name	Located within E.S.A. boundary	*Plant species* Nationally rare species	Regionally rare species	*Vegetation* Rich fen	Poor fen	Bog	Species-poor fen	Carr	Rare plant communities	*Features* Distinct Zonation	Up-welling springs (well-eyes)	Springs	Un-modified stratigraphy	Recorded History
*St. Leonards Moss**			✓	✓			✓	✓	✓					
Stoneyford Moss*	✓			✓			✓							✓
Stouslie Pool	✓			✓			✓							
*Synton Courses Loch**	✓						✓							✓
Synton Loch*	✓						✓							✓
Tandlaw Moss*	✓		✓				✓	✓						
*Tathyhole Moss**	✓						✓							
Threephead Moss*			✓	✓					✓	✓				
Tocher Lodge Moss							✓							
Todshawhill Moss*							✓							✓
Whitehaughmoor Moss W*	✓		✓	✓			✓		✓					
*Whitehaughmoor Moss E**	✓	✓	✓	✓					✓	✓		✓		
Whitehaughmoor Moss M*	✓		✓	✓					✓			✓		
*Whitmuihall Loch SSSI**	✓		✓	✓			✓							✓
Whitmuir Moss*	✓						✓	✓						
*Woolaw Loch**	✓	✓		✓	✓		✓		✓	✓		✓		
Woolaw Moss*	✓			✓										✓

Figure 7.1. Boundary of the Central Borders Environmentally Sensitive Area which includes 45 of the 68 Scottish Borders fens included in this study.

may be important. Many of the Scottish Borders fens support rich assemblages of rare water beetles and some are protected on the basis of this interest (e.g. Buckstruther Moss).

Practically, particularly in the Scottish Borders where the sites often lie in close proximity and have overlapping catchmnents, it is desirable to protect complexes of sites especially where the surrounding land can be included as a buffer zone. A substantial area of the Central Scottish Borders already lies within an Environmentally Sensitive Area (ESA) (figure 7.1) which affords some protection to fen sites and their catchments if the land-owner or tenant participates in the scheme. Presently 45 of the sites included in this survey lie within the Central Borders ESA boundary including the Whitlaw Mosses NNR and some of the Drinkstone Hill complex of sites (on the site of the former Wilton Common). This area includes sites which contain a number of contrasting fen types and vegetation types some of which are of primary importance for the maintenance of biodiversity and rare species populations (chapter 6) but the boundary of the present E.S.A. excludes Harden Moss, Mabonlaw Moss and Threephead Moss. Many of these sites have a well documented management history making them ideal for comparative studies on the impact of management history on fen vegetation development.

7.3 Conclusions

- The Scottish Borders fens are an important series of British fen sites, supporting a range of fen plant communities, many of them rare, and significant and often abundant populations of characteristic, scarce and rare fen plant species. The conservation and management of these sites is necessary to maintain biodiversity and populations of target species and to improve understanding of the impact of management history on processes of fen vegetation development.

- Most of the Borders fens have been modified to a varying extent by peat and marl extraction. Documentary evidence suggests that different sites were cut to a different extent due to the size, shape, quality of peat and ease of drainage. Where the site was easily drained and contained deposits of a very good quality the peat and marl deposits were completely stripped away. At other sites the deposits were only partially removed and a few examples of intact areas exist.

- Un-modified peat stratigraphic sequences from mire initiation during the late-glacial to the present exist at Blind Moss, Branxholm Wester Loch, Long Moss and Brown Moor Heights.

There is no evidence of un-modified stratigraphic sequences at the Whitaw Mosses NNR. Basal Deposits are intact at many sites and often include late-glacial deposits within basal blue-grey clays (Webb & Moore 1982).

- Water chemistry exhibits a high degree of vertical variation in the Scottish Borders fens. The relationship of water chemistry to vegetation is rather general with an axis representing a gradient of base-richness corresponding to the primary axis of floristic variation, and a second axis, orthogonal to that of base-richness, representing a nutrient richness gradient. There are few consistent statistically significant relationships between chemical variables and vegetation types indicating the lack of an absolute causal relationship between the water chemistry and the development of vegetation in the Borders fens. Except in extreme cases of nutrient enrichment and spring discharge it is likely that the differences in water chemistry are a result of other factors influencing the vegetation, for example the establishment and autogenic development of vegetation rafts.

- Hydroseral succession follows a pattern contrary to that widely described from other areas. The thickest rafts are always found nearer the centre of sites; thin rafts and pools can be found in all areas, and hydroseral sites are often surrounded by a lagg of treacherous swamp vegetation with the most stable areas near the centre. These features may be affected by basin size and shape, the steepness of the basin sides, grazing of the margins by cattle, and the nature of the colonising vegetation and the method of colonisation. It is possible that the sites do not represent successional sequences resulting from the direct colonisation of open water, but more complicated events, for example the colonisation of a bare peat surface followed by reflooding and the detachment of rhizomes to form a floating raft.

- There are few strictly ombrogenous areas in the Scottish Borders fens. Some 'raised bog vegetation' occurs at Branxholm Wester Loch, Long Moss, Blind Moss, Brown Moor Heights and Hutlerburn Loch, on solid peat which is believed to be un-disturbed. There is only one example in the Scottish Borders fens of embryonic raised bog developing over a former peat and marl cutting (Groundistone Moss). The development of poor-fen communities from rich fen may be affected by the size and shape of the basin. Deeper sites with floating rafts support poor-fen vegetation containing abundant *Sphagnum* species typical of base-poor conditions whereas some shallower sites with grounded rafts support abundant base-tolerant *Sphagnum* species.

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Appendix 1: Site Descriptions

Adderstonelee Moss NT 533 119

A large, fenced, site (12.24ha) surrounded by a mixture of rough pasture and arable fields. The site is drained via a large open outflow and surface drains, some deep occur over the site. *Salix cinerea* and *Betula pubescens* fen carr dominates the centre of the site. This is surrounded by rich-fen vegetation (*Carex lepidocarpa-* brown moss community, *Carex rostrata -Calliergon cuspidatum / Plagiomnium rostratum* community). *Phragmites australis* is sometimes dominant. A small area of *Carex dioica -Carex hostiana* rich-fen occurs on flushed peat at the northwestern margins of the site.

Ashkirk Loch SSSI NT 476 193

A relatively large (5.02ha) steep-sided fen site surrounding a small Loch. Drained by a surface drain from the loch leading to a deep stone-covered outflow (rumbling cundy). The vegetation is mainly open fen dominated by *Carex diandra, Carex lepidocarpa, Carex rostrata* and *Carex lasiocarpa* with a groundflora of *Calliergon spp.*(*Carex rostrata -Calliergon cuspidatum / Plagiomnium rostratum* community) In many areas the water table is permanently high and swamp vegetation dominated by *Phragmites australis* and *Carex rostrata* has developed. On the slopes surrounding the site species-rich *Carex dioica- Carex hostiana* rich-fen vegetation occurs. This site is prone to winter flooding. The surrounding land has been recently developed for forestry and is now ungrazed.

Beanrig Moss NT 517 293

A small site (1.35ha) with areas of quaking fen vegetation and *Salix* scrub. It is drained via a central open drain which discharges into Blackpool Moss to the south. A large area of the site supports plant communities characterised by base-tolerant *Sphagnum species (Carex diandra - Sphagnum contortum* community with *Sphagnum contortum* and *Sphagnum warnstorfii*). Along the western margins there is a small population of *Homalothecium nitens* occurring in an area apparently fed by springs and supporting *Carex dioica - Carex hostiana* rich-fen. The surrounding land is mainly used as improved permanent pasture. Some areas are mown for nature conservation annually during the summer. The site is fenced and ungrazed.

Bees Wood Moss NT 447 232

This small (0.12) circular site supports vegetation dominated by *Menyanthes trifoliata* (*Carex rostrata* species-poor community, *Menyanthes trifoliata* variant) which has developed as a quaking raft. The site is surrounded by forestry plantations of varying ages. The site is drained via an open shallow drain.

Berry Moss NT 491 250

This moderately sized (1.88ha), square site lies within intensively farmed fields. It is wooded with a canopy of *Salix cinerea* and *Salix pentandra* with a sparse understorey of *Carex disticha*, *Carex rostrata* and *Menyanthes trifoliata*. A deep outflow drain leads from the site. The site is unmanaged.

Bitchlaw Moss NT 525 121

A very small site (0.28ha) which is mostly open water with a small amount of Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum rich-fen vegetation developed as a floating raft. The site is fenced and surrounded by steeply sloping rough pasture. A deep drain, now dammed, leads from the site.

Blackcraig Moss NT 502 208

A moderately large(2.66ha), long, thin site surrounded by intensively farmed fields. Most of the site is vegetated with rather rank *Filipendula ulmaria* tall herb fen vegetation although there is a small area of *Carex diandra* dominated rich-fen to the western end. The site is effectively drained by a network of surface drains leading to an open outflow.

Blackpool Moss NT 517 290

This site (3.38 ha) is part of the Whitlaw Moses NNR. *Carex rostrata* and *Carex lasiocarpa* dominated species-poor communities are widespread and often occur as floating rafts. *Phragmites australis* dominated vegetation has developed over silted areas to the northwest. The central area of the site is dominated by *Salix cinerea* and *Salix pentandra* and is very wet. A small area to the northeast supports species-rich rich-fen vegetation but this has become impoverished in recent years (B.D. Wheeler, pers comm). It is drained via a large, deep stone-covered drain (rumbling cundy) and open surface drains. The surrounding land is mainly used as intensive permanent pasture. The site is fenced and ungrazed. Some areas are mown for nature conservation annually during the summer.

Blind Moss NT 458 183

A relatively large site (5.22ha) with an extensive area of raised bog vegetation adjacent to an area of strongly quaking raft vegetation floating on more than 1.5m depth of fluid peat. Marginal vegetation includes rich-fen dominated by *Carex rostrata*, *Carex diandra*, *Carex lasiocarpa* and

Carex lepidocarpa with brown mosses often forming a luxuriant groundlayer. A small population of *Homalothecium nitens* occurs along the northeastern margin. There is a surface drain which flows into the outflow stream. An inflow stream discharges into the southwest of the site. The surrounding land is mainly unimproved pasture which has been recently developed for forestry. The site is grazed.

Boghall Moss NT 491 186

This site (2.09ha) is fenced and surrounded by intensively farmed arable fields and permanent pasture. The vegetation is dominated by *Filipendula ulmaria* over most of the site with an area of *Carex rostrata - Potentilla palustris* species-poor fen vegetation in the centre. The site becomes very dry during the summer months. It is drained via a deep, covered drain. There is a 'well-eye' at the eastern margin.

Borthwickshiels Loch NT 425 153

Recently modified to create a fishing loch, this site is now mainly open water with peripheral species -poor plant communities dominated by *Eleocharis palustris* and *Carex rostrata*.

Branxholm Wester Loch NT 422 110

A large, fenced, site (9.84ha) containing a variety of vegetation types arranged in a distinct centripetal zonation. There is a loch at the northern end and the remainder of the site contains a central area of raised bog vegetation with *Betula* scrub surrounded by *Carex lepidocarpa* - brown moss rich fen, *Carex diandra - Sphagnum contortum* rich-fen and *Carex dioica- Carex hostiana* rich-fen. Well-eyes occur along the mire margins. The surrounding land is little improved with areas of forestry plantation, permanent pasture and moorland. The site is drained via shallow surface streams.

Brown Moor Heights NT 458 247

A small (1.13ha) circular site with distinct centripetal zonation of vegetation types. The central area contains raised bog vegetation surrounded by poor fen vegetation and at the edges rich fen vegetation with base-tolerant *Sphagnum* species (*Carex diandra - Sphagnum contortum* community). Much of the vegetation occurs as a gently quaking raft. The surrounding land is unimproved pasture and the site is grazed. An open outflow drain leads out of the northern end of the site.

Buckstruther Moss NT 540 120

This site is dominated by a quaking raft of *Carex rostrata - Sphagnum recurvum* poor-fen. There is a network of pools over the site with a larger pool at either end. Betula pubescens scrub occurs over the site. The outflow is now dammed. The site is fenced and surrounded by moorland and arable fields.

Clerklands Moss NT 494 253

This fenced site (1.65ha) supports rather rank vegetation with tussocks of *Carex paniculata* and much *Filipendula ulmaria*. Deep, open drains surround the site. The drains flow out of the site into Riddellshiel Loch.

Curdyhaugh Moss NT 504 282

A small site (0.5ha) receiving drainage water from Murder Moss. The site is vegetated with *Carex lepidocarpa* -brown moss rich fen and wet grassland communites. It is surrounded by a mature forestry plantation and is ungrazed.

Dry Moss NT 483 266

A relatively large, fenced, site (6.24ha) surrounded by improved permanent pasture and arable fields. The site is surrounded by deep drains which lead out into a deep outflow. Species-poor plant communities are extensive with *Carex rostrata - Potentilla palustris* fen particularly prominent.

Dunhog Moss NT 474 247

This is a long, thin site (3.03ha)which supports a variety of rich-fen vegetation types around a small central area of 'embryonic' poor-fen with *Salix* scrub. *Carex appropinquata* occurs on this site within the Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum plant community. This site is fenced and the once deep, covered outflow is now partly dammed. The outflow leads to Hare Moss. It is surrounded by improved permanent pasture

Fluther Moss NT 548 123

A small (0.32ha), circular site with much *Juncus acutiflorus* rush pasture. *Carex echinata* and *Carex diandra* occur over part of the site. The site is unfenced and lies within arable fields and is drained via a shallow surface drain.

Greenside Moss NT 518 258

The vegetation at this small site (1.1ha) occurs as a floating raft of vegetation with poor fen dominated by *Sphagnum recurvum* and *Sphagnum fimbriatum* at the centre surrounded by nutrient-enriched rich-fen. A pond along the south edge is used as a duck pond. It is surrounded by a mature forestry plantation and improved fields.

Groundistone Moss NT 498 195

This is a relatively large site (3.84ha) consisting of an area of quaking poor fen dominated by *Sphagnum recurvum* and *Sphagnum fimbriatum* surrounded by *Phragmites australis* swamp and pools of water. There is a small area of embryonic bog vegetation .

A deep outflow drain leads from the site but this is blocked. The surrounding land is intensively farmed as permanent pasture and for arable crops. Some cattle grazing occurs around the mire margins.

Haining Moss NT 467 273

A wooded site (3.17ha) with a canopy of *Salix cinerea* over a rather impoverished understorey with sparse *Carex rostrata* and *Mentha aquatica*. There is a small loch at the eastern end with *Typha* and *Phragmites australis*. The site is fenced and surrounded by improved farmland.

Hall Moss NT 489 197

This small site (1.2ha) supports rich-fen vegetation dominated by Carex lepidocarpa, Carex diandra and Carex rostrata. 'Brown mosses' form a sometimes luxuriant groundcover. The site is surrounded by permanent pasture and is drained via a deep and still effective stone-covered drain. It is unfenced and grazed, mainly by sheep.

Harden Moss NT 449 164

A rectangular site (2.6ha) supporting species-poor swamp plant communities dominated by *Carex rostrata*. Surface drains cross the site but standing water is present most of the year. It is particularly wet around the mire margins. The site is surrounded by a small marginal conifer plantation, rough pasture and moorland.

Hare Moss NT 468 247

This site was recently modified to create a pond habitat and is largely open water with fringing *Carex rostrata* and *Phragmites australis* dominated species-poor plant communities.

Hartwoodburn Moss NT 466 269

A small, fenced, site (0.82ha) with a duck-pond at one end. The species-poor vegetation is dominated by *Phalaris arundinacea*. The surrounding land is improved pasture.

Highchesters Moss NT 463 145

Carex rostrata - Potentilla palustris species-poor fen vegetation dominates this site (1.2ha). It is surrounded by improved pasture and drained via an open drain to the north.

Hummelknowes Moss NT 515 127

A relatively large site (2.83ha) which is designated as an SSSI. There are well-eyes along the northern edge and central development of Salix scrub. At the southern inflow inwashed silt supports dense *Phragmites australis* reedbed vegetation. Species-rich rich fen communities predominate over the rest of the site. It is surrounded by permanent pasture and arable fields and is drained via an open outflow to the east.

Huntley Moss NT 413 248

This small site (0.33ha) supports *Sparganium erectum* and *Agrostis stolonifera* dominated species-poor swamp vegetation. The outflow drain has been dammed. The site is fenced and surrounded by improved permanent pasture.

Hutlerburn Loch NT 420 253

A relatively large (4.43ha), upland site surrounded by rough pasture and grazed by sheep and cattle. There is a loch at the western end with fringing *Phragmites australis*. *Carex dioica - Carex hostiana* rich fen vegetation around the mire margins gives way to *Eriophorum vaginatum - Sphagnum papillosum* bog in the centre.

Kippilaw Moss NT 493 154

A very small (0.76ha) deep site containing central pools surrounded by quaking fen vegetation dominated by *Carex rostrata*, *Carex diandra* and *Carex paniculata*. It is drained by a deep stone-covered outflow drain which is now partly blocked. It is fenced and surrounded by permanent pasture and arable fields.

Ladywoodedge Moss NT 488 256

This site (2.26ha) is dominated by *Filipendula ulmaria* tall herb fen vegetation with a few areas of Carex diandra dominated rich-fen. There are some marginal well eyes and a pool containing *Chara*. A wide drain flows along the western edge of the site to the outflow. It is surrounded by improved permanent pasture.

Lilliesleaf Moss NT 539 251

A large (8.04ha) wooded site with dense *Phragmites australis* dominated vegetation underneath a canopy of *Salix cinerea*. The site is surrounded by intensively farmed arable fields.

Lionfield Moss NT 485 161

This site is mainly open water with some fringing species-poor vegetation dominated by *Eleocharis palustris*. It is surrounded by permanent pasture.

Little Moss NT 540 144

A small (0.71ha), triangular site surrounded by intensively farmed fields. The vegetation is dominated by dense *Phragmites australis.*

Long Moss NT 478 185

This site (2.74ha) contains an central area of *Eriophorum vaginatum - Sphagnum papillosum* raised bog vegetation to the south surrounded by *Carex lepidocarpa* and *Carex lasiocarpa* dominated rich fen vegetation at the edges and abruptly adjoining an area of strongly quaking raft vegetation to the north. There is an open drain to the north. The steep slopes surrounding this long thin site are used as rough pasture. The site is unfenced and grazed by sheep and cattle.

Mabonlaw Moss NT 455 167

A central drain runs though this long thin site (1.64ha) leading to a deep, stone-covered outflow. Wet heath vegetation dominates the northern area of the site. *Carex dioica- Carex hostiana* rich fen occurs around the margins. The slopes surrounding the site are used as rough grazing and the site is grazed by sheep and cattle.

Muirfield Moss NT 504 204

A large site (3.92ha) with a central drain leading to a deep stone-covered outflow drain. The vegetation is predominantly *Carex dioica - Carex hostiana* rich fen vegetation which has colonised the spring fed slopes. There is a small area where the vegetation occurs as a quaking raft. The site is surrounded by unimproved rough pasture and is grazed by cattle and sheep.

Murder Moss NT 504 285

This site (8.9ha) contains areas of quaking fen vegetation dominated by *Carex diandra, Carex lasiocarpa* and *Carex rostrata.* There are also areas of *Salix cinerea* and *Salix pentandra* fen carr, pools and peripheral well-eyes. It is drained via a deep stone-covered outflow drain. *Phragmites australis* dominated reedbed vegetation has expanded over the western end of the site near the inflow. The site is often flooded. It is fenced and surrounded by improved permanent pasture. The vegetation is mown for nature conservation in the summer.

Nether Whitlaw Moss NT 508 294

This long, narrow site (4.23ha) contains a central area of *Sphagnum recurvum* dominated poor fen vegetation surrounded by *Carex rostrata* dominated sedge swamp and rich fen. The entire vegetation surface is strongly quaking. The site is drained by a blocked open drain and receives drainage water from Lindean Reservoir. Surrounding fields are used as permanent pasture and for arable crops.

Newhouse Moss NT 518 234

This site has been recently modified to create a pond. Fringing species-poor vegetation is dominated by *Carex rostrata*.

Pickmaw Moss NT 493 281

Largely open water this fenced site (0.8ha)has fringing species-poor *Carex rostrata - Potentilla palustris* vegetation. It lies within intensively improved farmland.

Riddellshiel Moss NT 501 253

Carex paniculata and *Carex rostrata* dominated species-poor vegetation surrounds a large area of open water. There is a small patch of *Carex acutiformis* dominated vegetation. The site (1.49ha) is surrounded by improved farmland.

Rotten Moss NT 460 170

A small (0.5ha), fenced site supporting *Carex rostrata* and *Carex disticha* dominated rich-fen vegetation with some *Salix cinerea* scrub. The site is surrounded by rough pasture.

St. Leonards Moss NT 483 107

A site containing marginal Carex dioica -Carex hostiana rich-fen vegetation with a central drain leading to a deep stone-covered outflow drain which is now modified with a sluice. *Carex rostrata*, *Carex lepidocarpa* and *Carex diandra* are abundant at this site. It is surrounded by permanent pasture and arable fields. The site is fenced and ungrazed.

Sea Croft Moss NT 478 104

A narrow, fenced site (1.23ha) draining into St. Leonard's Moss. *Carex rostrata, Carex lasiocarpa* and *Eriophorum angustifolium* dominate rich-fen plant communities. There is an area of dense *Carex acutiformis* dominated vegetation near the outflow. The site is surrounded by arable fields.

Selkirk Hill Moss NT 486 285

This site has been recently modified in a pond creation scheme. *Menyanthes trifoliata and Carex rostrata* dominate the fringing vegetation.

Selkirk Pot Loch NT 478 283

This site is largely open water with fringing vegetation dominated by *Carex rostrata* with *Iris pseudacorus* and *Ranunculus lingua*. There is an area of dense *Phragmites australis* to the south. The loch supports *Nuphar lutea*.

Selkirk Race Course Moss NT 498 276

A small (2ha) but interesting site with a central floating island with rich-fen vegetation dominated by *Carex diandra* with luxuriant groundflora of *Calliergon giganteum* and *Scorpidium scorpioides*. The raft is surrounded by a treacherous raft of *Menyanthes trifoliata* and *Carex rostrata. Carex dioica-Carex hostiana* rich-fen vegetation is widespread around the sloping mire margins. The site is surrounded by rough pasture and is grazed by cattle and sheep. A covered outflow leads from the east of the site.

Shielswood Loch NT 453 191

Mainly open water there is a small area of fen along the south side of the loch. This is dominated by *Carex diandra* and *Phragmites australis.*

Stoneyford Moss NT 486 204

This site consists of a network of small hollows supporting species-poor vegetation dominated by *Carex rostrata* and *Deschampsia cespitosa* connected by surface drains which lead to Synton Loch. A small marginal area contains *Carex dioica - Carex hostiana* rich-fen vegetation. The surrounding land is permanent pasture.

Stouslie Pool NT 490 170

A very small site (0.26ha) with species-poor vegetation dominated by *Carex rostrata* and *Carex paniculata* (*Carex rostrata - Potentilla palustris* community). There is an open outflow to the east. The site is surrounded by improved farmland.

Synton Loch NT 483 206

This relatively large (3.19ha) site has been recently dammed to create a loch and consists mainly of open water with fringing *Carex rostrata*, *Equisetum fluviatile* and *Phragmites australis* species-poor vegetation.

Synton Courses Loch NT483 224

A very small site (0.14ha) surrounded by steep slopes. A quaking vegetation raft dominated by *Carex rostrata* fringes open water. The deep stone covered outflow has been partly blocked.

Tandlaw Moss NT 490 177

A large site (5.33ha) which often becomes very dry. Most of the site is dominated by Phalaris arundinacea dominated vegetation. There is a small loch at the western end which is surrounded by *Salix cinerea* scrub and *Carex paniculata* and *Carex rostrata* dominated vegetation (*Carex rostrata - Potentilla palustris* community. The site is surrounded by improved farmland.

Tathyhole Moss NT 475 218

Rather rank, species-poor vegetation dominated by *Filipendula ulmaria* and *Agrostis stolonifera* dominated this small (1.29ha) site. It is surrounded by intensively farmed land and is drained via a central drain leading to an open outflow.

Threephead Moss NT 450 175

This site (0.81ha) is surrounded by unimproved rough pasture. It is unfenced and well drained. The vegetation consists of hummocks supporting wet heath vegetation with runnels in-between supporting *Carex dioica - Carex hostiana* rich-fen.

Tocher Lodge Moss NT 438 231

Largely open water this site has fringing vegetation dominated by *Carex rostrata and Juncus acutiflorus* (*Carex rostrata - Potentilla palustris* community). It has been recently modified and the deep outflow has been dammed.

Todshawhill Moss NT 452 122

The central area of this site (1.3ha) is dominated by species -poor *Carex rostrata* and *Potentilla palustris* dominated vegetation surrounded by *Filipendula ulmaria* tall herb fen vegetation. There is a shallow central pool. The site is surrounded by improved farmland and a small conifer plantation. It is drained via a peripheral drain leading to a covered outflow.

Whitehaughmoor Moss W NT 471 176

A very small site (0.6ha) supporting *Carex diandra* dominated rich-fen vegetation. The site is fenced and ungrazed and is surrounded by rough pasture. It is drained via an open outflow to the south.

Whitehaughmoor Moss E NT 474 176

This small (0.3ha) triangular site contains very species rich-fen supporting the rare bryophytes *Homalothecium nitens* and *Cinclidium stygium*. The *Carex diandra - Sphagnum contortum* rich-fen plant community is well developed here. Surrounding fields are unimproved. The site is fenced and there is a shallow outflow to the south.

Whitmuihall Loch NT 497 272

This is a large site (8.9ha) with a loch at the eastern end, The vegetation is mostly species poor and appears to be nutrient enriched. *Carex rostrata*, *Carex diandra* and *Phragmites australis* are all dominant and often form dense swards. Around the loch there are vegetation rafts dominated by *Agrostis stolonifera* with *Cicuta virosa*. The site is drained via a deep outflow drain to the east. The slopes surrounding the site support woodland to the north and east. Surrounding farmland is improved pasture and rough grazing.

Whitmuir Moss NT 492 269

A wooded site (5.8ha) with a canopy of *Salix cinerea* and an impoverished understorey with *Carex rostrata* and *Mentha aquatica*. Marginal drains lead to an open outflow. The site is surrounded by improved farmland.

Woolaw Loch NT461 173

This small (0.4ha) site supports a floating raft with *Carex diandra - Sphagnum contortum* rich-fen vegetation at the eastern end and *Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* vegetation at the western end. It is surrounded by a mature forestry plantation and has a blocked outflow drain leading from the north of the site. There are nearby springs.

Woolaw Moss NT 465 172

This site (1.73ha) supports mainly *Juncus acutiflorus* rush pasture vegetation. It is surrounded by steep slopes and is drained via surface drains leading to a very deep stone-covered outflow drain. Part of the site has been recently excavated. It is grazed by cattle and is surrounded by improved permanent pasture.

Appendix 2: Locations of sampling sites and transects for detailed investigations into aspects of the ecology of some of the Scottish Borders fens.

A number of contrasting Scottish Borders fen sites were selected for detailed investigations into peat stratigraphy, site chemical conditions and peat fertility and vegetation raft development as described in chapters 3-5 of this study. The locations of transects and sampling sites are indicated in tables A2.2 - A2.14 and fen site sketch maps (figures A2.1 - A2.13). The last five columns in each table correspond to different investigations as indicated in table A2.1. The use of a sample site in each investigation is indicated by a tick symbol (✓). In all cases the sample code indicated in tables A2.2-2.14 is used throughout this study.

Table A 2.1. Codes for different investigations into vegetation development in the Scottish Borders fens as used in tables A2.2-A2.14.

Chapter and investigation	*Code in tables A2.2-A2.14*
Chapter 3: Stratigraphical investigations past peat and marl extraction and vegetation development in the Scottish Borders fens	*Ch.3 strat*
Chapter 4: Relationships between chemical composition of fen waters, peat fertility and vegetation composition	
a) Chemistry of Scottish Borders fen waters	*Ch.4 water chem*
b) Peat fertility	*Ch.4 peat fert*
Chapter 5: Vegetation rafts: composition, development and chemical conditions.	
a) Raft composition and stratigraphy	*Ch.5 rafts strat*
b) Chemical conditions at the raft surface and below the raft	*Ch.5 rafts chem*

The following symbols are used in figures 2.1 - 2.13:

———	Boundary of wetland vegetation.
- - - - - -	Boundary of site (e.g. fence) which does not coincide with the boundary of wetland vegetation.
×	Sampling site.
—+—	Transect and sampling site.
→→ →	Drains, water inflows and outflows.

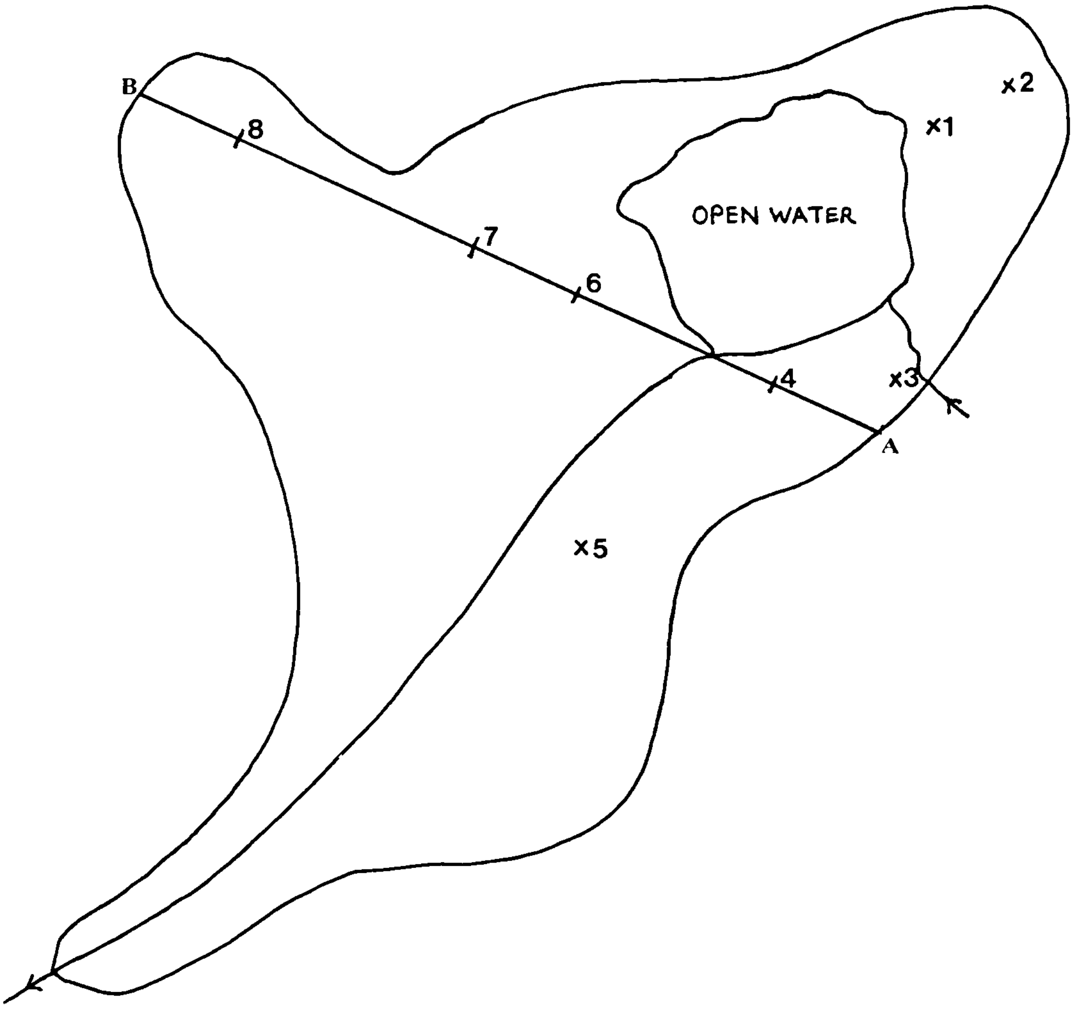

Figure A2.1. Locations of transect and sample sites at Ashkirk Loch. Scale 1:2500 (1cm = 25m).

Table A2.2. Sample sites at Ashkirk Loch, corresponding to the locations marked on figure A2.1. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
AL1	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓		
AL2 (edge)	*Molinia caerulea* wet grassland		✓	✓		
AL3 (inflow)	*Filipendula ulmaria* tall-herb fen		✓	✓		
AL4	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum community, Carex diandra* variant		✓	✓		
AL5	Mixed sedge rich-fen community		✓	✓		
AL6	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
AL7	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum community, Carex diandra* variant		✓	✓		
AL8	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum community, Carex diandra* variant		✓	✓		

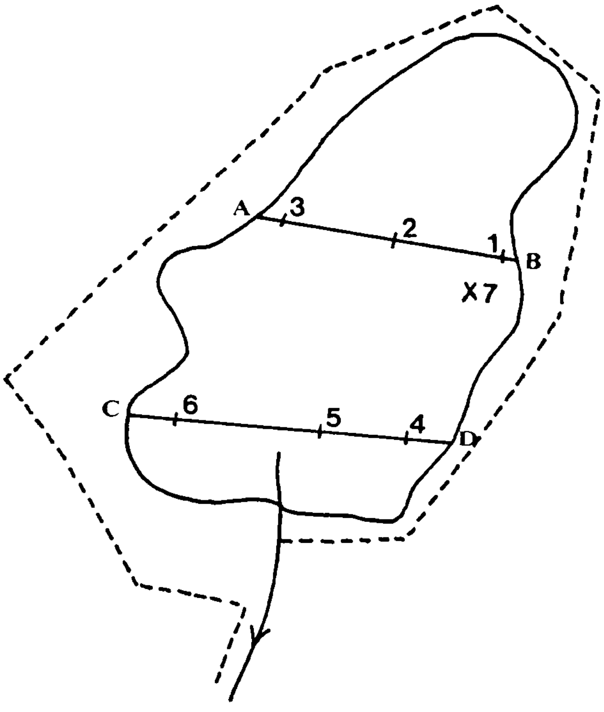

Figure A2.2. Locations of transects and sampling sites at Beanrig Moss. Scale 1:2500 (1cm = 25m).

Table A2.3. Sample sites at Beanrig Moss, corresponding to the locations marked on figure A2.2. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
BE1(edge)	*Carex diandra - Sphagnum contortum* community		✓	✓		
BE2	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum* community, typical variant		✓	✓		
BE3 (edge)	*Carex dioica - Carex hostiana* community		✓	✓		
BE4 (edge)	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum* community, typical variant		✓	✓		
BE5	*Juncus acutiflorus* rush pasture community		✓	✓		
BE6 (edge)	*Carex dioica - Carex hostiana* community		✓	✓		
BE7	*Carex diandra - Sphagnum contortum* community		✓			✓

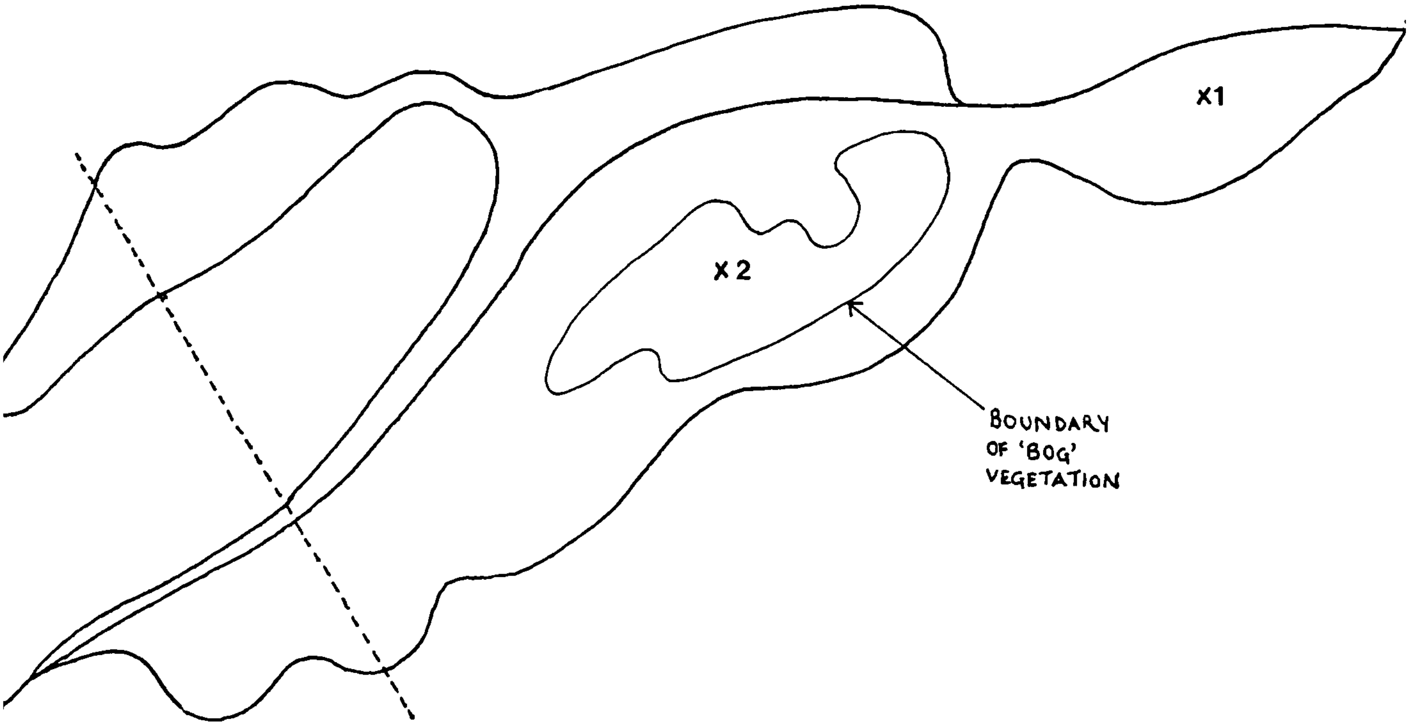

Figure A 2.3. Locations of sampling sites at Blind Moss. Scale 1:2500 (1cm = 25m).

Table A2.4. Sample sites at Blind Moss, corresponding to the locations marked on figure A2.3. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
BL1	*Carex diandra - Sphagnum contortum* community	✓				
BL2	*Eriophorum vaginatum - Sphagnum papillosum* community					✓

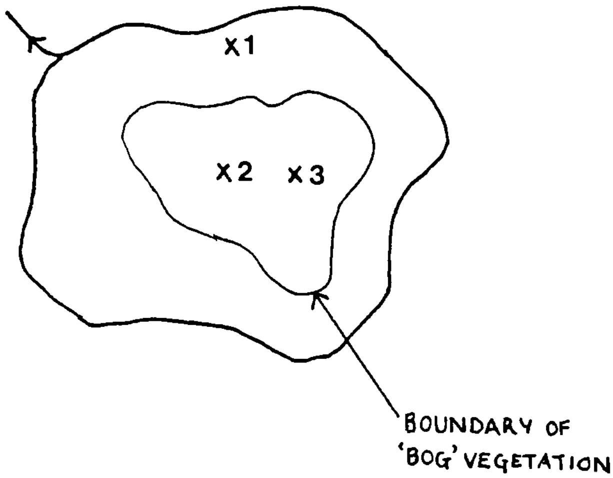

Figure A2.4. Locations of sampling sites at Brown Moor Heights. Scale 1:2500 (1cm = 25m).

Table A2.5. Sample sites at Brown Moor Heights, corresponding to the locations marked on figure A2.4. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
BMH1	*Carex diandra - Sphagnum contortum* community				✓	
BMH2	*Eriophorum vaginatum - Sphagnum papillosum* community	✓				
BMH3	*Eriophorum vaginatum - Sphagnum papillosum* community	✓				

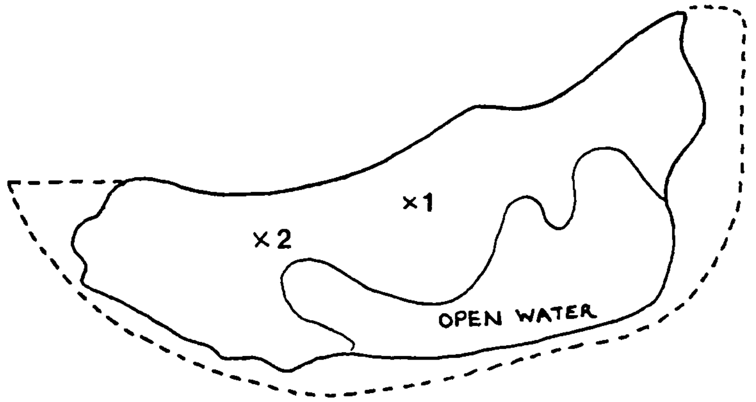

Figure A2.5. Locations of sample sites at Greenside Moss. Scale 1:2500 (1cm = 25m)

Table A2.6. Sample sites at Greenside Moss, corresponding to the locations marked on figure A2.5. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
GREEN1	*Carex rostrata - Sphagnum recurvum community*				✓	
GREEN2	*Carex rostrata - Calliergon cuspidatum / Plagiomnium rostratum* community, typical variant.				✓	

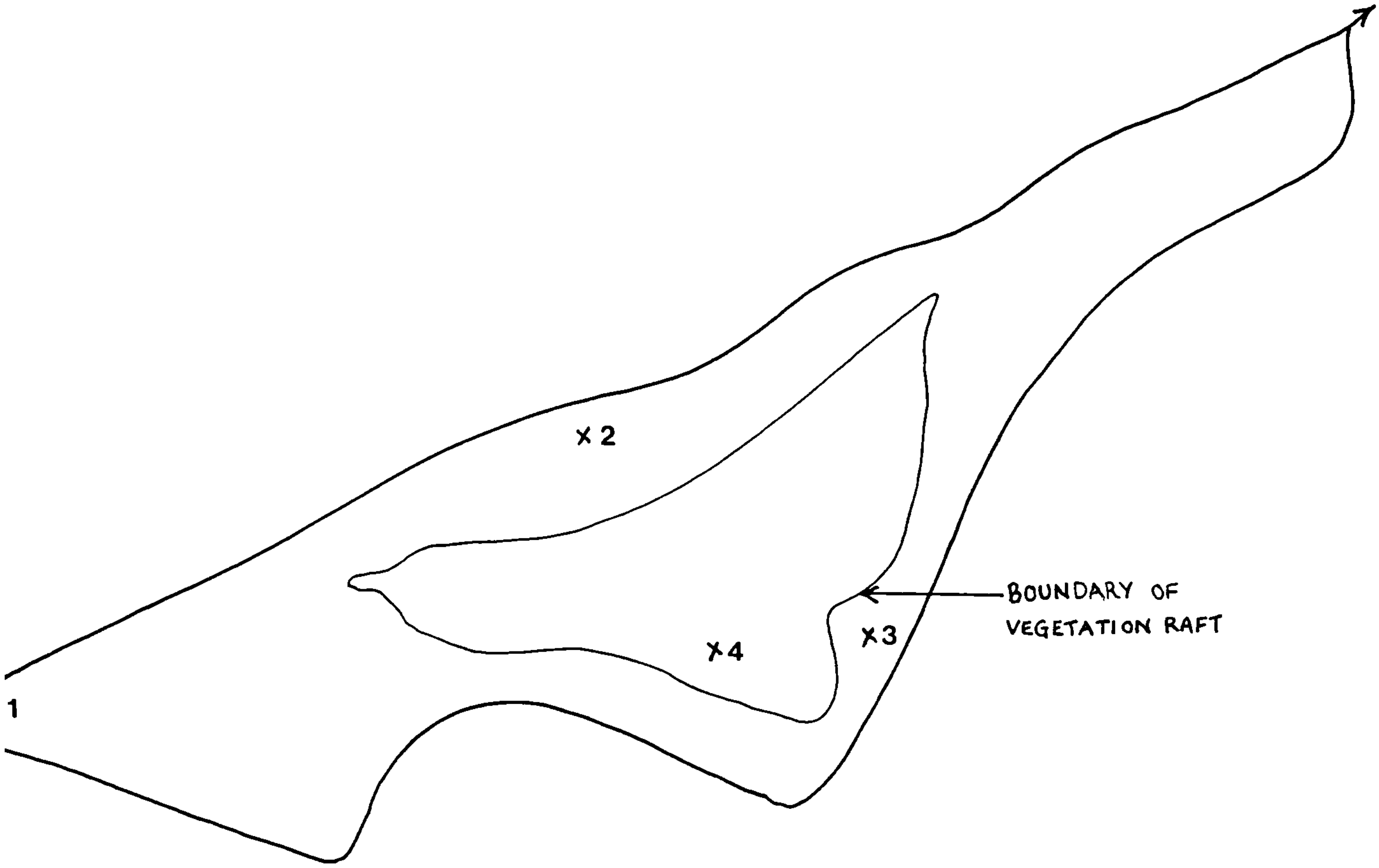

Figure A2.6. Locations of sampling sites at Groundistone Moss. Scale 1:2500 (1cm = 25m).

Table A2.7. Sample sites at Groundistone Moss, corresponding to the locations marked on figure A2.6. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
GM1(inflow)	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
GM2 (edge)	*Phragmites australis* reedbed community		✓	✓		
GM3 (edge)	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
GM4	*Eriophorum vaginatum - Sphagnum papillosum* community	✓				✓

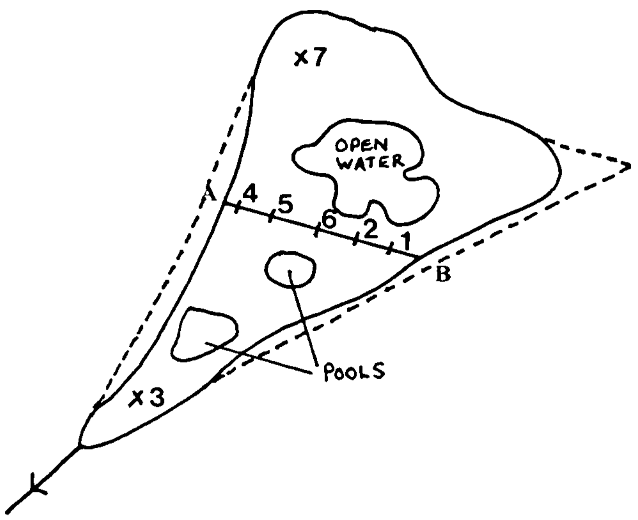

Figure A2.7. Locations of transect and sampling sites at Kippilaw Moss. Scale 1:2500 (1cm = 25m).

Table A2.8. Sample sites at Kippilaw Moss, corresponding to the locations marked on figure A2.7. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
K1(edge)	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓	✓	
K2	*Carex rostrata* species-poor community		✓	✓	✓	
K6	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓	✓	
K5	*Carex rostrata* species-poor community		✓	✓	✓	
K4 (edge)	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓		
K3	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
K7	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		

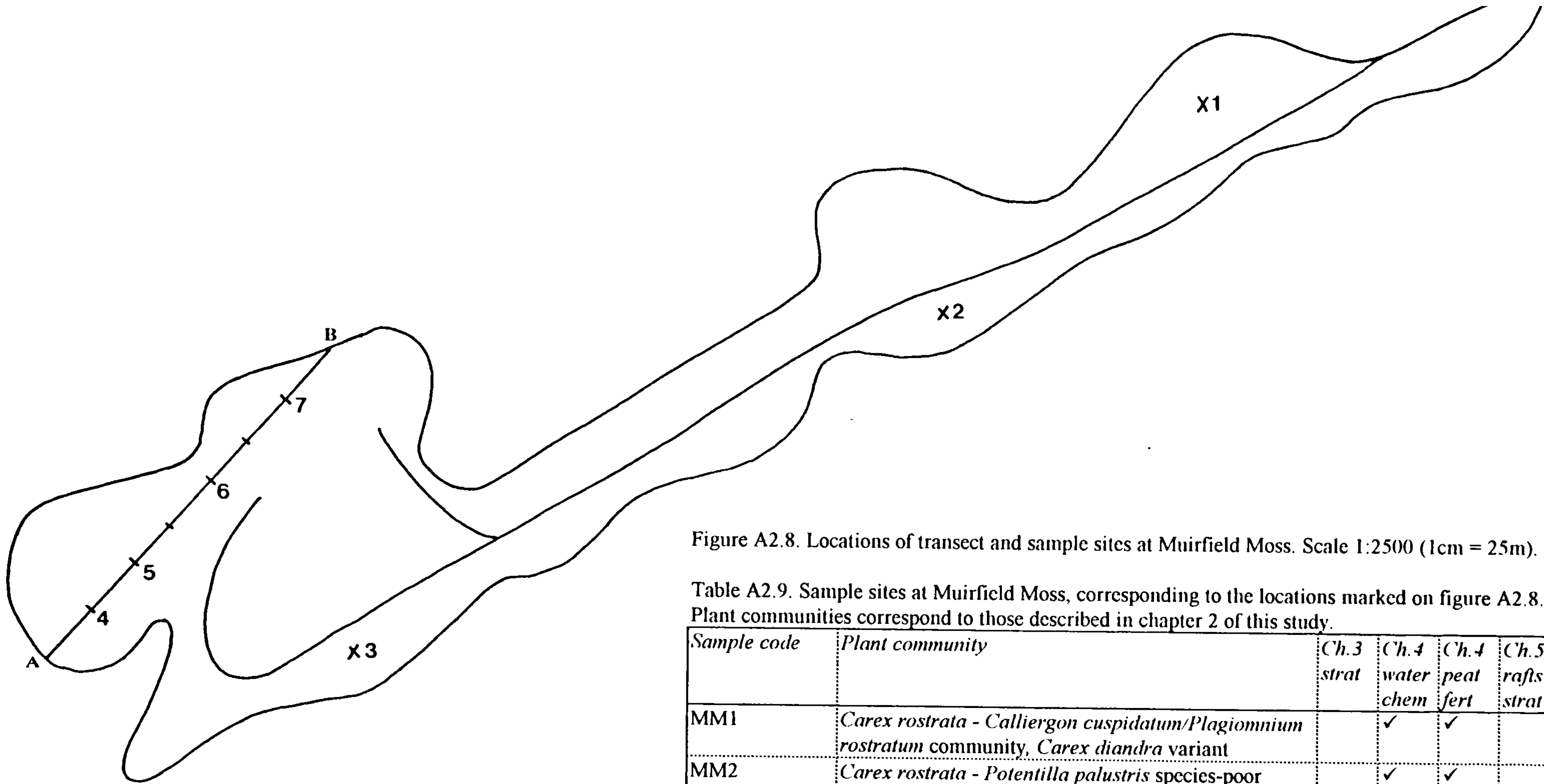

Figure A2.8. Locations of transect and sample sites at Muirfield Moss. Scale 1:2500 (1cm = 25m).

Table A2.9. Sample sites at Muirfield Moss, corresponding to the locations marked on figure A2.8. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
MM1	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓		
MM2	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
MM3	*Juncus acutiflorus* rush pasture community		✓	✓		
MM4 (edge)	*Molinia caerulea* wet grassland community	✓	✓	✓		
MM5	*Carex dioica - Carex hostiana* community	✓	✓	✓		
MM6	Mixed sedge rich-fen community	✓	✓	✓		
MM7 (edge)	*Molinia caerulea* wet grassland community	✓	✓	✓		

Table A2.10. Sample sites at Murder Moss, corresponding to the locations marked on figure A2.9. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
MU1 (inflow)	*Phragmites australis* reedbed community		✓	✓		
MU2 (edge)	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum community*, typical variant		✓	✓		
MU3	Mixed sedge rich-fen community		✓	✓		
MU4	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
MU5	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
MU6 (inflow)	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum* community, typical variant		✓	✓		
MU7	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓		
MU8	*Carex rostrata - Calliergon cuspidatum/Plagiomnium rostratum* community, *Carex diandra* variant		✓	✓		

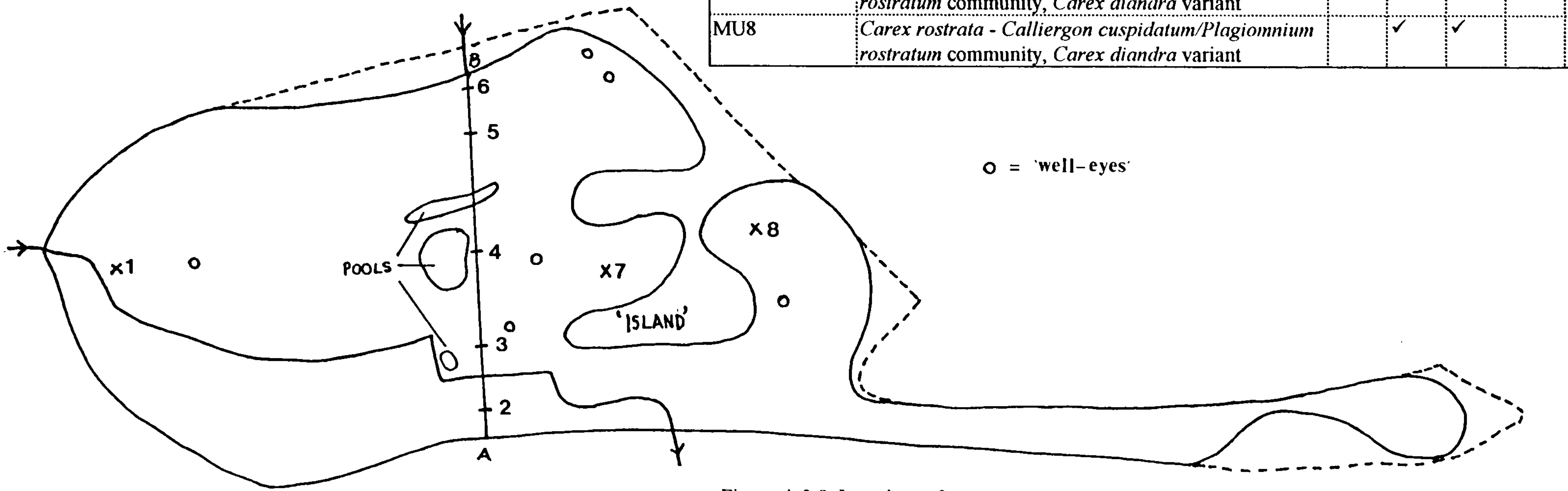

Figure A 2.9. Locations of transect and sampling sites at Murder Moss. Scale 1: 3500 (1cm = 35m).

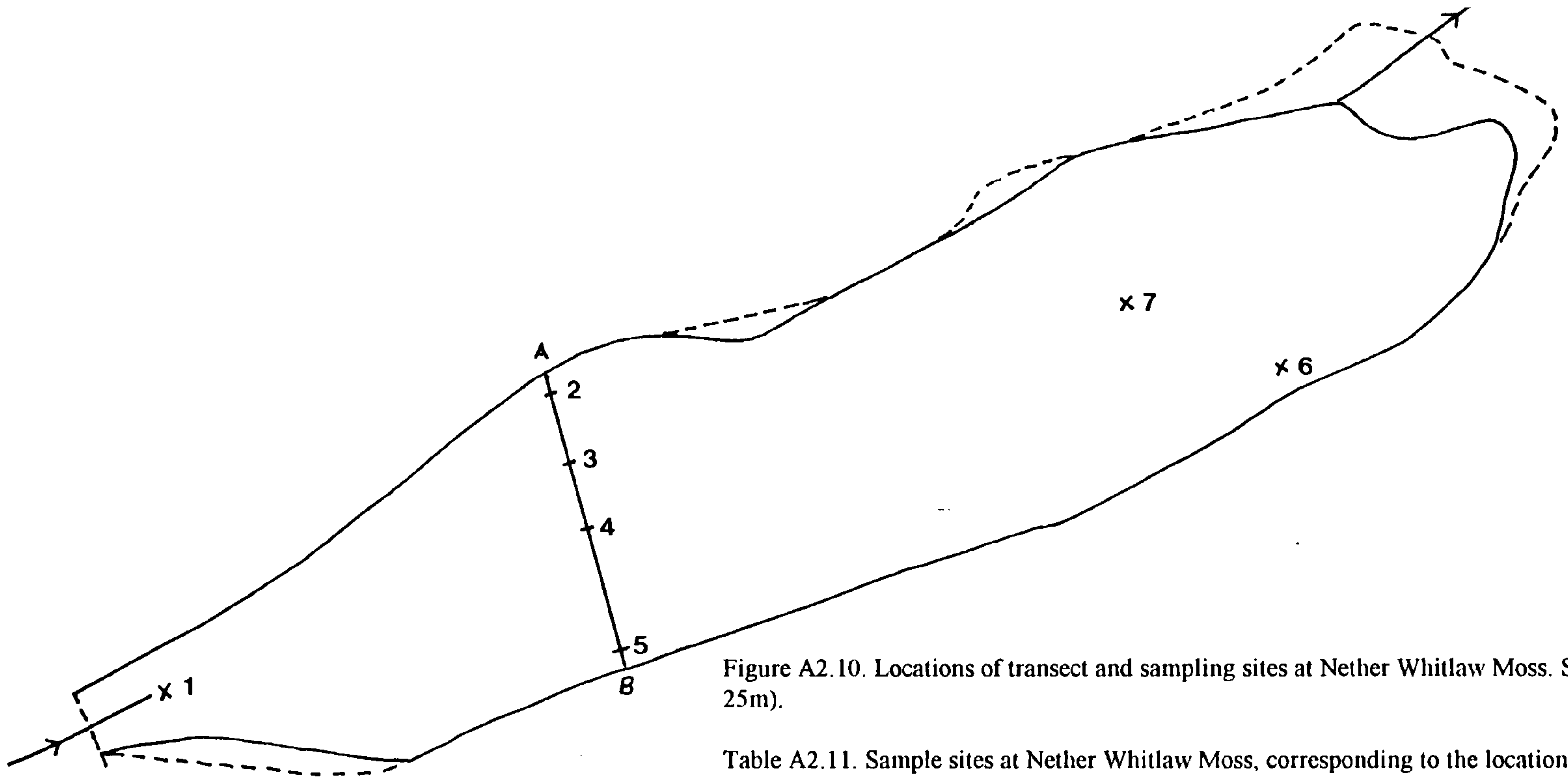

Figure A2.10. Locations of transect and sampling sites at Nether Whitlaw Moss. Scale 1:2500 (1cm = 25m).

Table A2.11. Sample sites at Nether Whitlaw Moss, corresponding to the locations marked on figure A2.10. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
NW1(inflow)	*Filipendula ulmaria* tall-herb fen		✓	✓		
NW2 (edge)	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum* community, typical variant	✓	✓		✓	✓
NW3	*Carex rostrata - Sphagnum recurvum* community	✓	✓		✓	
NW4	*Carex rostrata* species-poor community	✓	✓		✓	
NW5 (edge)	*Carex rostrata - Calliergon cuspidatum, Plagiomnium rostratum* community, typical variant	✓	✓		✓	
NW6 (edge)	*Carex rostrata - Potentilla palustris* species-poor community		✓			
NW7	*Carex rostrata - Sphagnum recurvum* community		✓		✓	✓

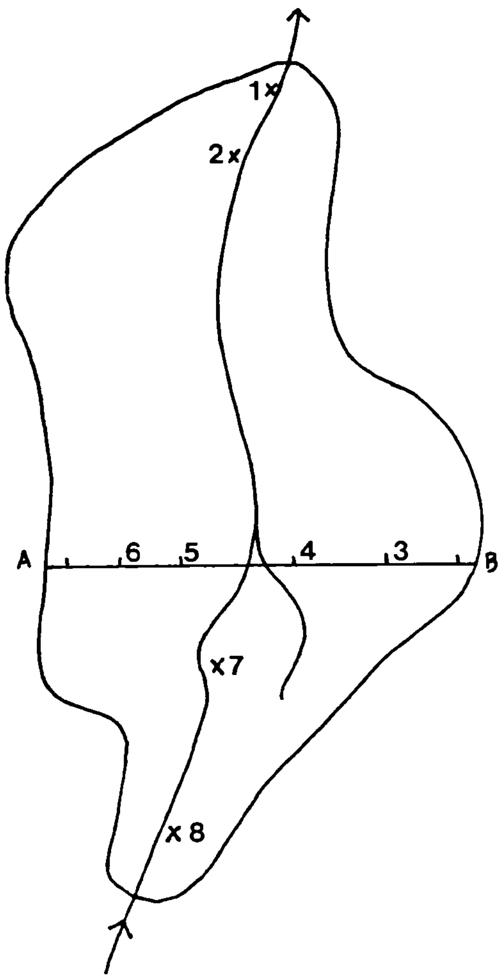

Figure A2.11. Locations of transect and sampling sites at St Leonard's Moss. Scale 1:2500 (1cm = 25m).

Table A2.12. Sample sites at St Leonard's Moss, corresponding to the locations marked on figure A2.11. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
SL1(outflow)	*Carex rostrata* species-poor community		✓	✓		
SL2	*Phragmites australis* reedbed community		✓	✓		
SL3 (edge)	Mixed sedge rich-fen community	✓	✓	✓		
SL4	*Carex dioica - Carex hostiana* community	✓	✓	✓		
SL5	*Filipendula ulmaria* tall-herb fen	✓	✓	✓		
SL6 (edge)	*Carex dioica - Carex hostiana* community	✓	✓	✓		
SL7	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
SL8 (inflow)	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		

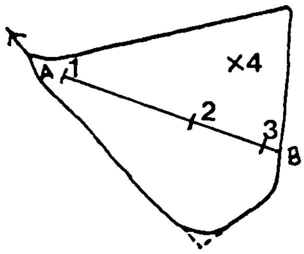

Figure A2.12. Locations of transect and sampling sites at Whitehaughmoor Moss (east basin). Scale 1:2500 (1cm = 25m).

Table A2.13. Sample sites at Whitehaughmoor Moss (east basin), corresponding to the locations marked on figure A2.12. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
WHM1(outflow)	Mixed sedge rich-fen community		✓	✓	✓	
WHM2	Mixed sedge rich-fen community		✓	✓	✓	
WHM3 (edge)	*Carex dioica - Carex hostiana* community		✓	✓		
WHM4	*Carex diandra - Sphagnum contortum* community		✓	✓		✓

Table A2.14. Sample sites at Whitmuirhall Loch, corresponding to the locations marked on figure A2.13. Plant communities correspond to those described in chapter 2 of this study.

Sample code	*Plant community*	*Ch.3 strat*	*Ch.4 water chem*	*Ch.4 peat fert*	*Ch.5 rafts strat*	*Ch.5 rafts chem*
WL1	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
WL2	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
WL3	*Phragmites australis* reedbed community		✓	✓		
WL4 (edge)	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
WL5 (edge)	*Carex rostrata - Potentilla palustris* species-poor community		✓	✓		
WL6 (outflow)	*Phragmites australis* reedbed community		✓	✓		

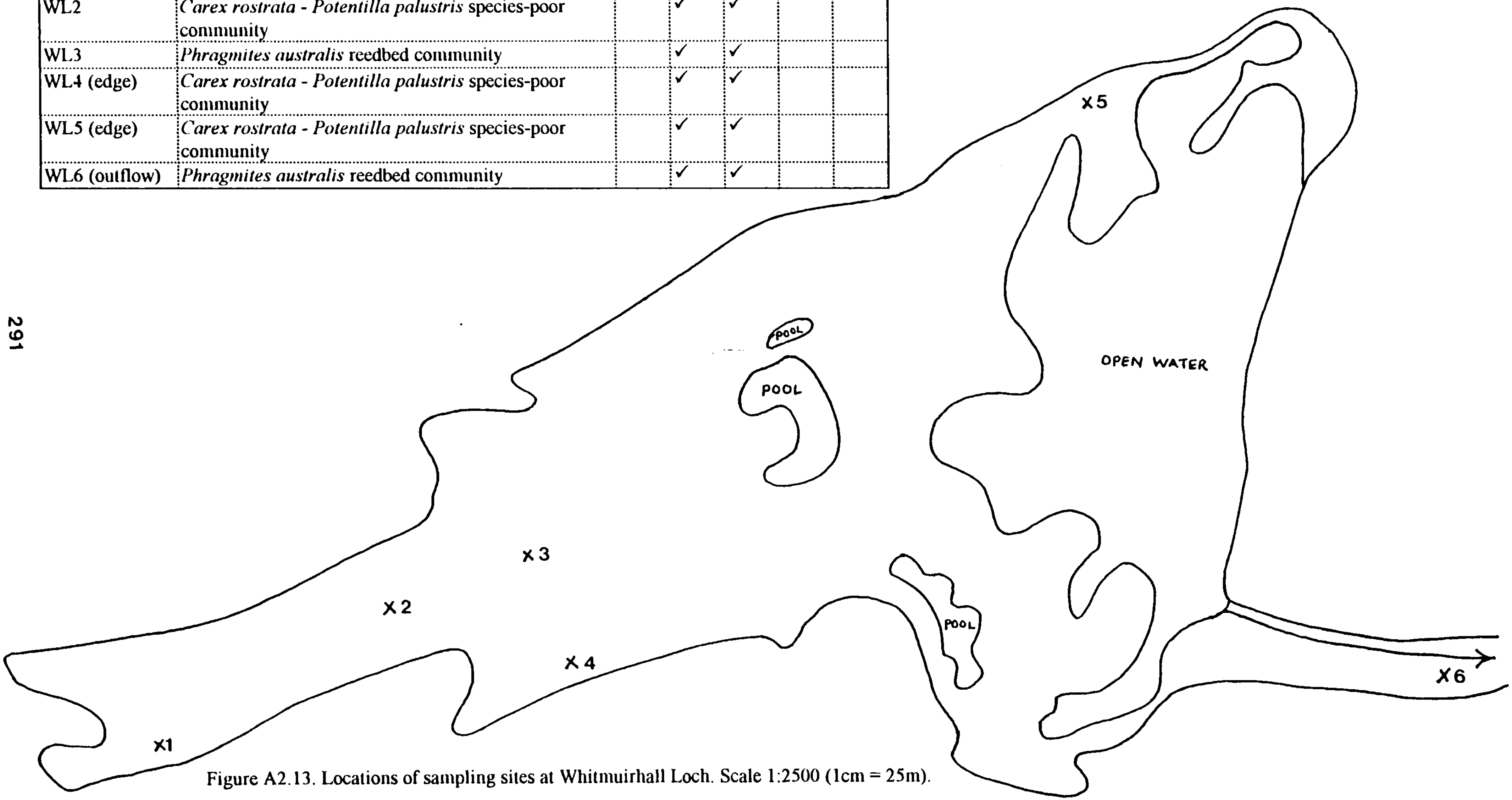

Figure A2.13. Locations of sampling sites at Whitmuirhall Loch. Scale 1:2500 (1cm = 25m).

Appendix 3:

Notable mire species (all rich-fen species (RFS), poor-fen species (PFS), bog species (BGS), rare fen species (RFS)) and nationally and locally rare species recorded in the Scottish Borders fens survey.

Species	*RFS*	*PFS*	*BGS*	*RARE*	*Nationally rare**	*Locally rare**
Alnus glutinosa	X					
Aneura pinguis	X					
Angelica sylvestris	X					
Aulacomnium palustre	X	X	X			
Bryum pseudotriquetrum	X					
Calamagrostis stricta	X			X	X	X
Calliergon cordifolium	X	X				
Calliergon cuspidatum	X	X				
Calliergon giganteum	X			X	X	
Calliergon stramineum		X		X		
Caltha palustris	X					
Campylium stellatum	X	X				
Carex acutiformis	X					
Carex appropinquata	X			X	X	X
Carex curta		X	X			
Carex diandra	X	X		X	X	
Carex dioica	X			X		
Carex disticha	X					
Carex echinata	X	X				
Carex hostiana	X	X		X		
Carex lasiocarpa	X	X		X	X	
Carex lepidocarpa	X					
Carex limosa		X		X	X	X
Carex nigra	X	X				
Carex panicea	X	X				
Carex paniculata	X					
Carex pulicaris	X			X		
Carex rostrata	X	X				
Carex vesicaria	X					
Cicuta virosa	X			X	X	X
Cinclidium stygium	X			X	X	
Cirsium palustre	X					
Climacium dendroides	X					
Corallorhiza trifida				X		
Cratoneuron commutatum	X			X		
Dactylorhiza fuchsii	X					
Dactylorhiza incarnata	X					
Dactylorhiza purpurella	X			X		X
Drepanocladus revolvens	X	X				
Drosera rotundifolia	X	X	X			
Dryopteris carthusiana	X					
Eleocharis palustris	X	X				
Eleocharis quinqueflora	X			X		
Epilobium hirsutum	X					
Epilobium palustre	X	X				
Epilobium parviflorum	X					
Equisetum fluviatile	X	X				
Equisetum palustre	X	X				
Erica tetralix		X	X			
Eriophorum angustifolium	X	X	X			
Eriophorum latifolium	X			X	X	X
Eriophorum vaginatum		X	X			
Filipendula ulmaria	X					
Fissidens adianthoides	X					
Galium palustre	X					
Galium uliginosum	X					
Homalothecium nitens		X		X	X	
Hydrocotyle vulgaris	X	X				
Iris pseudacorus	X					
Juncus acutiflorus	X	X				
Juncus alpino-articulatus	X			X	X	

Appendix 3. cont.

Species	*RFS*	*PFS*	*BGS*	*RARE*	*Nationally rare**	*Locally rare**
Juncus articulatus	X					
Juncus bulbosus	X	X				
Juncus effusus	X	X				
Lychnis flos-cuculi	X					
Mentha aquatica	X	X				
Menyanthes trifoliata	X	X	X			
Molinia caerulea	X	X	X			
Mylia anomala		X	X			
Myosotis laxa caespitosa	X					
Myosotis scorpioides	X					
Narthecium ossifragum		X	X			
Odontoschisma spahgni		X	X			
Parnassia palustris	X			X		
Pedicularis palustris	X	X				
Pellia endiviifolia	X			X		
Phalaris arundinacea	X					
Philonotis calcarea	X			X		
Philonotis fontana	X	X		X		
Phragmites australis	X	X				
Pinguicula vulgaris	X	X		X		
Plagiomnium rostratum	X					
Polytrichum alpestre		X	X			
Potamogeton coloratus	X			X	X	X
Potamogeton polygonifolius	X	X				
Potentilla palustris	X	X				
Pyrola rotundifolia	X	X		X	X	X
Ranunculus flammula	X	X		X		
Ranunculus lingua	X			X	X	X
Rhizomnium pseudopunctatum	X			X	X	
Sagina nodosa	X			X		
Salix cinerea	X					
Salix pentandra	X			X		
Salix repens agg.	X					
Scorpidium scorpioides	X	X		X		
Scutellaria minor	X					X
Selaginella selaginoides	X	X		X	X	
Sparganium minimum	X				X	
Sphagnum auriculatum		X	X			
Sphagnum capillifolium		X	X			
Sphagnum contortum	X	X		X	X	
Sphagnum cuspidatum		X	X			
Sphagnum fimbriatum		X	X			
Sphagnum fuscum			X	X	X	
Sphagnum imbricatum			X	X	X	
Sphagnum magellanicum		X	X			
Sphagnum palustre		X				
Sphagnum papillosum		X	X			
Sphagnum recurvum		X	X			
Sphagnum squarrosum		X				
Sphagnum subnitens	X	X	X			
Sphagnum teres		X		X	X	
Sphagnum warnstorfii	X	X		X	X	
Stellaria alsine	X					
Triglochin palustris	X					
Typha latifolia	X					
Utricularia minor	X			X	X	X
Vaccinium oxycoccos		X	X			
Valeriana dioica	X					
Veronica scutellata	X			X		
Viola palustris	X	X	X			

* As defined in Fenbase (Wheeler 1997)