UNIVERSITY OF SOUTHAMPTON

PALAEOECOLOGY AND THE CONSERVATION MANAGEMENT OF LOWLAND RAISED BOGS.

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I shall not see a world that will be dear to me,
Summer without flowers,
Kine will be without milk,
Women without modesty,
Men without valour,
Captures without a king ...
Woods without mast,
Sea without produce.

The Cailleach

To whose eternal work of decay and renewal
I dedicate this study of Her process.

Abstract

Eight cores of three metres depth, spanning much of the late Holocene, were removed from raised bog sites in north-west England, central Scotland and Northern Ireland (Arnaby Moss, Ballynahone Bog, Coalburn Moss, Cranley Moss, Deer Dyke Moss, Mullenakill Bog, Wedholme Flow, Wreaks Moss). In addition a 77 cm core of recent, secondary peat was removed from one site (Arnaby Moss) in order to investigate the dynamics of its growth. Sampling at 4 cm intervals, counts were made of the plant and testate amoebae remains. From this data thirteen plant communities are recognised on their appearance as discrete phases of stratigraphy and described according to their floristics. The depth to the water table predominating during phases of each plant community was predicted by a multivariate statistical technique using the data on testate amoebae community composition. The predominance of a hydrological gradient in determining vegetation composition is apparent in Detrended Correspondance Analyses of the vegetation data. Accordingly, a model is constructed that describes the relationship between water table depth and the plant communities in order to predict the effect of management or climate change upon the vegetation of raised bogs. Primary focus is paid to the regeneration of *Sphagnum* dominated communities and this phenomenon is considered from six starting points according to the state of the extant vegetation and the depth and quality of the water table. Contemporary vegetation data fom the nine sites studied describes their current condition and on the basis of future management on or near these sites changes in the vegetation are predicted according to the model proposed. Radiocarbon dates taken from three sites permit the assessment of rates of change, between communities and their individual rates of peat accumulation. The effect of fire on the vegetation of lowland raised bogs is also considered.

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1. INTRODUCTION

1.1 AIMS AND OBJECTIVES

The hydrological restoration of raised bogs, whilst still somewhat ad hoc, has received much attention in the literature. Unfortunately, in contrast, very little research has been undertaken on the associated vegetation dynamics and accordingly, site managers are frequently unable to predict beyond broad generalisations the consequences of hydrological restoration upon the site's plant community(s). This study aims to contribute to this field by investigating palaeovegetation communities in relation to their palaeohydrology. The former is explored by the analysis of plant macrofossils and the latter involves determination of past water-levels by factorial analysis of testate-amoebae communities. This approach is therefore dependent upon the existence of palaeoecological analogues for the contemporary, damaged raised-bog state. For this reason the approach is limited to sites which have not been wholly cut-over, unless rafting vegetation has developed (e.g. Peatlands Park) because no widespread analogues exist for this drastic condition within the palaeoecological archive. In addition, on wholly cut-over sites, the palaeoecological profile antecedent to the present day is removed and this record is deemed desirable within this study because of its stratigraphic diversity. Accordingly, all but one of the sites investigated have undergone damage by drainage but their vegetation has not been interfered with beyond this perturbation, with exception to localised fires (e.g. Ballynahone Bog and Coalburn Moss). The diagram for Arnaby Moss Regeneration Peat represents 70 cm of regeneration peat which has developed spontaneously upon fen peat and allows for investigation of this phenomenon.

1.2 PERCEPTIONS AND MISCONCEPTIONS OF RAISED BOGS

Raised bogs form enchanting landscapes; the peripheral woodland that fringes many sites serves to soak up the intrusive sounds of modern living while the apparently bleak, undulating expanse of the mire itself provides a sense of space which may be enlivened by the songs of Skylark (*Alauda arvensis*) and Meadow Pipet (*Anthus pratensis*) or haunted, by that plaintive mew of the Curlew (*Numenius arquata*). Closer examination of the bog's surface, often through blanketing heather and heaths, reveals a carpet of many hues and textures provided by the oft predominating Sphagna, growing in which may be found such unusual plants as the insectivorous Sundew (*Drosera rotundifolia*), the showy Bog Asphodel (*Narthecium ossifragum*) or, that curious community of plant and fungus that forms the archaic architecture of the lichens. If one has the capacity to see further there is also to be found a multitude of microscopic life forms which swarm within the water film of the surface vegetation and where they remain, the bog pools. Careful watching within the microcosm of these now rare pools will reveal a multitude of tiny, dancing invertebrate forms and the predatory darting of aquatic beetles and copepods. Here too brightly coloured, dragonfly males fight, apparently delicate wings clashing against armoured bodies, their burr and whiz enlivening a summer's day with primeval display.

Unfortunately many of these pleasures are somewhat esoteric and given the apparent bleakness of bogs and their inhospitatlity underfoot few ever venture onto them without a boardwalk to explore and enjoy their wild nature which is, as Wheeler (1995) points out, an integral part of the appeal of raised bogs. Due to this lack of experience the predominating, public view of mires is rather negative and the popular image is of a wet, smelly, disease ridden place without value except for the presence of peat and its potential for conversion to agricultural land. This perception is revealed most cogently and possibly enforced by common usage of the words 'bog' or 'bogging' to describe anything unpleasant or lacking in value (Macafee, 1996). Raised bogs are also seen as dangerous places where one can be "bogged down" or swallowed up, never to be seen again, and such views may have evolved, in part, from bad encounters upon the aptly named quaking-fens that may overly deep water. More esoterically, mires were also seen as the haunt of malevolent spirits who would harass those foolhardy enough to invade their territory (Anon., 1995; Jacobs, 1970), often manifesting as the popular Will o' the Wisp, an entity seemingly more prevalent in English folklore than in that of the Celts and possibly more restricted to the rich fen habitats of that country. Other fears no doubt stem from the view of mires as places that harbour disease, for instance the occurrence of the malarial vectors in the genus *Anopheles* (Dobson, 1980) or less seriously through the irritation caused by members of the ubiquitous, biting-midge family Ceratopogonidae. As with our attitude to snakes and wolves, such views and fears seem deeply entrenched in the human psyche (*cf.* Carter, 1998).

As a consequence of such negative views one of the challenges that faces mire conservationists is education of the public into the intrinsic value and aesthetic appeal of raised bogs. This aim was pursued by the Lowland Peatlands Project of English Nature as 'pride of place' and at some sites facilities to achieve this end may be extensive, such as at Peatlands Park, Northern Ireland with its recently appointed education officer and purpose built centre (Stanfield, 1995). Other sites with lesser resources for education, such as Moine Mhor, Lochgoilphead have at least supplied board-walks and interpretative signposts over small areas of raised-bog.

David Bellamy's television series in the early 1980s brought the ecology of British mires and habitats into prominent, public view. However, such high profile television is difficult to obtain today in the shadow of so many other worthy causes and the priority seemingly given to the fauna of other regions such as Africa's savannah. Unfortunately this bias is further enforced by the attention grabbing, romantic imagery of some groups, such as Greenpeace, who thereby attract valuable attention for their high-seas exploits. Unfortunately it subsequently appears that the public are increasingly made to feel that the conservation importance of far away places exceeds that of our own country. This is despite the fact that the British peatlands have attracted international conservation attention and been compared to the African savannah on this basis (Thompson, 1987).

1.3 THE NATURAL RAISED BOG STATE

1.3.1 Raised bog succession and growth

Raised bogs are the natural end-point of a number of successional pathways which develop through geological time (Walker, 1973). Initial development classically takes place in the confines of a basin which gradually becomes infilled by the accumulation of mud and peat from a succession of communities collectively referred to as the hydrosere (Clements, 1916). Weber (1908) initially investigated the hydrosere but it was not until the work of Walker (1970) that sufficient stratigraphic data had been accumulated for a useful review. Walker (1970) determined the frequency of succession from one particular community to the next in a survey of forty stratigraphic sections and concluded that certain pathways are more common than others and that full expression of the hydrosere from open water is a rare event. Tallis (1996) has simplified Walker's (1970) pathways into the five stages described in Table 1.1 that may be considered to hold true under the maintenance of a stable groundwater table.

Stages (i) to (iv) in Table 1.1 are directly influenced by the groundwater table and consequently reflect the geology and pedology of the catchment area in their hydrochemistry. These differences in hydrochemistry can be utilised in a fundamental classification of mire systems where distinction is commonly drawn between oligotrophic mires sustained purely by rainwater (ombrotrophy) and minerotrophic mires sustained by the groundwater table (Du Reitz, 1949; Sjors, 1950; Moore, 1968 & Moore and Bellamy, 1974). In peatland parlance these broad mire types have respectively come to be referred to as bog and fen. Further classification of bogs may stem from differences in the surrounding topography which directs mire development (e.g. Bellamy and Moore, 1974), conservation value (e.g. Moen, 1985), vegetation (e.g. Rodwell, 1991) small scale vegetation topography (e.g. Lindsay *et al.*, 1985) or a combination of ecological factors (Bellamy and Bellamy, 1966).

	Sediment type	**Vegetation**	**Hydrology**
(v)	Bog peat	*Sphagnum* dominated	Raised water mound
----------------- **Groundwater table** -----------------			
(iv)	Fen carr peat	Colonisation by *Alnus*, *Betula* and *Salix* species	Surficial water
(iii)	Fen peat	*Sphagnum*-Cyperaceae or herbaceous communities	Surficial water
(ii)	Swamp mud	*Phragmites communis*	Shallow water
(i)	Lake mud	Aquatic macrophytes	Open water

Table 1.1 Summary of the hydrosere proposed by Tallis (1996) based on the conclusions of Walker (1960). Sediment types listed according to their stratigraphic position in relation to the water table.

Minerotrophic systems are not specifically included within this study but where extensive cutting has taken place over a raised bog, the underlying peat of a minerotrophic stage may become exposed and give rise to fen vegetation. The nutritive properties of this peat are preserved (Bellamy and Rieley, 1967) and in addition, the groundwater table may also become exposed and exert an influence on any recolonising vegetation. Fortuitously for restoring ombrogenous vegetation the drainage that has commonly taken place around most of our raised bog deposits has lowered the level of the groundwater table (e.g. Poelman & Joosten, 1992), often to below the level of fen peat that it originally sustained (pers. obs.). Thus, a return of fen vegetation is only apparent if the groundwater table is exposed or restored and the ensuing vegetation may consequently return along the hydrosere to raised bog under appropriate climatic conditions (van Wirdum, 1995). Such a scenario is considered within this study by the analysis of minerotrophic vegetation developing on the exposed fen peats of Arnaby Moss, Cumbria. In this instance, extensive cutting has exposed an expanse of fen peat but such a return to an early successional stage may also be seen on a smaller scale in the drains imposed upon the ombrogenous peat of lowland raised bogs (Smart *et al.*, 1986a and 1986b). Fortuitously, the invasion of species and communities alien to the hydrosere at this point does not appear to be a common feature of British raised mires but it has been observed at Westhay Moor, Somerset (Cousins, 1996) and more commonly in Canada (Jonsson-Ninniss & Middleton, 1991).

It is also necessary to draw some distinction between the two types of ombrogenous bog that occur in Britain; blanket bog and lowland raised bog. Only lowland (<300m) raised bogs are considered further and this type is, to some uncertain extent, distinct from the blanket bogs which occur in the same geographical areas of high rainfall in the north and west of Britain. There is no clear distinction between them floristically or developmentally (Proctor, 1992; Wheeler, 1993). However, the generally held view is that blanket bogs usually arise through the waterlogging of an upland soil (podsol) on shallow slopes by a process of paludification so coming to "blanket" the land or alternatively, by the coalescence of mires originally confined to a basin or hollow which illustrates cogently their relationship to raised bogs (Pearsall, 1950). In addition, blanket bogs are usually considered not to possess the hummock-hollow topography seen on raised bogs and do not possess a marginal drainage stream (Barkman, 1992).

Mires forming in valley bottoms and basins can be classified according to their topographic origins and may be variably influenced by minerogenous and ombrotrophic water supplies (Goode, 1972). Accordingly, they may be titled "transitional mires" in relation to their trophic source (Moore and Bellamy, 1974). However, a clear and consistent classification of mires has yet to be formulated (Wheeler, 1993) and as this author implies, it may be more desirable to consider mires on an individual basis rather than gloss over their variation in an attempt to make them fit a certain classification. However, from the point of view of communication some generally acceptable terminology must be maintained.

Transition from a minerotrophic, fen stage to the ombrogenous peat forming communities of a raised bog has been specifically addressed in the work of Hughes (1997). A large role is played in this sequence of events by the species of *Sphagnum* that colonise the fen surface. This transition may occur by the accumulation of ombrogenous water on a relatively impervious fen peat creating conditions suitable for aquatic Sphagna to colonise or, by the sublime appearance of ombrogenous *Sphagnum* species within any of the seral stages indicated above, in Table 1 (Walker, 1970 and Hughes, 1997). Additionally, the aquatic phase may be bypassed through the appearance of swamp or fen peat upon the estuarine sediments exposed by early-Holocene, sea-level change (Proctor, 1995). This is considered to be the origin of many of the raised bogs along the Cumbrian coast. Walker (1970) found such situations to be more common than full expression of the hydrosere.

Unfortunately most dating of these peatland deposits concerns itself with the rate of peat *accumulation* under different communities but contemporary observations indicate that the rates of *change* are highly variable, on the scale of years to centuries (Harding, 1993; Lindsay & Ross, 1994 and Fojt & Harding, 1995).

The ombrogenous peat of a raised bog incorporates the remains of a number of plant communities any of which may dominate the mire surface as a whole or occupy discrete areas of defined microtopography alone. This microtopographic variation constitutes the pool, hollow, lawn and/or hummock microforms currently found as the surficial features of many, contemporary raised bogs. It is claimed that this topographic variation is one of the most distinctive features of raised bogs and this adds further to the argument for their conservation (Lindsay *et al.*, 1985). The well known series of plants (Tansley, 1939; Andrus *et al.*, 1983; Karlin & Bliss, 1984; Rydin, 1985a, 1985b & 1993; van der Molen *et al.*, 1993) and communities (Rodwell, 1991) occupying this microtopography do so in relation to the concomitant, hydrological gradient which is itself a proxy for a number of other variables (van der Molen *et al.*, 1993). This gradient is indicated below in Figure 1.1, by reference to the species encountered during the course of this study.

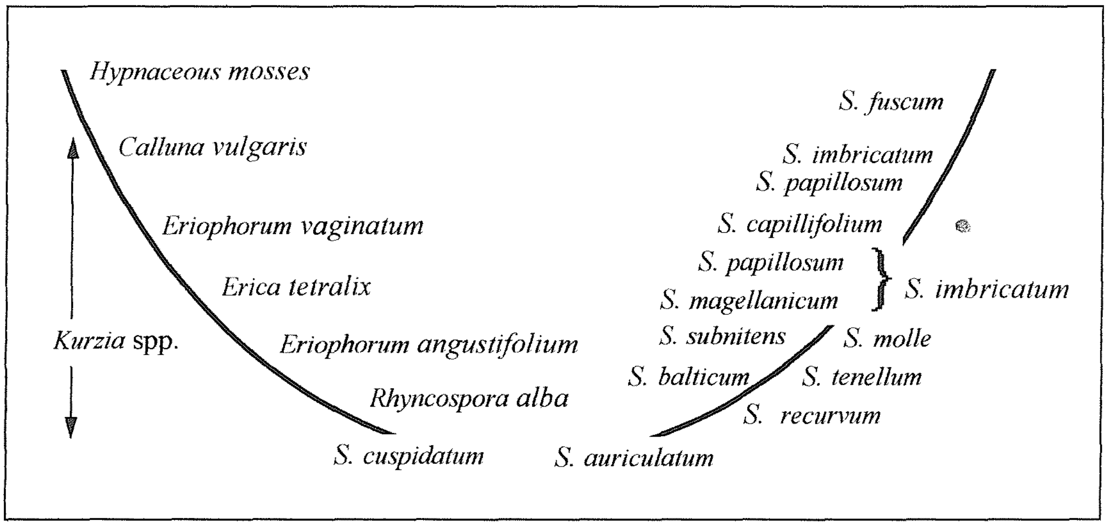

Figure 1.1 Species zonation along the hummock-hollow topography of an ombrogenous bog. Based on Tansley (1939), Lindsay *et al.* (1988), Daniels & Eddy (1990) and Koojiman & Kanne (1993).

The manner in which ombrogenous peat accumulates (bog growth *sensu* Barber, 1981) was initially thought to be related to how the species and physical conditions prevalent in the individual microforms of hummock, hollow and lawn lead to the accumulation of peat at different rates (von Post and Sernander, 1910; Osvald, 1923). Barber (1981) describes in a detailed way the development of these ideas which he accredits particularly to Osvald (1923) who provided a phytosociological mechanism for the initial concept of von Post and Sernander (1910) which was based on scanty stratigraphic evidence (Barber, 1981). The basic tenet was that the initially rapid upward growth by a hummock community reaches a point where its increasing isolation from the water table leads to a slowing or cessation of its growth. This stagnation of the hummock means that it is gradually overtaken by the upward growth of surrounding areas. Accordingly, the hummock becomes a pool or hollow as the upward growth of these initially lower lying areas supersedes it. These newly formed hummocks then stagnate and become overtaken by reinvigorated growth of the now low lying, original hummock. The cyclic appearance of these hummocks and hollows and their attendant communities is known as the Regeneration Complex, a process which should leave in the peat profile, a series of lenticelular structures (Barber, 1981).

The Regeneration Complex hypothesis outlined above was subject to some query in the subsequent literature but it was not until some fifty years had passed that it came under closer scrutiny. This was most cogent in the work of the Walkers (Walker, 1961; Walker & Walker, 1961) who studied the peat faces exposed by cutting at a number of Irish raised bogs. Of particular relevance to this study is their "evidence for a bog surface reacting all over and in the same direction to a change in conditions", a change that they considered to be climatic in origin (Walker & Walker, 1961). The concept of regeneration that they subsequently engendered was rejuvenation of the whole vegetation surface, by an increase in wetness, followed by maturation towards a more xeric vegetation type in which vascular species become increasingly prominent in relation to the Sphagna. In contrast to the Regeneration Complex, pools and hummocks are apparently persistent features throughout this succession (Walker, 1961; Walker & Walker, 1961; Barber, 1981). A contemporary approach was undertaken by Backeus (1972) in remapping an area in Sweden that von Post and Sernander (1910) had studied in formulation of their theory. Finding no distinct changes in the vegetation, this author concluded that cyclic regeneration had not occurred (Backeus, 1972).

In his investigation of extensive peat faces, Barber (1981) formally falsified the Regeneration Complex as an autogenic means of succession on raised bogs; partly in the absence of down grade, hummock to pool phases but more specifically in his demonstration of the climatic control over the growth of raised bogs. In addition, this author also concluded that the Regeneration Complex could only be seen as a succession following the reinstatement of a wetter seral stage through the intercedence of climatic change exceeding the hydrological threshold of the preceding community. These observations were expressed as the Phasic Theory of peat growth which maintains that the growth of a peat bog occurs in discrete phases that may follow the succession to hummock outlined in the Regeneration Complex theory but that changes in these phases are due to climate change (Barber, 1981). Von Post considered that the transition between phases was related to the hydrological threshold of the prevalent community which, when surpassed, would result in its replacement by another more suited to the new hydrology (Conway, 1948). The Phasic Theory of peat growth and concept of hydrological threshold values for raised bog plant communities are engendered within this study where a series of communities appearing as distinct, stratigraphic phases will be described according to their hydrological tolerances.

A raised-bog continues to grow, or accumulate peat, as long as biomass production in the upper layer of living vegetation and fresh peat (acrotelm) is greater than the rate of decomposition there and in the underlying, waterlogged peat (catotelm). Matter accruing as or raining down upon, the actively growing vegetation of the acrotelm, is thus gradually incorporated, by the upward growth of *Sphagnum* and tussocky Monocotyledonae, into the underlying, waterlogged peat of the catotelm, the site of peat accumulation (Clymo, 1992). Matter that comes to constitute the catotelm peat is effectively pickled in the acidic environment produced by the living *Sphagnum* (Clymo, 1963, 1973 & 1984) and additionally, by the anaerobic, permanently waterlogged conditions found there (Ingram, 1978, 1982). These characteristics, to an uncertain extent, inhibit any further decay but mass may continue to be lost from the individual components at varying rates (Clymo, 1965; Clymo, 1983; Johnson *et al.* 1990; Johnson and Damman, 1993). However, these remains often remain identifiable to the species, genus or sub-genus level (Barber, 1993) and indeed, the manner of staining due to the mineralisation process may be diagnostic of certain taxa.

Unfortunately, the absence of some species in the stratigraphic record, such as *Tricophorum caespitosum* (Godwin, 1956), would suggest that they may not survive the process of passage from acrotelm to catotelm or, subsequent decay within the latter in a recognisable state. Other, currently common raised bog species that appear to preserve poorly include; *Andromeda polifolia*, *Drosera* spp., *E. nigrum*, Hepaticae (except *Kurzia* spp.), *Narthecium ossifragum*, *Rubus chamaemorus*, *Utricularia* spp. and *V. oxycoccus*. Finally, as Barber (1993) points out, the remains of other plants may not be representative of their past abundance but nevertheless, it is only such palaeoecological data that will provide reliable, long-term data on the regeneration of bog landscapes (Joosten, 1995a).

The term "regeneration" is used above in the context of the Regeneration Complex. However, this word has wider connotations within the fields of raised bog ecology and conservation. It is used from this point onwards in the thesis to refer to the reinstatement of *Sphagnum* dominated, peat forming vegetation upon a degraded, peatland surface that may or may not bear vegetation.

1.3.2 Hydrology

As has been alluded to above, a feature of distinction, largely unique to ombrogenous bogs, is the presence of a water table perched above that of the groundwater (Wheeler & Shaw, 1995). The potential roles of capillarity in retaining rainwater or drawing up groundwater to maintain this water table were dismissed by Ingram (1982); by respective reference to the inadequate pore resistance of peat and the experimental work of Granlund (1932, cited in Ingram, 1982) who showed that wetting from the bottom of a block of peat could only attain a maximum height of 50 cm. Ingram (1982) proposed instead, a groundwater mound hypothesis that additionally explains the "inverted saucer" morphology of a raised bog. This has gained general acceptance within the field of raised bog hydrology although some limitations and possible improvements have been pointed out by Wheeler and Shaw (1995). In addition, although Kneale (1987) found the groundwater mound model to be suitable for descriptive purposes she found that measurement of the necessary variables precluded its use as a predictive model of mire shape.

The hypothesis, as outlined by Ingram (1982) considers the groundwater mound and its morphology to be a function of the balance between both precipitation and the hydraulic resistance of peat. The distinctive, inverted saucer shape of a raised bog results from the resistance of peat to lateral flow causing water to "pile up" in the mire centre (Bragg, 1995). Despite this resistance to water loss, in the absence of atmospheric recharge, Ingram (1982) considers the hydrology of a raised bog to be inherently unstable because the water stored via resistance is gradually lost through seepage and evapotranspiration (see Figure 1).

In formulation of his hypothesis, Ingram (1978, 1982) defined two structural layers within the stratigraphic profile of a raised bog already alluded to above in relation to peat growth. The lower layer he terms the catotelm and this layer is defined by; constant and complete waterlogging, anaerobia, low porosity and high resistance to water flow (Ingram, 1978, 1982, 1996). The overlying acrotelm is composed of current plant growth, particularly the Sphagna, and the fresh peat accumulating under this vegetation. The water table is free to oscillate within the stratigraphic boundaries of the acrotelm and the periodically aerobic conditions found here also make it the major site of peat decomposition, prior to accumulation within the underlying catotelm (Clymo, 1965; Ingram, 1978, 1982, 1996). The pore space of the acrotelm is highly variable, tending towards greater values at the surface. Accordingly, it functions as a V-shaped weir, damping oscillations of the water table and limiting its penetration into the catotelm during dry periods (Ingram, 1982). Accordingly, the lower limit of this layer is, by definition, the lowest depth to which the water table may recede, naturally a depth of up to 50 cm (Ingram, 1982). This buffering of the water table also maintains a close coupling between the water table and extant vegetation (Bragg, 1982 and 1989) and in addition, the entire raised bog system may undergo small fluctuations in height related to the prevailing hydrology (Ingram, 1996) that may also assist in the maintenance of this coupling (Ingram, 1992).

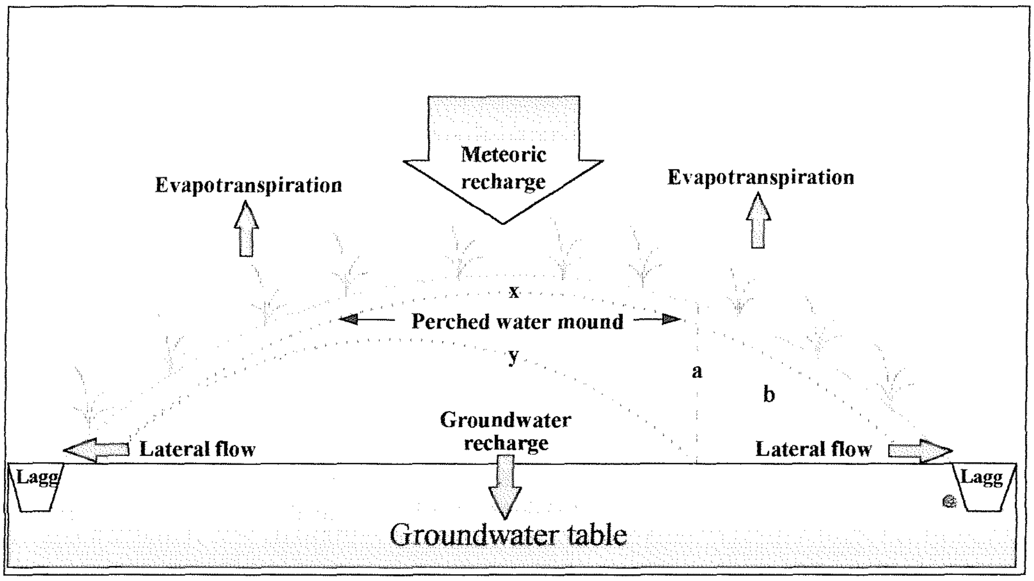

Figure 1.2 Diagrammatic representation of the hydrological cycle in a raised mire. The horizontal relief has been exaggerated to a mound for graphic reasons but it does conform more closely to the shape of an inverted saucer. Marginal peat cutting of the raised bog boundary to **a,** by removal of the peat at **b,** leads to recession of the perched water mound from **x** to **y** - see the text for further details. (After Ingram, 1978; 1982).

The acrotelm also enhances dispersion of water from the mire surface, particularly during periods of excess, along a hydrological gradient formed by the sloping flanks of both the groundwater mound and the corresponding acrotelm (Ingram, 1982; Bragg, 1995). These flanks of a raised bog are termed the rand and the hydrological gradient they maintain leads to a peripheral stream or lagg. The lagg stream expedites drainage of water away from the raised-bog and is commonly fringed, in the natural state, by minerotrophic, fen vegetation (Wheeler and Shaw, 1995) due to the nutrient load that accompanies the run-off it receives and its basis in the groundwater table (Ingram, 1992).

In the hydrological budget proposed by Ingram (1982) inputs are meteoric or occultic (mist, fog or dew) and losses occur through; evaporation, transpiration, recharge to the groundwater table, lateral flow within the catotelm and through pore space in the acrotelm. These components are graphically presented in Figure 1.2. Most discharge from the raised bog naturally takes place via lateral flow and losses to the underlying substrate are only considered important if drainage has lowered the regional water table (Heathwaite *et al.*, 1993). Assuming that the atmospheric recharge to a raised bog is greater than losses through lateral flow and groundwater recharge, in the long term, bog growth will continue to proceed.

1.3.3 Biogeochemistry

The chemistry of a raised bog is naturally both nutrient poor and acidic (e.g. Wheeler and Shaw, 1995). The acidity is partly due to the unbuffered influx of rainwater, which is itself acidic, both naturally and through pollution (UKRGAR, 1990), but more specifically, to the physiology of *Sphagnum*. The cell walls of this genus possess ionic exchange sites and hydrogen ions are displaced from these as the plants scavenge nutritive cations from the mire water (Clymo, 1963, 1973 & 1984). This is accomplished so efficiently that the Sphagna have been utilised in pollution monitoring because of their ability to concentrate heavy metals to easily measurable levels (Cameron & Nickless, 1979; Makinen, 1977; Pakarinen & Tolonen, 1976 & Pakarinen, 1978). Unfortunately, this successful adaptation for scavenging nutrients also has obvious implications for the susceptibility of *Sphagnum* to atmospherically borne nutrients (Ferguson *et al.*, 1984; Lee & Woodin, 1988).

The acidity generated by *Sphagnum* is crucial, in conjunction with waterlogging, low temperatures and nutrient levels, to maintain the slow rate of micro-organismal decomposition typical of peatlands. The role of anonymous, toxic compounds has also been considered to explain the inefficiency of saprobes in decomposing peat (Verhoeven, Maltby & Schmitz, 1990) and *Sphagnum*, in common with other mosses, is known to possess antibiotic properties (McCleary, Sypherd & Walkington, 1960; Banerjee & Sen, 1979). Filamentous fungi do not appear to be affected by these antibiotics (Banerjee & Sen, 1979) which, in light of the importance of mychorrizal associations for many heath plants, is an intriguing ecological factor in terms of its evolution. The actinomycete *Frankia*, for example, which forms nitrogen fixing nodules on the roots of *Myrica gale*, has been found to fix up to 34 kg N.ha-1.yr-1 (Schwintzer, 1971) and most Ericaceae form beneficial, mycorrhizal associations (Cullings, 1996; Dickinson, 1996). These associations are not generally present in the Cyperaceae, probably because their extensive root networks possess a sufficiency of root hairs for sequestering nutrients from the peat (Powell, 1975). Actinomycetes also appear to be responsible for most of the decomposition that takes place in the acrotelm whereas bacterial numbers increase within the catotelm where a very slow rate of decomposition occurs (Dickinson & Maggs, 1974).

The scarcity of plant nutrients found in raised bogs is also linked to the ombrogenous water supply that they receive. This feature is exacerbated further by the incomplete nutrient cycling prevalent in raised bogs (Verhoeven, Maltby & Schmitz, 1990) where decomposition and mineralisation are largely restricted to the duration of residence within the acrotelm (Clymo 1965 & 1978; Ingram, 1978, 1982). Subsequently, the matter and its nutritive potential accumulate within the catotelm to undergo further decay there at a much lower rate than in the acrotelm. As a result, the dominant ions present at the vegetation surface are meteoric H^+ and SO_4^{-2} (Sjors, 1950; Proctor, 1992) and the presence of other major ions is naturally related to inputs from sea spray (Na, Mg & Cl) and dust (N, P, S, Al & other heavy metals) (Proctor, 1992).

Despite the figures quoted above for *M. gale*, the rate of N fixation in raised bogs is generally low, up to a factor of ten less than that to be found in intermediate and rich fens (Waughman & Bellamy, 1980). This combined with low internal, nutrient dynamics, means that the hydrochemistry of raised bogs closely matches that of the regional rainfall and any associated pollution loading (Proctor, 1992; Proctor, 1994; Proctor & Maltby, 1998). Thus the vegetation subsisting under these conditions has been shown to be nitrogen limited (Rosswall & Granhall, 1980; Aerts, Wallen & Malmer, 1992) although in areas where deposition of this nutrient is high, phosphorous may become limiting (Verhoeven, Maltby & Schmitz, 1990; Koojimann & Kane, 1993).

1.3.4 Phytosociology

In comparison to other habitats, including minerotrophic mires, variation in the vegetation of ombrogenous mires is rather subtle (Wheeler, 1993) and this has lead to difficulties in distinguishing discontinuities between communities (Rodwell, 1991; Wheeler, 1993). Initial, phytosociological work focusing on the definition of palaeoecological raised bog communities was undertaken by von Post, Sernander and Osvald in their formulation of the Cyclic Regeneration Theory (von Post & Sernander, 1910; Osvald, 1923). These workers focused primarily on the plant associations found in the discrete raised bog microforms of hummock, hollow and lawn and their postulated role in the Cyclic Regeneration Theory. More recently, Svennson (1988) investigated the relationship between climate and the plant communities that he described as occurring in "stages" (*cf.* phases) from a raised bog in Sweden. The communities this worker recognised were based on the dominant species of *Sphagnum*, namely; Fuscum, Rubellum-Fuscum and Magellanicum, although a number of other peat types were recognised on account of their dominant vascular species (Svensson, 1988).

An extensive survey of the past and present, bog and fen communities in Central Europe was undertaken by Rybnicek (1972) whose coverage of ombrogenous communities was then limited by the lack of available data. Latterly, Barkman (1992) produced a comprehensive study of the Dutch and north-west German, raised bog and heath pool communities and considers their position from a number of ecological perspectives, including palaeoecological data. Most of the other phytosocoiological studies are concerned with the contemporary communities present on a single bog (Adam *et al.*, 1975; O'Connell, 1981) or region (McVean & Ratcliffe, 1962; Ratcliffe, 1964; Birse & Robertson, 1976; Birse, 1980; Ruuhijarvi, 1996). This continuing description and mapping of contemporary mire vegetation, throughout Europe, is reaching fruition in the production of a continental vegetation map (Rybniceck & Yurkovskaya, 1995).

Within Britain, the most botanised country in the world, the plethora of raised bog communities recognised within a multitude of papers, books and theses, has been assimilated into the National Vegetation Classification of mires and heaths (Rodwell, 1991). This publication has accordingly become adopted as the standard by non-/governmental organisations and therefore, the palaeocommunities recognised here are related to it. Within this classification, the *Erica tetralix*-*Sphagnum papillosum* community (M18), dominated by *Sphagnum* with lesser amounts of Cyperaceae and Ericaceae, is currently considered to be that which should prevail under contemporary, natural conditions (Wheeler & Shaw, 1995).

1.3.5 The palaeoecological and archaeological archive

The "stately march through the millennia" (Clymo, 1991) of raised-bogs has resulted in a wealth of information being recorded within their stratigraphy which may span much of the Holocene. The data within these scribes of nature can be exploited by a wealth of modern scientific techniques to reveal palaeoenvironmental events. Such data takes many forms and operates over many spatial and temporal scales.

Analysis of plant macrofossils allows for the determination of past plant communities that existed upon the raised-bog surface. The stratigraphic zonation of these communities is indicative of past climatic events since the groundwater mound of a raised-bog is directly coupled to the atmospheric evaporation/precipitation balance which is reflected in the species composition under the prevailing climate (Conway, 1948, Barber 1981). Initial work by Aaby (1976) instigated the plausible exploitation of this record which was later substantiated by the work of Barber (1981) who illustrated both the continuity of the record and that climate does play a major role in peat formation. Controversy still remains, as pointed out by Barber (1993), over the formation of thin bands of highly humified peats and the development of large pool systems (as queried by Tolonen *et al.*, 1985 and Foster *et al.*, 1988, respectively). Such climate research obviously has an important role to play in the global warming 1990s which followed the neo-glaciation fears of the 1970/80s. Of great interest is the fine scale resolution of recent climatic events within the raised-bog record (Barber, Chambers & Maddy, 1994 and Barber, Chambers, Maddy, Stoneman & Brew, 1994). Such studies generally span the late Holocene and the high resolution is made possible by the accretion of raised-bog sediments at an average rate of *c.* 1 mm.annum^{-1} (Barber, 1993) or even faster (Fallahogey, Barber unpublished).

Within this study and the work of Barber and Scaife (1995) and Barber *et al.* (1996), exploitation of the macrofossil record is also beginning to find usage in the contemporary conservation of raised bogs through the charting of their past development, in relation to hydrological species interactions. The work of Joosten (1985) and Smart *et al.* (1986a and 1986b) has elucidated the processes of contemporary regeneration within peat cuttings, on a decadal scale. Chemical analyses of recent peats has also allowed for the quantification of caesium, lead, plutonium and magnetised particles which reflect the increasing abundance of pollutants in our atmosphere and their current levels can be calibrated against an unpolluted baseline lower in the stratigraphy (Clymo, 1978; Oldfield *et al.*, 1978 and 1979). Chambers (1997) has used palaeoecological data to consider the possibly natural presence of trees on British raised bogs and predicts their prevalence under increased global warming. The naturalness and dynamics of an ecosystem also avail themselves to the investigation of stratigraphy as Charman (1997) points out by reference to the work of Segerstrom (1994).

Other sources of data within raised-bogs include the pollen record which has been utilised to study vegetation changes in terms of palaeoecology (e.g. Casparie, 1972), climate (e.g. Tipping,

1995) and human impact (e.g. Oldfield, 1963). Testate amoebae are now becoming a common technique in the elucidation of palaeohydrology as it relates to peatland development (Warner & Charman, 1994) or sea level change (Charman, Roe & Gehrels, 1998). All of these topics are also relevant to conservation; in terms of the past quality of a site, its response to environmental change and the history of anthropogenic influence.

The archaeological archive of raised-bogs in the British Isles is not limited despite their inhospitality to settlement and relative freedom from exploitation up until the 1800s (Taylor, 1973). Many artefacts have now been recovered and these were dated initially according to their position within the stratigraphy (Godwin, 1946 and Mitchell, 1945) although radiocarbon dating has now made such practice obsolete. Many of these finds have been found in isolation but one major exception to this is the presence of the Sweet Track in the Somerset Levels which linked a community of Iron Age lake dwellings (Dewar and Godwin, 1963 and Godwin and Clapham 1948). Ritually entombed bog bodies are also occasionally uncovered by peat excavators and their discovery is of archaeological interest because of the high degree of preservation, not only of the cadaver but also any accompanying artefacts which can then be viewed collectively in context (Stead *et al.*, 1986).

Much of this irreplaceable archive is now under threat from the removal of peat, especially under new modes of harvesting which, with heavy machinery, strip peat in layers from the top, truncating the valuable profiles or potentially damaging archaeological artefacts which may be missed in any case due to isolation of the operator from the peat surface (Coles, 1995). As pointed out by Barber (1993), no account of these records was assimilated into the criteria used to select raised-bog sites of conservation interest, despite the role that raised bog stratigraphy could have in the conservation and/or restoration of other habitats. However this situation now appears to be somewhat remedied with account of this archive being taken in SSSI citations and the UK Action Plan on Biodiversity (Anon., 1994). Unfortunately, when peat removal is allowed to take place, the upper layers are the first to go and it is these strata which contain the most valuable information antecedent to our current climate (Bradley and Jones, 1993).

1.3.6 Climatic interactions

The accretion of matter within peatlands distinguishes them from other terrestrial, climax ecosystems which cycle matter. As such, peatlands are a sink for, rather than a cycler of, carbon dioxide in the global, atmospheric budget and this has led a number of scientists to investigate their possible role in climatic change, most notably that marking the inception of glacial episodes (Billings, 1987; Franzen, 1994; Gorham, 1991; Klinger, 1991; Klinger et al., 1996; Sjors, 1980). It now is obvious that the destruction of our peatlands, through drainage, cutting and the subsequent oxidation of the peat, will release significant quantities of this greenhouse gas back into the atmosphere, which in their damaged state they will not be able to reclaim. These reserves of carbon in northern peatlands, which have accumulated over thousands of years, are vast with figures of up to 860 Gt C (Bohn, 1976) being estimated although more typically values fall in the range 450-500 Gt C (Botch *et al.*, 1995 and Gorham, 1991). Whilst most research in this area has focused upon the postulated role of peatlands in the initiation of glacial episodes (Klinger *et al.*, 1996) it is not difficult to qualitatively assess the atmospheric impact of carbon dioxide being released from raised-bogs. This problem is exacerbated further by the locally supraoptimal levels of N pollution which inhibits *Sphagnum* growth (favouring phanerophytes) and accelerate decomposition (Lee *et al.*, 1990).

A further role for raised-bogs in the global climate has been realised through research into methane production in peatlands. This gas is produced at all levels within peatlands (Brown *et al.*, 1998; Chanton, *et al.* 1995; Dinel *et al.*, 1988). Most of the methane produced in the upper layers is lost immediately to the atmosphere (Chanton, *et al.*, 1995) but of that produced at lower layers a 'substantial' amount is retained within the peat massif (Mathur, *et al.*, 1991), possibly enriched by advection from the catotelm (Chanton, *et al.*, 1995). Rycroft *et al.* (1975) initially suggested that this gas would assist the waterlogging in raised-bogs by blocking the pore space through which the ultimately stagnant water could otherwise flow. This view has been supported by the work of Brown *et al.* (1989) who, along with Chanton *et al.* (1995) indicated the atmospheric effects of the release of this greenhouse gas, particularly when the catotelmic reserves are released through anthropogenic disturbance or indeed, unfavourable climate change itself via a positive feedback loop.

1.3.7 Biodiversity

The value of the palaeoecological record in tracing the biodiversity of past-environments has been discussed above but the contemporary fauna and flora of these sites is also a valuable resource with more economic value than has been realised and which is currently under threat from anthropogenic disturbance. There are perhaps three complementary arguments for the conservation of biodiversity itself (Ehrlich and Wilson, 1991) which are applicable to the conservation of raised-bogs as a whole:

(i) The moral imperative. This urges that we are only the stewards of this planet and that we accordingly have an obligation to pass the planet on to our ancestors in a similar state to that in which we found it in. Vermeer and Joosten (1992) add to this a religious component, as part of our responsibility to God and the fact that we identify with other aspects of nature, sharing common beginnings and the same ultimate end. This is reflected in society's apparent choice of species whose morphology and ethology we can relate to being those most favoured for conservation.

(ii) The balance of nature. This argument highlights the interconnectedness of nature and the frequently unpredictable outcomes of our actions. Used imaginatively, at times in the benefit of hindsight, this argument can indicate a sustainable use for a landscape, such as the forest gardens of

Java which maintain a high diversity of both fauna and flora within an economic system (*cf.* Collins, 1990).

(iii) The natural resource argument. Despite the limited flora of raised bogs a number of taxa have found recent, economic usage. *Myrica gale*, for example, has recently become the major component of a new midge repellent supporting cottage industry in Argyll (Mabey, 1996). The usage of harvested *Sphagnum* as a field dressing is well known but more recent proposals for its exploitation include filling for nappies or sanitary towels (Daniels, 1989) and production of an absorbent board (Keys, 1992). *C. vulgaris*, much used in the past for virtually every purpose imaginable is also making an economic comeback with the re-emergence of *fraoch* (heather ale) as a popular beverage (Vickery, 1995; Dawin, 1996; Mabey, 1996). However despite these recent moves the usage of these species and others of economic benefit is still largely restricted although the potential for imaginative and sustainable exploitation is surprisingly large.

The botanical biodiversity of raised bogs is not especially great and probably never has been. Wheeler (1993), for example, lists 193 plant species that have been found in the British Isles within this habitat by comparison to a figure of 693 species for fens. Of the species occurring in raised-bogs greatest diversity exists among the Bryophyta and vascular plants are restricted to those that can tolerate the stress (*sensu* Grime, 1979) of an acidic, waterlogged, oligotrophic soil. This harsh environment is typified by such specialists as the insectivorous *Drosera* spp. and *Pinguicula* spp. which rely on this subsidiary mode of nutrition to supplement the impoverished supply of nutrients on raised-bogs. Of the remaining species many, such as Heather (*Calluna vulgaris*), are generalists found in a wide variety of habitats including blanket-bog, a habitat sharing much in common with raised-bogs in terms of species (Wheeler, 1995), communities and distribution (Rodwell, 1991). However a number of species which are rare in a national or continental perspective are to be found upon the raised-bogs of Britain. These include three plant species listed in Schedule 8 of the Wildlife and Countryside Act, 1981 (Reid, 1994): Slender-leafed Cotton grass

(*Eriophorum gracile*), the liverwort *Jamsionella undulifolia* and the bog-moss *Sphagnum balticum*. A further number of bryophyte species, threatened in a European perspective have been identified as not 'rare' or 'scarce' on ombrotrophic bogs in Britain, namely the mosses: *Campylopus atrovirens, Splachnum ampullaceum, S. sphaericum, Tetrapolodon mnioides* and the liverworts: *Cephalozia leucantha, Kurzia trichoclados* (derived from Hodgetts, 1992) and we accordingly have an international obligation to safeguard these species.

In addition, a number of notable invertebrates are also threatened by peat bog removal such as the Large Heath butterfly (*Coenonympha tullia*) listed in Schedule 5 of Countryside and Wildlife Act (1981) (Morrison, 1989; Reid, 1994). The characteristic ground-beetle fauna of ombrotrophic bogs can also contain rare and notable species which are threatened by commercial habitat destruction (Holmes, *et al.*, 1993a and 1993b). However, it is interesting to note that the ground beetle diversity of "managed raised-bog" can be higher than in "unmanaged raised-bog" (Holmes *et al.*, 1993b; McFerran *et al.*, 1995). This is considered to be due to a concomitant increase in microenvironmental diversity (McFerran *et al.*, 1995).

The effects of raised-bog destruction on birds has also received some recent attention (Bolscher, 1995 and Ward *et al.*, 1995). Ward *et al.* (1995) point out that of the thirteen Red Data Book species which utilise the raised-bog habitat only four are largely dependent upon it, these are: the Greenland white-fronted goose (*Anser albifrons*), golden plover (*Pluvias apricaria*), greenshank (*Tringa nebularia*) and red-necked phalarope (*Phalaropus lobatus*). These authors also point out the need to take into account, the time factors necessary to develop certain wetland communities and the fact that certain transitional types may support bird species more rapidly and in greater numbers than raised-bogs. This is also true for communities of other Phyla. As already pointed out fens, very often the precursors of raised bogs, are much more diverse botanically but for the conservation of some bird species, especially the Bittern and warblers, botanically impoverished reedbeds may be favoured. Accordingly, some conflict can arise from adherence to the biodiversity argument and in any case, rarity as a measure of conservation importance, especially within our outlying British Isles, is often a function of a species or taxon being at the extreme limit of its natural range wherein it may be otherwise abundant .

The microtopographical relief of hummock and hollow with its associated species' zonation, related to hydrology, is unique to the ombrogenous habitat of raised and blanket bog (Lindsay *et al.*, 1985). It is this three dimensional structure that enhances the diversity of a raised bog by creating a series of microenvironments whose function is related to their depth to the water table (van der Molen (1993). Other topographical features of raised bogs are of interest, namely the lagg and rand. The former may be still be observed on some relatively undisturbed raised bogs, such as Wreaks Moss, Cumbria but the peripheral lagg of most sites has been destroyed by the proximity of agricultural land although isolated, slightly modified segments may remain, as at Coalburn Moss, Lanarkshire.

1.4 SOURCES OF DAMAGE TO THE NATURAL RAISED BOG STATE

1.4.1 Introduction

Losses of peatland vegetation occur through the planting and colonisation of woodland on drained sites, improvement for agriculture and cutting for the fuel and horticultural industries (see Figure 1.3). In addition, some small amount (not illustrated) is utilised in the provision of housing and social infrastructure. The loss of raised bog habitat as a result of this exploitation is, in some areas, almost total. Lancashire for example lost 95% of its then remaining resource between 1948 and 1978 and in areas with less landscape pressure, the Forth Valley for example, losses over the same timespan are still significant, in this case 42% (Nature Conservancy Council, 1985). The overall picture in Great Britain is such that 98% of the raised-bog resource has been utilised in various combinations of the perturbations outlined so that only 11 700 ha remains in semi-natural condition (IPCC, 1992).

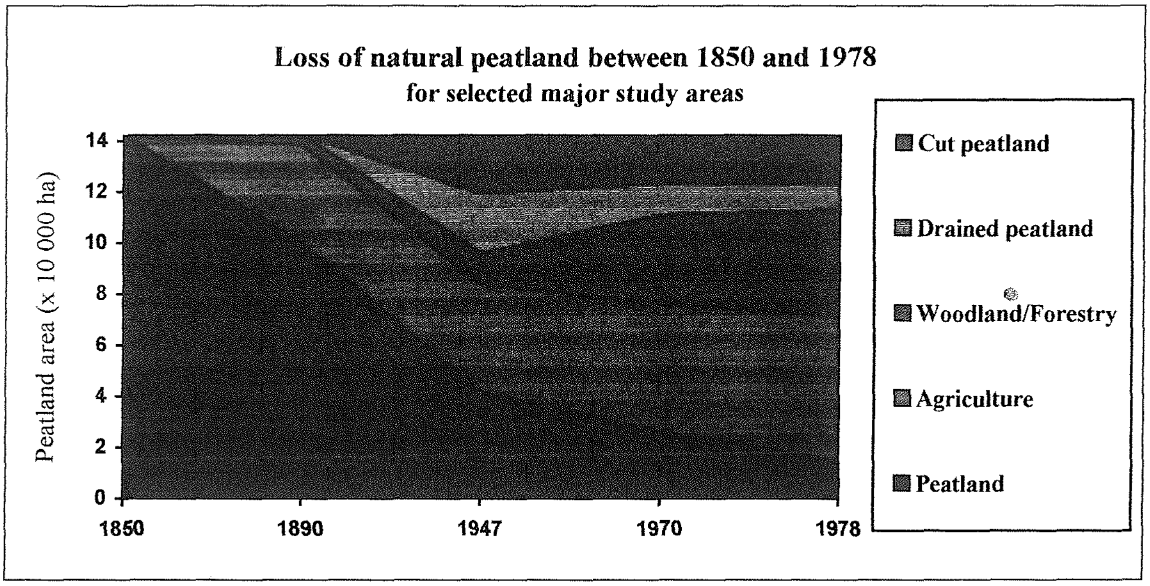

Figure 1.3 The loss of area recorded for a large sample of peatland sites in Britain and Ireland. Mapped form early, national cartographic surveys (Ordnance Survey 1st Edition 1:10 560 scale)) the followed through subsequent mapping editions, then using aerial photography and finally field survey. (Nature conservancy Council, unpublished data).

Even in the apparently Green Isle of Ireland the losses are dramatic, 80 000 ha of peatland have been drained since 1946 (Williams, 1990) and in regard of raised bogs, only 7% of the original resource bears an intact surface (Cross, 1992). On a West European scale the situation is even more bleak with only 500 ha of semi-natural raised bog remaining in Switzerland and Germany and only 5 ha remaining within the Netherlands (Barkman, 1992). This emphasises further the obligation that the British Isles have to preserve and restore its remaining resource which is, in common with other central and western European mires, of global importance (Oldfield, 1987). The quality of these remaining areas is obviously not accounted for within these figures and as Wheeler (1995) points out, such a concept is difficult to universally apply in the evaluation of a site. Quality assessments have been made however, using criteria relevant to the purpose of an individual study. The work of Money (1995), for example, takes a site by site approach, elucidating those raised bogs which would be most efficiently restored within the timespan and budget of the Lowland Peat Programme, using criteria such as the ease of vehicular access, potential for public use, consent of land-owners, etc..

1.4.2 Drainage

In all cases of raised-bog exploitation drainage, to reduce the water content of the peat, is the starting point for utilisation by any means. These drains may take the form of simple canals, trenches of various depths and/or subsurface tunnels aptly titled mole drains. The imposition of drains into the peat massif decreases the inherent drainage resistance of the peat by two pathways. Lateral loss of surface water from the site is expedited by their presence as is an increase in vertical seepage through the peat, especially where the drains may cut into transmissive subsoils (Heikurainen, 1975; Joosten, 1992). For this reason Lindsay (1988) and Eggelsman (1990) recommend a peat depth of at least 50 cm to be left after cutting. Unfortunately its implementation may not be possible in cases where the underlying subsoil has an undulating surface and its efficacy also depends on the porosity of the remaining peat (Wheeler, 1995).

The initial consequence of drainage is for the water table to drop as discharge increases. This occurs initially around the drain margins until a new hydraulic equilibrium is reached (Heathwaite *et al.*, 1993). According to the ground water mound hypothesis these changes are not localised because the raised-bog functions as a single hydraulic entity but, as pointed out by Lindholm and Markkula (1984) the water table will not necessarily fall to the lowest level of cutting and as can be seen in Figure 1.1, areas may remain where the water table stays relatively close to the surface, offering refuge to the lawn and possibly pool habitats. Overall however, these habitats are altered as the vegetation shifts from domination by *Sphagnum* mosses to a state where woody species become predominant (Ingram, 1992). This shift to woody species increases further the rate of water loss from a raised bog because of root penetration short circuiting the acrotelm and increasing evapotranspirative water loss (Lindholm and Markkula, 1984). Additionally, the loss of pools on the raised bog surface marks a decrease in water storage and recharge to the peat during dry periods (Beets, 1992).

Further implications for the drainage and water storage of a raised-bog arise from the irreversible structural changes to the peat through the chemical deterioration of its constituent, organic components (Eggelsman, 1984; Ingram, 1992). In the presence of oxygen these normally waterlogged deposits become oxidised, releasing their inorganic constituents by the complex process of mineralisation. These irreversible changes modify the hydrology of the site by increasing; trophic status, surface run-off, water table fluctuations, and susceptibility to fire while decreasing water storage and altering morphology, especially the height:width ratio upon which the groundwater mound is dependent (Heathwaite *et al.*, 1993). These changes also reduce the natural porosity of peat which is typically 80-97% (Heathwaite et al., 1993) and causes a decrease in the height of the mire, of up to 20 cm.annum^{-1} in a virgin site, over 40-50 years (Ivanov, 1981).

1.4.3 Afforestation and Agriculture

The management of raised-bogs for agriculture causes major shifts in the vegetation, such as to the type of meadow now widespread in the Somerset Levels. Subsequent purchase of such land for restoration and conservation is restrictive because the value is increased by comparison to that of unimproved peatland (Taylor, 1983). Attempts at the restoration of land managed in this way are not common although it may come to be included within the boundaries of a hydrological buffer zone. Similarly, the restoration of commercially afforested mires does not appear to have been attempted on a large scale in Britain although some sites, such as Deer Dyke Moss, have emerged from under a thick blanket of woodland which proceeded drainage.

Although raised bog communities are apparently stable, a number of distinguished authors have proposed that raised bog vegetation is not necessarily climactic but can be instead the penultimate sere in a succession to oak woodland (e.g. Tansley, 1939 and Godwin, 1975). This view has been contested by Klinger (1996) who concludes that raised bog communities persist for thousands of years in the absence of disturbance. However, Chambers (1997) warns against haste in ascribing a treeless perception to raised bogs by indicating instances of their occurrence in the past and suggesting their return in the future under the influence of global warming. Contemporary tree colonisation on British raised bogs does appear to be related to their drainage but this explanation is not sufficient to explain their rapid colonisation in Cumbria by *Betula* spp. and *Pinus sylvestris* during the post war period (P. Singleton, pers. comm).

The damage caused to raised bogs by trees results primarily from water loss via evapotranspiration, especially from the deep layers to which the roots may penetrate. In addition, the litter produced by some trees e.g. the acidic needles *of Pinus sylvestris* or the enriching litter of *Betula* spp., may alter the peatland nutrition. The subsequent effect of afforestation on ombrogenous vegetation is for its replacement by that more prevalent on heaths (Smith and Charman, 1988) but the additional roles of grazing and burning on this are unclear (Charman & Smith, 1992). Physical damage may also result to the site during unsympathetic harvesting and the penetration of tree roots may interfere with archaeological artefacts (Coles, 1995).

1.4.4 Peat Cutting

Peat cutting has two major outputs; the horticultural and fuel industries (Joosten, 1995b). Education of the public by campaigns such as that run by the Irish Peatlands Conservation Council (IPCC; http://aoife.indigo.ie/~ipcc/index.html) coupled with the now ready supply of alternatives seek to reduce the former whilst the latter is dogged by the fact that Ireland, for example, relies heavily upon peat burning for the generation of 30% of its electricity (IPCC, 1992). Most of this cutting is currently undertaken by commercial enterprises although small scale, subsistence cutting for fuel continues and has been known in the British Isles since at least the fourteenth century (Taylor, 1983). The current scale of commercial operations is now very large, whole raised-bogs being cut over by machinery, often at considerable expenditure as indicated by the £13 mil. compensation initially sought by Bulrush plc. to cessate operations on Ballynahone Bog (Keith Stanfield, pers. comm.). The most widespread, contemporary peat extraction techniques in the British Isles are outlined in Table 1.2. Preparation for cutting typically involves; drainage, the removal of surface vegetation, drying of the peat to *c*. 50% moisture content and provision of access, the latter of which is responsible for upstanding banks of peat (baulks). (Wheeler and Shaw, 1995).

Method	Methodology	Consequences for conservation
Block trench cutting	The traditional approach now largely replaced by specialised machinery. Blocks are cut form trench faces and stacked on the remaining baulks in order to facilitate drying.	Produces a topography of baulks, flats and trenches which may facilitate rewetting. The acrotelm is removed and frequently stored in the trenches which thus function both as a refuge and source of inoculum.
Milled peat extraction	The upper surface is loosened to a depth of *c*. 1.5-5.0 cm and vacuumed after *in situ* drying.	The acrotelm is harvested and the necessary imposition of mole drains, which are difficult to locate, hampers rewetting.
Peat extrusion	Peat is extruded from below the surface using nozzles cutting at an angle to facilitate closure of the slits.	Acrotelm may be removed to facilitate passage of the nozzle and the slits caused by this harvester may inadvertently function as subsurface drains. Where the acrotelm remains it may suffer severe damage (compaction, root dismemberment, etc.) during harvesting.

Table 1.2 Main peat extraction methods in the British Isles and their consequences for the restoration of raised bogs. Source: Roderfield (1993) and Wheeler and Shaw (1995).

Cutting increases the deleterious effects of drainage by removal of the buffering acrotelm (Wheeler and Shaw, 1995) and exposure of the underlying peat to the air causes oxidation of these layers. This may be ameliorated if the mire surface is cut close to the water-table but if large, marginal losses are also incurred, the resultant height:width ratio of the peat may result in an undesirable groundwater mound morphology (see Figure 1.2; Bragg, 1992; Joosten, 1992). In addition to this, the final shape and size of the site has important implications for the influx of pollutants, propagules and the prominence of edge effects and accordingly, circular sites are favoured (Wheeler and Shaw, 1995). Undesirable colonist species may include ruderal nitrophiles such as *Chamaenerion angustifolium* and *Urtica dioica*, responding to the increase in mineralisation (Jonsson-Ninnis and Middleton, 1991).

1.5 THE RESTORATION OF RAISED BOGS

1.5.1 Introduction

As a concept, the restoration of a raised-bog differs fundamentally from its conservation because the latter term implies that there is an inherent value worth preserving whereas the former indicates a loss of value that must be returned or restored to the site. Typically the restoration of a raised-bog involves the reinstatement of hydrological conditions amenable for the development of appropriate vegetation, usually the *Erica-Sphagnum* community described by the National Vegetation Classification as M18 (Wheeler and Shaw, 1995). In practice this may take many decades to achieve and therefore a less exacting definition is given by Joosten (1992) where restoration is deemed successful if there is a return to a seral stage and/or community which will, in time, climax as a raised-bog. Anthropogenic intervention is usually necessary because there is little evidence to suggest that natural, spontaneous regeneration will occur upon degraded raised bog surfaces (Joosten, 1995a) because the hydrological integrity of the mire must be intact (Heathwaite, *et al.*, 1987). Since there are virtually no intact raised bogs in the British Isles this means that some degree of restoration must usually precede or accompany conservation over the chronological sequence outlined below (Heathwaite, *et al.*, 1993);

1. Rewetting (a few years)
2. Renaturation - vegetation change (1-2 decades)
3. Regeneration - the accumulation of peat (3-5 decades)

Two approaches are considered to exist for the restoration of raised-bogs; species centred and mire centred (Wheeler and Shaw, 1995). The *species centred* approach aims to restore and/or enhance the vegetation interest in possibly limited areas of the raised-bog in question with the aim of enhancing and/or preserving the biodiversity of the site, according to the topography remaining after peat cutting. In contrast, the *mire centred* approach aims to restore the raised-bog itself as a functional entity. This may result in a loss of biodiversity upon the site because only the bog-building species are of primary importance and in attaining their necessary conditions other, notable taxa may be lost or hinder management (e.g. the flooding of nationally rare *Lycopodium inundata* at Peatlands Park, N.I., K. Stanfield, pers. comm.). This has brought criticism to some restoration projects in the Netherlands particularly (Vermeer & Joosten, 1992). In all of the sites considered in this study, restoration has primarily focused upon restoring the hydrological conditions necessary for the raised bog to return to a self-sustaining state although this has arisen spontaneously at Arnaby Moss Regeneration Peat.

1.5.2 The restoration of lowland raised bogs

Hydrological restoration is achieved by one of two routes: either rewetting the massif or flooding it. The most elementary way to achieve either end is by damming all or some of the drainage ditches. These dams may form a series in order to maintain water upon a gradient or, under more favourable conditions, the inception of one key dam may rewet the entire surface sufficiently for the regrowth of *Sphagnum* (e.g. Felicia Moss, R.A. Lindsay cited in Bragg, 1995). In extensively cut-over, sloping sites the use of dams may be necessary over the entire surface and these structures are usually termed bunds (Wheeler & Shaw, 1995). Bunds hold back water over the peat surface in terraces and this approach is one of flooding the cut-over surface. In addition bunds serve to ameliorate erosion and increase water infiltration into the peat (Roderfield, 1993).

The cut faces of upstanding massifs may also be protected by an impermeable bund which restricts lateral flow. Such a situation occurs where marginal peat cutting has occurred (e.g. Wreaks Moss) or where cutting has left one area of peat upstanding in relation to another (e.g. Wedholme Flow). Bunds may be manufactured from peat, clay, water in ditches or man-made textiles such as PVC (Wheeler & Shaw, 1995).

The creation of pools or lagoons on the mire surface by the implementation of bunds or excavation, serves to increase water storage in the upper peats, thereby lessening the propensity of the water table to deleterious fluctuations (Beets, 1992). Flooding prevents the colonisation of the generally undesirable, flooding sensitive species such as trees and *Molinia caerulea* (Vermeer & Joosten, 1992). However, these plants may prove to be desirable as anchor species to support the flaccid growth of colonising Sphagna (Joosten, 1992; Meade, 1992; Grosvernier *et al.*, 1995).

Rafts of vegetation may develop in the open water of lagoons and ditches and these are hydrologically buffered because they follow the water table's rise and fall unless grounded by summer drought. To avoid this, a minimum water depth of 20 cm is suggested from the benefit of practical experience in the Netherlands (Joosten, 1992). An excessive water depth is also deleterious since many of the desirable taxa are sensitive to flooding (Bragg, 1989 and Money, 1994) and therefore some control must be sought over the maximum water depth which should not exceed, in theory, the 50 cm calculated by Schouwenarrs (1995).

In comparison to rooting directly in the peat, the raft ensures that submersion of its constituent species does not occur and it may thus allow ombrogenous species to develop within possibly base or nutrient rich conditions by spatially separating the 'roots' of these species from such water (Wheeler and Shaw, 1995). However, rafts of *Sphagnum auriculatum* and *Sphagnum cuspidatum* are unable to refloat following desiccation and they remain submerged following rewetting.

Trees may eventually come to colonise the raft, especially when it becomes grounded or becomes proud of the water surface and this colonisation is particularly favoured by the moisture regime and morphology of the common raft-former, *Sphagnum recurvum* (Ohlson and Zackrison, 1991). Rooting in wholly denuded peat is inhibited by a number of factors; summer drought, frost heave, erosion, crust formation, the high temperatures generated by the peat's low albedo and, revegetation may therefore be retarded in this situation without the development of a raft (Salonen, 1987b).

The quality of retained water must also be accounted for and as such, the impoundment of meteoric water is recommended (Wheeler and Shaw, 1995). Low inputs of minerals such as nitrogen and phosphorous may favour the growth of Sphagnum (Money, 1995; Rochefort, Gauthier & Laquere, 1995) but excessive levels of nutrients inhibit this and result in the replacement of ombrogenous vegetation by that of poor-fen habitat, most notably *Sphagnum recurvum* and *Juncus effusus* (Wheeler and Shaw, 1995).

The hydrological restoration techniques discussed above aim to bring the water level to the peatland surface but the converse is also made possible by reconformation of the cut over surface.

This may be allowed to occur naturally through mineralisation and slumping of the peat or, more rapidly with heavy machinery (Bragg, 1989). Additionally, small scale reconformation of the surface to hummock-hollow relief may be achieved by agricultural machinery and enhance *Sphagnum* establishment (Heathwaite, *et al.*, 1993). Reconformation may be limited by the large scale conformation of a cut over mire, such as at Peatlands Park where a 1.5 m fall across a bare peat surface remained after levelling of the baulks and this has proven impossible to rewet (Shaw, 1993).

Following the rewetting or flooding of a site a change in vegetation will become apparent over 1-2 decades (Jonnson-Ninnis and Middleton, 1991; Heathwaite *et al.*, 1993). On rewetted sites with a vegetated surface this will take the form of a species-shift, frequently the expansion of *S. tenellum* (*cf.* Lindsay & Ross, 1994) and a certain amount of colonisation may occur also. Where sites have been extensively cut-over and flooded *revegetation* of these surfaces will take place by the establishment of *Sphagnum* rafts upon open water possibly stabilised by the rooting of vascular species in the underlying peat. The colonisation of all these surfaces is dependent upon the influx of propagoules from other sites or *in situ* refugia and vegetative means appear to be much more prevalent than those of a sexual nature (Rochefort, Gauthier & Laquere, 1995; Campeau & Rochefort, 1996). Colonisation and propagation may be enhanced by spreading economically useless acrotelm peat over the cut surface after its removal and storage within ditches (Wheeler & Shaw, 1995).

1.5.3 The restoration of raised bogs - a brief history

Much of the current state of contemporary raised-bog restoration measures are based upon the Dutch experiences of success and failure. Most of the Dutch peat reserves had been worked out by the middle of this century due to a general lack of interest in their conservation which, it is assumed, stemmed from the popular view of such places (Schouten 1990). Accordingly, only 8 000 ha of drained and largely cut-over bog remained in the Netherlands by 1990 (Schouten, 1990) from an estimated 1 mil. ha (Casparie, cited in Schouten, 1990). The preservation of these remaining peatlands was initiated by the voluntary body, Vereniging tot Behoud von Natuurmonumenten, which purchased an area of peatland for conservation purposes in 1934. Subsequently, the conservation of these areas was not seriously considered on a large scale by conservationists until the 1970's and, in 1990, the Dutch government declared all remaining areas of peatland nature reserves (Beusekom, 1990). Prior to this, the government had been responsible only for the conservation of state owned land, through the National Forest Service, although a few sites were purchased with conservation in mind since acquisition of the Kralose Heide in 1941 and later, the notable 'Groote Peel'. The realisation by the Dutch that their peatlands were in a very poor condition also prompted formation of the Foundation for the Conservation of Irish Bogs, through the auspices of the EEC. This body then purchased a number of Irish raised bogs in order to protect these more pristine sites from the state of decimation seen in the Netherlands (Lindsay, 1990).

The Bargerveen is a cut-over bog complex which has had a long history of regeneration. It is situated in the south-east of the Netherlands and borders onto Germany. It is especially notable for containing the Groote Meerstal, a former bog pool which is possibly the only completely undisturbed area of peat in the Netherlands. While a number of land uses have disturbed the peatland the main areas of conservation interest have undergone damage primarily as a consequence of buckwheat farming (Vermeer and Joosten 1992). This practice involves drainage of the peat and subsequent burning of the upper layers to form an ash enriched substratum upon which the crop is grown. Purchase of the area as a reserve was first considered in 1959 on the recommendations of Van Leeuwen and Westhoff (1959, cited in Vermeer and Joosten 1992). However, it was deemed to be of no recreational value and purchase, as a nature reserve, was not made until 1968. This delay proved expensive fiscally and in terms of managerial involvement because the cost of purchase had by this time doubled and a channel, whose bed was cut into the sands of the subsoil, had been dug to facilitate drainage (Schouten 1990). After purchase it was observed that the bog was continuing to degenerate because the Groote Meerstal was drying out (Schouten 1990). To prevent this two dikes were constructed to reduce the loss of water from the pool to the north-west and many birches (*Betula* sp.) were also removed reduce evapotranspirative losses. Grazing is still continued on the reserve on all but the most sensitive areas in order to keep continued tree growth to a minimum (Vermeer and Joosten 1992). Further dams were erected in order to reduce groundwater evacuation to the neighbouring Kamerlingswijk canal which, like the previously mentioned drainage ditch, cuts right through the peat layers and into the highly transmissive, subsoil sands (Vermeer and Joosten 1992). Further drainage ditches around the area were dammed and those which cut into the subsoil were filled in completely, in order to cut down further on losses due to the groundwater recharge. The reserve has been steadily enlarged over the subsequent years and more dams put in place in order to create a hydrological buffer zone around the Groote Meerstal in particular.

The work undertaken so far has been of a restorative nature and very encouraging results have been seen within a short timespan. The areas of dry and wet heath around the Groote Meerstal became inundated with water and the upper layers detached as the *Betula* root layer rotted (Vermeer and Joosten 1992). Subsequently these became floating mats and always being in contact with the water table, they became ideal for colonisation by *Sphagnum* spp. In the oldest areas (flooded *c.* 1970's) terrestialisation had reached a point in 1992 where the minerotrophe *Sphagnum recurvum* var. *mucronatum* had become the dominant species whilst in the younger areas *Carex curta, Juncus effusus* and *Molinia caerulea* indicated the slightly eutrophic conditions (Vermeer and Joosten 1992). Such indicators of eutrophication may eventually disappear as new peat accumulates to spatially separate the roots of the vegetation form the mineralised peat layers and their associated, nutrient rich water.

The Groote Meerstal initially had a cover of *Sphagnum recurvum* var. *mucronatum, Eriophorum angustifolium, Carex rostrata* and locally, *Vaccinium oxycoccus* and *Drosera rotundifolia.* This developed into a floating mat, predominantly of *Sphagnum cuspidatum* until, by

1986, the centre began to show the classic topography of hummocks and hollows with the appearance of *S. magellanicum, S. papillosum, S. capillifolium and Erica tetralix* (Jansen and Oostervald 1987, cited in Vermeer and Joosten 1992).

While this example can be credited as a success story it makes very clear the point that despite the small size of the initial objective, in this case the restoration of the Groote Meerstal, extreme measures may be needed both fiscally and in terms of physical scale. Schousten (1990) notes that the reserve employs 10 people and has cost over DFl. 30 mil. for acquisition and restoration with further, annual costs of DFl. 700 000. From the initial 66 ha purchased in 1969 the reserve had (by 1990) increased to some 2000 ha, in three main blocks (Vermeer and Joosten 1992). Work by Steefkerk and Osterlee (1984) shows that the hydraulic head of the subsoil is still far below the basal peat layers and accordingly, large volumes of water are being lost through vertical water movement. In such instances it is necessary to widen further the bogs management to include hydrological controls over the surrounding land (Perrochet & Musy, 1992; Poelman & Joosten, 1992; Heathwaite, 1994) but this is complicated by the fact that the reserve borders onto Germany with attendant administrative problems.

The successful reinstatement of suitable hydrological conditions for the growth of ombrotrophic peat proved not to be the end for the Groote Peel. Conservation of this site also included the maintenance and possible expansion of a black - headed gull (*Larus ridibundus*) colony in conjunction with its restoration as a mire ecosystem (Joosten 1988). Unfortunately, the guano accumulating around the breeding site of this flock caused serious eutrophication when the reserve was flooded, with the result that the minerotrophe *Juncus effusus* was able to spread freely. This area already suffers from eutrophication through the influx of precipitation and groundwater from the surrounding farmlands and consequently, management measures have been taken in this respect; the initial planting of trees to 'filter out' nitrogenous emissions and latterly, the implementation of an emission, buffer zone of 600m around the whole reserve (Vermeer and Joosten 1992).

Socio-economic factors may also complicate the conservation and/or restoration of particular sites. In the Shannon system, Ireland, for example, alluvial fields (termed "callows") are farmed by the local populace and due to the retention of water in associated mire systems these fields may only be put into usage for a short period in the summer. In such an economically poor area the livelihood of the local farmers and thus, communities could be enhanced by the availability of these fields all year round. The removal and cutting of peat is considered likely to decrease the storage capacity of the Shannon system with a consequential reduction in the amount of time low lying fields are liable to inundation (Welsby 1990). Here we see possible damage to the ecosystem on the local scale of individual bogs with their associated wetland units and further, the possibility of damage to wetlands all the way along the river system if the regional water table falls.

As a final example, the Rusland Valley Mosses, Cumbria are heavily wooded and harbour a population of red deer. Local pride in these animals is strong and moves to interfere with them for the purposes of raised-bog conservation (*i.e.* tree clearance) was met with strong, local opposition (Money 1995). Obviously red deer are not a particularly threatened species but it is probably best that we do not unnecessarily provoke local feelings, even over cases of apparently ill judged priority, in order to avoid a counter productive state of 'them and us' when moneys and effort can be directed into other demanding projects. In addition, nature conservation is dependent on proving the non-economic value of a landscape and this can only be shown by support of these aesthetics by the public.

2. METHODOLOGY

2.1 SITE SELECTION

Given that practically all of the mire systems in Britain have suffered some degree of anthropogenic disturbance this study was restricted to those damaged sites where active conservation management is proposed or being undertaken. This restriction was imposed to ensure the relevance of this study to practical conservation management. Nine such sites have been selected throughout the United Kingdom; five in England, and two each in Scotland and Northern Ireland. This selection encompasses sites which have been cut, drained and in some cases, burnt. Additionally, the sites selected cover a wide geographical area and accordingly, a presumed range of climatic conditions. A continuous peat record was also sought which necessitated that some area of uncut mire surface remained on the site. Unfortunately, this excluded investigation of Thorne Moor as an east coast representative since, during selection, it had been advised that no uncut surface remained here. An exception to this rule is Arnaby Moss Regeneration Peat, a mire expanse which had been cut down to the underlying fen-peat and from which a core of spontaneous, regeneration peat, 70 cm in depth was taken to explore the processes of spontaneous regeneration.

2.2 FIELD METHODS

2.2.1 Coring strategy

In all cases the lawn microtope was sampled, preferably with *Sphagnum magellanicum* predominating but as many of the sites were too dry for this species other types of lawn were sampled through necessity. A surface sample of peat was removed in a monolith tin, 50 cm deep x 10 cm^2. Samples below this depth were removed using the Russian-pattern, sediment sampler modified by Barber (1994). Two parallel boreholes, ten centimetres apart were alternately cored to a depth of 3m, each with a 5cm overlap to compensate for distortion from the nose-cone. Only one core was removed from each site except for the sites in Northern Ireland where two were taken to prevent the need for a return visit in case of problems. Cores were removed from close to the centre of each raised bog, laid in plastic guttering and enclosed within a polythene bag.

Contrary to the opinion of Moore (1986), Barber *et al.* (1997) have shown that the hydrological regime of a raised bog can be represented in one core. This was investigated by macrofossil analysis and radiocarbon dating of ten cores across two sites and a coherent series of vegetation change was found in each (Barber *et al.* 1997). Further credence to the representation of mire development in a single core can be sought on exposed peat faces where apparently contemporary horizons may be seen running for hundreds of metres (e.g. Wedholme Flow) and in the literature where comparable diagrams are produced from multiple sites within the UK.

2.2.2 Contemporary quadrat strategy

A baseline survey of the study sites was considered necessary in order to form the basis of any prediction of how the vegetation might respond to environmental change. Quadrats were placed using the random numbers generated by a Casio *fx*-911N calculator. These numbers were used to determine compass bearing and distance, in paces from the initial starting point at the bog centre or subsequently, the last quadrat. A five point scale comparable to that of Braun-Blanquet (1927) and reproduced below was used to quantify the abundance of species:

Value	**Cover**
1	1 - 5%
2	6 - 25%
3	26-50%
4	51-75%
5	76-100%

The measure used to quantify the vegetation was cover, determined for upstanding, vascular species by the vertical projection of their aerial parts onto the ground. This was considered the measure most comparable to the palaeoecological data since it reflects, at least partially, accruement of plant matter on the mire surface prior to its incorporation as peat. No account was taken of whether a plant was actually rooted within the quadrat or not so that the frequency data thus obtained refers simply to the likelihood of finding a part of that plant within any one quadrat.

This appropriate size of quadrat was ascertained by relating it to the scale of vegetation patterning on Ballynahone Bog and Mullenakill Bog, the first sites studied, but it must be understood that scales of patterning exist within the vegetation that are not determinable by eye alone and hence, any choice of quadrat will be arbitrary (Kershaw, 1973). A quadrat size of 1 m^2 was accordingly found to be an appropriate size to enclose a single microform, with the variable inclusion of others. This approach was favoured on the basis of presenting the data (see Results section) in such a way that the ecological relationships of the floristic elements in each microtope could be discerned. However, this size of quadrat conflicts with the 2 m^2 recommended for the National Vegetation Classification (Rodwell, 1991) to which this data was referred. In the experience of K. Watson (pers. comm.) this does not appear to be problematic, particularly with regard to the number of quadrats sampled within this study.

Nesting quadrats of different sizes and plotting the number of species present at each level until a plateau is reached has been used to determine an appropriate size of quadrat for the vegetation studied with the onset of this plateau being taken as the minimum area (Shimwell, 1992). This was performed during the course of this study with values typically <1 m^2 and therefore the size of quadrat was deemed appropriate on this basis also.

Determination of the appropriate number of quadrats was assessed by observing the stabilisation of a running mean constructed for the percentage occurrence of *C. vulgaris*, the most common and consistent vegetation component within the study sites. Such a determination is presented below for Ballynahone Bog and Mullenakill Bog, the first sites surveyed in such a manner

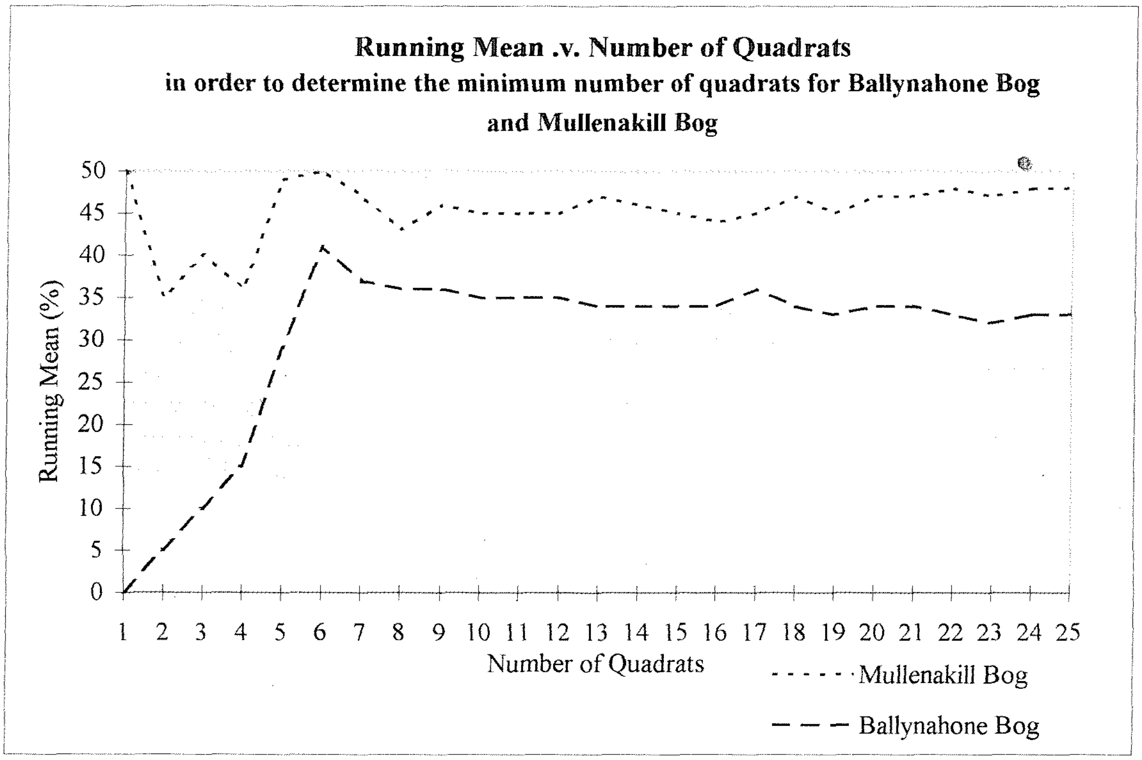

Figure 2.1 Plot of the running mean derived for percentage occurrence of *C. vulgaris*, plotted against the number of quadrats, in order to illustrate determination of the minimum number of quadrats required. Data for Ballynahone Bog and Mullenakill Bog.

and therefore used to set the standard for those sites remaining. As can be seen, the running mean stabilises after six to nine quadrats. However, to acquire a sufficiently large data set for statistical analysis, include rare species and ensure a healthy margin of error, it was arbitrarily decided to take twenty-five quadrat samples per site. Exceptions to this include the homogeneous vegetation of Arnaby Moss Regeneration Peat ($n = 20$) and the small, discrete areas of Cranley Moss which were investigated just to show how the vegetation within these areas is derived from that of the wider expanse. It is apparent from Figure 2.1 that the mean has not stabilised at a truly constant value and fluctuates within ± 2 % but these small variations are not deemed to be of ecological significance (*cf.* Kershaw, 1973).

2.3 PREPARATORY METHODS

2.3.1 Plant macrofossils

Macrofossils, in this study, are defined as the remains of plants which are visible and quantifiable under the x10 objective of a dissection microscope, i.e. branches, flowers, fruits, leaves and stems. This distinguishes them from the microfossils which in this study include pollen and the testate amoebae and for which a compound microscope is required of 100 x to 400 x magnification.

Samples were processed by the following method within a week of collection and the cores were then refrigerated at 4°C. Preparation involved cutting a 4 cm^3 sample, of 1 cm stratigraphic depth, from the cores at 4 cm intervals. This sample was then washed through a 250μm sieve to remove the fine, unidentifiable residue. Greater amounts of Unidentified Organic Matter are present in the stratigraphy of Deer Dyke Moss due to the use of a more moderate water flow to wash the sample. These washed samples were then transferred to 25 ml sample bottles in a solution of 10 % ethanol (approx.) to prevent fungal contamination.

2.3.2 Pollen

Pollen samples of 1 cm^3 were prepared for the upper 35 cm of peat at Deer Dyke Moss. These samples were taken contiguously down to a depth of 10 cm depth and then alternately, to 37 cm depth. Preparation involved the use of standard sodium hydroxide and acetylation methods as described by Barber (1976).

2.3.3 Testate amoebae and other microfossils

Testate amoebae samples were prepared following the method outlined by Hendon and Charman (1997) using a sample size of 4 cm^3 and the addition of 1500 exotic markers (*Lycopodium* spores). This large sample size was chosen to ensure a sufficiency of tests within the sample without continual recourse to the laboratory in Southampton. Due to time restrictions sampling was at 8 cm intervals with 150 testate amoebae counted per level unless the concentration was low in which case counting ceased at 100 shells (as per Warner, 1990).

The purpose of the exotic marker, *Lycopodium*, is to determine the concentration of testate amoebae shells in the peat at a given depth. However, no recourse was made to this data throughout the study since the water table model derived from the testate amoebae data set provided a rational set of figures and there was accordingly, no need to question the results obtained in respect of the test concentration. It is therefore suggested that this stage of the preparatory method can be dispensed with.

2.4 IDENTIFICATION OF PEAT COMPONENTS

2.4.1 Unidentified Organic Matter (UOM)

This component comprises the algal mud of a pool or the products of decomposition during dry periods in the development of the bog. All residue which cannot be referred to the following categories is included within this grouping

2.4.2 Sphagnopsida

Sphagnum is generally the most abundant peat component during the late Holocene, often occurring in apparent monoculture throughout much of this period. Its remains are readily recognised within the peat where whole plants may often be preserved but commonly it is only the dismembered leaves and stem fragments which are encountered. The ubiquitous branch leaves can be recognised by the unique interspersion of porous, sigmoid, hyaline cells thickened by spiral fibrils with thinner, opaque and often enclosed, photosynthetic cells. This arrangement is bound by a border of varying thickness (1-6 cells) which may appear dentate in *S. compactum* and *S. molle* due to resorption (erosion) of the marginal, cell wall. The stems can also be recognised and separated from the of vascular species roots by a combination of the inflated, pellucid, cortical cells, annual nodes and the fascicle scars. In addition, the branches of *S. tenellum* are diagnostically distinct in the presence of retort cells.

The phenotypic plasticity and relative paucity of reliable characters within the genus make for difficulty in identifying the individual species even when fresh and this has resulted in most, previous investigators ceasing identification at the level of section (or sub-genus). This approach is relatively quick, easy to execute and it yields reliable results suitable for statistical manipulation where the presence of many 'rare' species generated by the splitting of sections could prove problematic. However, where feasible, the resolution of taxa to species level allows for a fuller understanding of the vegetation processes because more specific autoecologies can be considered and hence, the corresponding hydrological condition of the site and its response to change more accurately determined. This is revealed most cogently by consideration of the ecologically 'dry' section *Acutifolia*, where *S. subnitens* and *S. capillifolium* would be taxonomically included but the former is most commonly encountered in the 'wet' conditions of a lawn or pool as opposed to the drier lawn or hummock favoured by the latter. Even closely allied species within a microtope may be seen to reliably segregate according to the hydrological conditions, both temporally and spatially e.g. *S. fuscum* overtopping *S. capillifolium* on hummocks (Rydin, 1985). Identification to species level is also important within this study because of the need to construct and define consistent vegetation communities in which the Sphagna often play a dominant role. Indeed, within the National Vegetation Classification identification of Sphagna is stated to be essential for the allocation of mire types (Rodwell, 1991). To assist further researchers and to qualify my approach a key is given below to the typical ombrotrophic species whose branch leaves may be routinely found during investigation of such sites.

The key is constructed form the contemporary data given in Hill (1978), Daniels & Eddy (1990) and my own palaeo-/ecological and archaeobotanical experience. Using it may lead straightforwardly to an apparent resolution of the species' identity but this is often deceptive (Dickson, C.A., 1970). Accordingly, the leaf should be checked against the fuller description given below the key or in a full flora (e.g. Daniels & Eddy, 1990 and Hill, 1978) and most desirably, be checked against modern comparative material. In addition, reliance should not be placed wholly on the branch leaf characters alone. If searched for carefully stem leaves may be found and their presence serves to confirm the identity of a particular taxon. Leaves from immature or pendant branches can be dissimilar to those of spreading branches and in such cases confident identification may not be feasible. Should leaves can usually be discerned by their longer shape and more faint outline which suggestive of immature development in the construction of the cell wall. The leaves of *S. tenellum* may often appear faint but are ovate and the hyaline cells are broad. In any cases of uncertainty the leaf is simply included within the sum of the appropriate section.

After some practice it is not necessary to undergo measurement of each and every leaf and its taxonomic features because the eye eventually comes to readily determine the small differences in leaf structure used to separate some of the taxa. This is particularly the case in rich levels where a few species are present and the opportunity here to compare and contrast leaf structure is invaluable. It is prudent however that caution should be exercised since recalibration of the eye does seem necessary sometimes, especially when dealing with such similar species as *S. capillifolium* and *S. fuscum* which could be easily confused if investigation of only one or two leaves is made without any comparison.

The distribution of the Sphagna on raised-bogs is generally held as reflecting the microtopographical changes in hydrology encountered in the microtopes; hummock, lawn and pool. The ecological notes accompanying each species outlines the species' position in this sequence. To prevent repetition references are not given but the data is mostly derived from and indeed, repeated within the following works: Andrus (1986); Andrus *et al.* (1982); Rydin (1985a, 1985b and 1993), Rydin and McDonald (1985) and the two floras cited above. Technical terms can be found within the comprehensive glossaries of Daniels & Eddy (1990) and Smith (1978).

Key to Sphagnopsida

1 Apical cells about as wide as they are long, apex commonly hooded (cucculate) **2**

Apical cells *markedly* longer than they are wide **3**

2 Leaf margin apparently dentate; commisure of hyaline cells never ornamented, hyaline cells 110-130µm long at mid-leaf .... **(V) Section Rigida**

Leaf margin plane; commisure of hyaline cells frequently ornamented, hyaline cells 70-120µm at mid-leaf .... **(I) Section Sphagnum**

3 Photosynthetic cells exposed on both surfaces; abaxial pores numerous, arranged along the commisures; leaves usually stained brown .... **(III) Section Subsecunda**

Photosynthetic cells more exposed on one surface than the other (less marked in *S. cuspidatum* and *S. majus*); pores never so numerous or so strictly arranged along the commisures; leaves often unstained (pellucid)... **4**

4 Photosynthetic cells more exposed on the abaxial (dorsal/convex) surface; leaves commonly pellucid .... **(IV) Section Cuspidata**

Photosynthetic cells more exposed on the adaxial (ventral/concave) surface; leaves stained brown .... **(II) Section Acutifolia**

(I) Section *Sphagnum*

1 Commisure ornamented (often poorly developed - check basal angles of leaf); Photosynthetic cells exposed on both surfaces **2**

Commisure not ornamented; photosynthetic cells completely enclosed .... **(ii) *S. magellanicum***

2 Commisure ornamented with comb-like fibrils .... **(i) *S. imbricatum***

Commisure ornamented with papillae .... **(iii) *S. papillosum***

(i) *S. imbricatum*

Commisure ornamentation Comb fibrils (*imbrications*). **Photosynthetic cells** Triangular, greatest exposure adaxial.

Ecology The most abundant species during the late Holocene and now most notable as a hummock builder but also forming lawns. Now rare except in western Scotland and Ireland where it occurs locally..

(ii) *S. magellanicum*

Commisure ornamentation None. **Photosynthetic cells** Oval and enclosed on both surfaces.

Ecology Rare in palaeoecological contexts before recent centuries, this species is now an abundant component of lawns and hummocks.

(iii) *S. papillosum*

Commisure ornamentation Papillae. **Photosynthetic cells** Oval to barrel shaped and exposed on both surfaces.

Ecology Uncommon in palaeoecological contexts this species, like the others in its section, forms lawns and hummocks, Li *et al.* (1992) suggesting it to attain maximum productivity in the former. However, it is currently regarded as more preferential to hummocks than *S. magellanicum*.

(II) Section Acutifolia

1 Leaves small (<1.5mm) **2**

Leaves large (>1.6mm) **3**

2 Basal hyaline cells c. 160μm; pores in these cells 8-25μm .... **(i)** ***S. capillifolium***

Basal hyaline cells c. 130μm; pores in these cells 15-40μm .... **(ii)** ***S. fuscum***

3 Leaves apparently dentate; not abruptly narrowed at mid-leaf; photosynthetic cells enclosed abaxially .... **(iii)** ***S. molle***

Leaves not dentate; abruptly narrowed at mid-leaf; photosynthetic cells not enclosed abaxially .... **(iv)** ***S. subnitens***

(i) ***S. capillifolium***

Branch leaves Small, 0.8-1.5mm x 0.4-0.6mm; ovate to narrow ovate. **Hyaline cells** Basal cells longer and wider than those in apex (*c.* 160μm x 25μm *cf. c.* 100μm x 16μm). **Abaxial pores** 4-9/cell; 8-25μm; along commisure, in triplets or pairs opposing across the photosynthetic cells, may appear elliptic due to bulging hyaline cells. **Adaxial pores** 0-1/cell; 10-20μm; generally absent apart from marginal cells. **Photosynthetic cells** Triangular to trapezoid; not enclosed abaxially (narrow exposure); exposed broadly adaxially.

Ecology A low hummock species and occasional lawn former, particularly under wet conditions. It is classically found fringing the lower flanks of hummocks on which *S. fuscum*, *S. imbricatum* or *S. papillosum* are dominant.

(ii) ***S. fuscum***

Branch leaves Small, 0.9-1.3mm; ovate to narrow ovate. **Hyaline cells** Basal cells longer and wider than those in apex (*c.* 130μm x 25μm *cf. c.* 90μm x 15μm). **Abaxial pores** 3-7/cell; in base 12-30μm, at apex smaller, *5-10*μm; along commisure, in triplets or pairs opposing across the photosynthetic cells, may appear elliptic due to bulging hyaline cells. **Adaxial pores** 0-1/cell; 5-20μm; generally absent apart from marginal cells but always occurring towards the leaf apex.

Photosynthetic cells Triangular, rarely trapezoid; not enclosed abaxially (narrow exposure); exposed broadly adaxially.

Ecology A hummock former that reaches the highest levels above the water table sometimes as individual shoots amongst members of *S.* section *Sphagnum*.

S. capillifolium and S. fuscum are very similar but can be readily separated, in most cases, by careful attention to the details pointed out in the key.

(iii) *S. molle*

Branch leaves Large, 1.6-2.2mm x 0.5-1.2mm; ovate; *apparently toothed* (due to presence of resorption furrow). **Hyaline cells** 160-180µm x 25-45µm. **Abaxial pores** 6-12/cell; 12-22µm; *often obscured* due to bulging cell walls. **Adaxial pores** Absent except occasionally in the marginal cells. **Photosynthetic cells** Triangular, occasionally trapezoid; usually enclosed abaxially; exposed broadly adaxially.

Ecology Forms low hummocks intolerant of shade. Notable as a colonist of bare peat.

Readily identified by the toothed margins in the upper half of the leaf. Possible confusion exists with S. compactum *but the hyaline cells in the apex of that species' branch leaves are almost as broad as long. Within this section the spathulate stem leaves are diagnostic of* S. molle, S. fimbriatum *and* S. girgensohnii *but the latter two are minerotrophic hydrophiles and therefore infrequent on dry or undamaged raised bogs.*

(iv) *S. subnitens*

Branch leaves Variable but generally large, 1.6-2.7mm x 0.5-1.3; ovate to ovate-lanceolate; frequently narrowed abruptly in upper half. **Hyaline cells** Basal cells longer and wider than those in apex (130-200µm x 25-40 *cf.* 100-130 x 18-25) **Abaxial pores** 3-10/cell; 15-30µm; along commisure, in triplets or pairs opposing across the photosynthetic cells. **Adaxial pores** Absent , apart from marginal cells (1/cell). **Photosynthetic cells** Triangular to trapezoid; not enclosed abaxially (narrow exposure); exposed broadly adaxially.

Ecology Relatively indifferent with regard to the water table being found immersed or occasionally forming low hummocks.

(III) Section Subsecunda

(i) *S. auriculatum*

Branch leaves Variable, 1.0-3.5mm; ovate, concave and *occasionally falcate*. **Hyaline cells** Narrow; 100-200µm x 15-20µm. **Abaxial pores** Numerous, usually 20-50/cell, occasionally absent or very few; lying along commisures. **Adaxial pores** ≤15/cell; 2-6µm but usually absent or very few. **Photosynthetic cells** Lens to barrel shaped, exposed on both surfaces, more so abaxially and occasionally enclosed adaxially.

Ecology A phenotypically plastic species with two, usually well marked varieties, both of which favour the wet conditions of lawns or pools.

Easily identified by the numerous pores arranged along the commisure. However where these pores are absent or few the leaf is often found to be falcate which readily separates this taxon from section Acutifolia, especially when attention is also paid to the exposure of the photosynthetic cells and size of the leaf.

(IV) Section Cuspidata

1 Photosynthetic cells commonly exposed on both surfaces; leaves long >1.7(-1.5)mm; lanceolate; without a waist at c. mid-leaf or above; border up to 6 cells wide **2**

Photosynthetic cells enclosed adaxially; leaves generally short <1.7(-3.0)mm; ovate; if larger with a waist at *c*. mid-leaf or above (*cf. S. recurvum*); border up to 4 cells wide **3**

2 Adaxial pores absent or few [0-3(-6)/cell]; abaxial pores numerous (≤18/cell); commonly arranged in two rows; leaf length ≤3mm .... **(iii)** ***S. majus***

Adaxial pores present (3-10/cell), abaxial pores absent; leaf length ≤5mm .... **(ii)** ***S. cuspidatum***

3 Hyaline cells at mid-leaf short (<110μm) 4

Hyaline at mid-leaf cells longer (>100μm) **5**

4 Hyaline cells broad (20-35μm); leaf strongly concave .... **(vi)** ***S. tenellum***

Hyaline cells narrow (9-20μm); leaf not strongly concave .... **(i)** ***S. balticum***

5 Leaf broadest at *c.* 30% leaf length; photosynthetic cells narrowly enclosed adaxially .... **(iv)*****S. recurvum***

Leaf broadest at *c.* mid-leaf; photosynthetic cells deeply enclosed adaxially .... **(iv)** ***S. pulchrum***

(i) ***S. balticum***

Branch leaves Small, 0.9-1.7mm x 0.4-0.7mm, ovate. **Hyaline cells** 90-110μm x 9-20μm in upper mid-leaf. **Abaxial pores** 0-3; 2-5μm; *along the commisures*, pseudopores may also be present and a resorption gap in the upper angle of the cells. **Adaxial pores** 5-12/cell; 5-9μm. **Photosynthetic cells** Oval-triangular, deeply enclosed on the adaxial surface.

Ecology A species found low down on hummocks or in lawns. Its lower limit is often the upper limit of *S. tenellum*.

Separable from the other members of this section on account of its short hyaline cells which are not so broad as those of S. tenellum.

(ii) *S. cuspidatum*

Branch leaves Very large, 1.5-5.0mm x 0.3-0.9mm, lanceolate to linear, frequently falcate. **Hyaline cells** Long and narrow; measurements variable 100-230µm x 12-20µm but in palaeocontexts usually in the larger size range. **Abaxial pores** Mostly absent apart from occasional pseudopores/resorption gaps. **Adaxial pores** 3-10/cell; 4-8µm; unringed and occasionally faint, lying near cell angles. **Photosynthetic cells** *Trapezoid and exposed on both surfaces.*

Ecology An aquatic species which is found most commonly floating in pools where it can maintain contact with the water table. Also emergent around pool margins where its habit becomes compact, the branches sub-secund and their leaves more falcate. As such, it may exist outwith the pool microtope and linger on stratigraphically as isolated shoots within the lawn of succeeding *Sphagnum* sect. *Sphagnum* species (Rydin, 1985).

The large, narrow leaves of this moss, frequently falcate, make it an easy species to identify. Usually there can be no doubt in its identity but where such a problem arises the trapezoid photosynthetic cells, exposed ad- and ab- axially serve as a confirmatory character. The deep border of ≤ 6 cells is also distinctive. For differences from S. majus *see under that species.*

(iii) *S. majus*

Branch leaves Large, 1.7-3.0mm, ovate-lanceolate to linear lanceolate, frequently falcate. **Hyaline cells** Long and narrow; 100-220µm x 13-22µm. **Abaxial pores** 8-18/cell; 5-8µm; scattered but may be arranged in two rows, usually unringed and hence, faint. **Adaxial pores** 0-6/cell; 5-7µm; usually absent or very few. **Photosynthetic cells** Trapezoid and often moderately exposed adaxially but with wider exposure abaxially.

Ecology An aquatic species which is found most commonly floating in pools where it can maintain contact with the water table.

Differentiated from S. cuspidatum *and all other members of* S. *section* Cuspidata *by the presence of numerous pores on the abaxial surface. This species has not yet been recorded from* *palaeoecological contexts and it is not clear if this is a reflection of its past (and present) rarity or that it is overlooked as the much commoner* S. cuspidatum.

(iv) *S. pulchrum*

Branch leaves 1.2-1.8mm x 0.5-0.9mm, broadly ovate, *widest at mid-leaf.* **Hyaline cells** 100-150μm x 13-25μm in upper mid-leaf, slightly shorter in pendant branch-leaves. **Abaxial pores** 0-2/cell; 3-9μm; resorption gaps in apical angles. **Adaxial pores** 3-9/cell; 5-10μm; usually adjacent to cell angles. **Photosynthetic cells** Equilateral or shortly isosceles. Deeply enclosed adaxially.

Ecology Typically to be found fringing the margins of pools but as these are overgrown it may be seen to form small lawns such as at Ballynahone Bog, N.I. (pers. obs.).

Separable with care from S. recurvum. *In* S. pulchrum *the photosynthetic cells are more deeply enclosed; this may be seen with careful optical sectioning or a transverse section (and comparative material!). Careful note should also be paid to the shape of the leaf.*

(v) *S. recurvum*

Branch leaves Variable, 1.2-3.0mm x 0.3-0.8mm; ovate to narrow ovate, *widest at c. 33% from base*. **Hyaline cells** Long and narrow; 120-160μm x 10-20μm in the upper mid-leaf, those of the narrower pendant-branch leaves shorter (80-120μm). **Abaxial pores** Absent apart from occasional pseudopores/resorption gaps. **Adaxial pores** 5-9/cell; 5-10μm; faint and usually at cell angles, sometimes appearing elliptical due to protruding cell wall. **Photosynthetic cells** *Isosceles triangular*, narrowly enclosed adaxially.

Ecology One of the more minerotrophic species that may form an apparent monoculture in peat cuttings. Usually to be found at or around the water table but it may, at times appear as an aquatic or form low hummocks.

For differences from S. pulchrum, *see under that species. The leaves of* S. recurvum *may occasionally be narrow but they never approach the linear-lanceolate shape of* S. cuspidatum.

(vi) *S. tenellum* (Section Mollusca)

Branch leaves Small, 0.8-1.5mm x 0.4-0.9mm, broadly ovate and *concave*. **Hyaline cells** *Short and wide* (50-110µm x 20-35µm). **Abaxial pores** 0-2/cell; usually absent with occasional pseudopores in distal angle. **Adaxial** pores 2-5/cell; 4-18µm. **Photosynthetic cells** Equilateral triangular; narrowly closed adaxially, broadly exposed abaxially.

Ecology Fringing the edge of pools with *S. balticum* taking over at its upper limit. Also to be found forming lawns or, as sporadic shoots amongst other lawn formers.

Readily identified by the small, concave, ovate leaf with short, broad hyaline cells. The protruding retort cells of the branches are diagnostic and these are frequently encountered in palaeoecological contexts.

(V) Section Rigida

(i) *S. compactum*

Branch leaves Large, 1.8-3.0mm x 0.9-1.8mm; shape variable, oblong and ± cucullate to ovate with a squarrose acumen (the latter indicative of shade); *apparently dentate*. **Hyaline cells** Large but relatively short, 110-130µm x 30-40µm in upper mid-leaf. **Abaxial pores** 0-8/cell; 5-16µm; usually just set back from the commisures. **Adaxial** pores Absent apart from marginal cells. **Photosynthetic cells** Oval and completely enclosed.

Ecology Forming lawns and low hummocks under at least seasonally wet conditions of low shade. One of the first species to recolonise following fire or also on bare peat exposed by the destruction of Rhododendron..

For differences from S. molle *see under that species.*

2.4.3 Bryopsida

This order includes all the 'true mosses', *i.e.* excluding the monogeneric Sphagnopsida, dealt with above and the Andraeaopsida, a single genus of mosses confined to siliceous boulders in the montane, alpine and arctic zones. Within palaeoecological, raised-mire contexts those most likely to be encountered are typically found today on dry, ericaceous heaths. Indeed, their occurrence within the peat record of lowland raised-bogs is typically during the drier phases of mire growth when *Calluna* is dominant and we are thus presented with past analogues for the contemporary state of some damaged raised-mires. Identification of the mosses is often straightforward as their habit and leaves are well preserved within peat and accordingly, modern floras such as Smith (1978) and Watson (1955) can be successfully used. Watson (1981) offers the simplest approach and all of the mosses encountered on raised-bogs, in palaeocontexts, are likely to be found within his simple, concise volume. Although now out of date (first published in 1896), Dixon (1954), is still a useful text with excellent footnotes and italicisation of the most important taxonomic features.

A key is given below to those species encountered during the course of this study to both aid later researchers and to qualify my identifications. Bryopsid mosses can usually be recognised within palaeocontexts on account of their habit, where well preserved and/or the delicate, unistratose leaves typically stained a rich golden-brown, except for the multistratose leaves of *Polytrichum* defined below (couplet **2**).

Key to the Bryopsida

1 Nerve (mid-rib) single; continuous to the leaf apex or slightly below .... **(acrocarps) 2**

Nerve double or absent; never continuous to the leaf apex .... **(pleurocarps) 9**

2 Leaf opaque with the multistratose cell structure obscure; lamellae present on upper surface of the nerve **3**

Leaf translucent, and the monostratose cell structure obvious **4**

3 Leaf ± cylindrical due to inrolling of the lamina over the nerve .... **(vii) *Polytrichum juniperinum* type**

Leaf flat; margin sharply toothed .... **(vii) *Polytrichum commune* type**

4 Nerve > 30% of leaf width at base .... **(ii) *Campylopus* spp.**

Nerve < 25% of leaf width at base **5**

5 Leaf cells distinctly papillose; not porous **6**

Leaf cells smooth, commonly porous (in *Dicranum*) **7**

6 Basal cells elongate, upper quadrate; cell walls strongly sinuose .... **(ix) *Racomitrium canescens***

Cell length ± constant throughout; cell walls not sinuose .... **(i) *Aulacomnium palustre***

7 Leaves ovate, apex acute to sub-acute; usually not stained golden-brown .... **(vi) *Pohlia* spp.**

Leaves lanceolate, apex very acute, longly tapering; usually stained golden-brown .... **8 [(iii) *Dicranum* spp.]**

8 Leaves transversely undulate and rugose; cells in upper half of leaf not porose; nerve not or slightly toothed at back above .... ***Dicranum undulatum***

Leaves sometimes transversely undulate above, never rugose; cells in upper half of leaf porose; nerve with toothed lamellae at back above .... ***Dicranum scoparium***

Leaves not undulate, tubular or at least deeply channelled above; cells in upper half of leaf porose; nerve not toothed or with lamellae at back above .... ***Dicranum leioneuron***

9 Leaf cells unipapillose, < 3x long as wide; leaves strongly concave

.... **(xi)** ***Thuidium tamariscinum***

Leaf cells not papillose (obscurely so at back in *Hylocomium splendens*), > 3x long as wide, leaves not strongly concave **10**

10 Leaves squarrose or strongly reflexed .... **(x)** ***Rhytidiadelphus squarrosus***

Leaves not squarrose or strongly reflexed **11**

11 Angular cells not differentiated; apex sharply dentate .... **(iv)** ***Hylocomium splendens***

Angular cells differentiated (quadrate to rectangular cf. linear-vermicular); apex finely denticulate

.... **12 [(v)** ***Hypnum*** **spp.]**

12 Branching of stems irregular, not pinnate; alar cells neither enlarged or inflated

.... ***Hypnum cupressiforme***

Branching of stems regular, pinnate; alar cells enlarged or inflated .... ***Hypnum jutlandicum***

(i) ***Aulacomnium palustre***

Once known this species is instantly recognisable by the presence of a single, conical papillae per cell. If present, the tomentose stems are also very distinctive.

Ecology A common and often abundant moss in mire habitats and as van Geel (1978) points out it is, within such habitats, ecologically undistinctive.

(ii) *Campylopus sp.*

As a genus the plants are very distinctive, the nerve being very broad and occupying most of the leaf surface. Confusion perhaps only exists with ***Polytrichum commune*** type but here the presence of lamellae on the upper surface of the nerve is distinctive and diagnostic. Identification to species level is hampered by the loss of hair points and need to take a cross section of the nerve, a difficult process with delicate sub-fossil material!

Ecology Nine of the twelve British species grow in mire habitats ranging from heath to flush, on hummocks or bare peat. Therefore, without identification to species level no ecological information can be construed from the presence of the genus.

(iii) *Dicranum spp.*

The three species encountered during the course of this study were separated according to the characters outlined above at triplet **8**.

Ecology A number of contemporary bryologists doubt the existence *of D. leioneuron* as a species distinct from *D. scoparium* (G.P Rothero, pers. comm.) but for the purposes of this study it is convenient to maintain them as separate taxa because at least as a form of the latter, the former is apparently resident in mires only on *Sphagnum* hummocks (Smith, 1978*). D. scoparium* itself has a very wide ecological amplitude and is capable of growing on a wide range of substrata outside the mire habitat. Currently a rare and decreasing moss the decline of *D. undulatum* reflects the loss of its bog habitat and Dickson (1973) suggests anthropogenic factors to be responsible both for this and its currently disjunct range.

(iv) *Hylocomium splendens*

This species has an instantly recognisable 'jiz' in palaeocontexts. The tri-pinnately branched stems are mistakable only with those of *Thuidium tamariscinum* which always has a rough texture and is never so blackened as *H. splendens* appears to become. Microscopically the two are instantly distinguishable, the cells of *T. tamariscinum* being short and unipapillose whereas those of *H. splendens* are long, vermicular and only occasionally but obscurely papillose.

Ecology In the raised mire context this species is typically indicative of dry heath conditions, usually in association with other hypnaceous mosses. It is unlikely to be present upon a lowland raised bog unless there is some degree of humus accumulation.

(v) *Hypnum* spp.

The two species of this genus encountered are separated by the characters outlined above in couplet **12** but it should be noted that without whole shoots identification is difficult on characters of the alar cells alone. In addition, the occurrence of *H. imponens* may also be expected and this species would key out as *H. jutlandicum* in the key above. Taxonomically, mid-leaf cell length (*H. imponens*, 64-90μm *cf. H. jutlandicum*, 44-72μm) and fine detail of the alar cells may assist in differentiation but reference to comparative material is essential. Reference to the new key devised by Smith (1995) during a revision of this historically complex genus may be found helpful.

Ecology *H. jutlandicum* is typically found under ericaceous heath, especially around the base of *C. vulgaris*. Its sub-fossil record is non-existent according to Dickson (1973) and this is presumably a consequence of previous authors lumping many of the taxa present within the *H. cupressiforme* aggregate. *H. cupressiforme*, in the strict sense, is a variable species capable of growth in a wide range of situations which limits its use as an ecological indicator. *H. imponens* is a currently rare species of wet situations on mires.

(vi) *Pohlia* spp.

An acrocarpous genus which is easily recognised, once known, by a combination of the long, pellucid cells, ovate leaf shape and denticulate apex. Whole shoots may also be found frequently within the peat but identification is not possible without the mature capsules which are rarely preserved in palaeocontexts (Dickson, 1973)

Ecology Given the small stature of the specimens found within this study (<5mm) it would appear prudent to presume their occurrence on bare patches of peat whereby they may avoid shading and competition from larger, more aggressive species.

(vii) *Polytrichum commune* type

Contained within this taxon are two species; *P. commune* and possibly, *P. formosum*. The former species is much more typical of the bog environment than the latter and separation of the two rests on a transverse section showing the structure of the terminal, lamellar cell. In *P. commune* this cell is flat topped or grooved (strawberry-shaped) in section, whereas *P. formosum* has this cell rounded. However, to see this is a tedious and difficult operation on sub-fossil material which tends to tear rather than cut.

Ecology It may generally be assumed that the plants are growing in *Sphagnum* hummocks and/or lawns.

(viii) *Polytrichum juniperinum* type

Two very similar species are within this taxon; *P. alpestre* and *P. juniperinum* and the former is sometimes regarded as a sub-species or variety of the latter (Smith, 1978). *P. alpestre* is a large (3-20cm) plant which has a dense, white to off-white tomentum, *P. juniperinum* is smaller (1-10cm) and is in general not so densely tomentose and if it is, the tomentum is brown, never white. Differentiation is difficult in palaeocontexts where colour alters and length is hard to determine due to fragmentation.

Ecology Both species may commonly be seen growing through *Sphagnum* and I would suggest *P. juniperinum* to be much more tolerant of dry conditions than *P. alpestre*.

(ix) *Racomitrium canescens*

This species is an unusual find on raised mires (J.H. Dickson, pers. comm.) and it has also been recorded by P. Hughes (pers. comm.). Having the distinctive, incrassate, sinuose cells of the genus this species is readily identified from the others by its densely papillose cells. As Dickson (1973) points out, it is unusual that only one record of this easily identified species has existed from the Pleistocene (prior to the work of P. Hughes).

Ecology It is currently regarded as a plant of coarse grained soils such as tracksides, alluvial deposits, quarries, etc. (Dickson, 1973; Smith, 1978). Its occurrence on the humus rich substrate of a raised bog is therefore peculiar and all the more so when one would have expected the occurrence of *R. lanuginosum*, a currently common species on peaty substrates, particularly blanket-bog. However as stated by McMullen (1994), "It is often the case that organisms do not read the same textbooks as ourselves and hence, do not understand their role in the environment as clearly as we do". It is likely that the species is indicative of bare or eroded peat during a dry phase which is causing some retardation in growth of the bog surface.

(x) *Rhytidiadelphus squarrosus*

Stems of this moss invariably seem to survive relatively intact and the squarrose leaves forming a star when viewed end on are unmistakable with those of any other British species (Perry, 1992).

Ecology Usually in association with other hypnaceous mosses it is strongly indicative of dry-heath.

(xi) *Thuidium tamariscinum*

An attractive species almost resembling a fern in the fresh state with its rich tri-pinnate branching that often survives intact within the peat. This coupled with the short, unipapillose cells makes it unmistakable, possible confusion arising only with the similarly branched *Hylocomium splendens* whose cells are much longer and never so papillose.

Ecology Like the other hypnaceous mosses it is indicative of dry heath conditions. Watson (1981) regards it as a species especially indicative of thin peat and I would refine this to thin acid peat which may be overlying a depth of minerotrophic peat, as at Wreaks Moss.

2.4.4 Hepaticae

Only three species have been found within this order of often small, delicate plants whose gametophyte remains are very rare in the Pleistocene record (Dickson 1973). Remains from two of the three taxa covered here were encountered only in the unhumified peat of the acrotelm and in practise, I expect only *Kurzia* spp. to be found in the more ancient peat of the catotelm.

(i) *Chiloscyphus polyanthus*

This species bears a superficial resemblance to *Odontoschisma sphagnicola* but the leaves are more complanate, less rounded (±oblong) and the dorsal margin is shortly decurrent. Two distinct varieties are recognised (Smith, 1990) and of these only var. *polyanthus* has been found in almost contemporary times on Cranley Moss. Hydrophile, calcifuge it tells us nothing distinctive about the ecology of the raised bog habitat.

(ii) *Kurzia* spp.

The three British species within this genus can only be separated by characters of the female bracts (Smith, 1990) which, to date, have not been found. Remains are typically of short stem fragments, up to 1.5mm bearing a few of the distinctive hand-like leaves which may cause confusion with the genus of larger mire plants, *Lepidozia*.

Reported previously only by Overbeck (1972) it would appear that the genus is grossly overlooked as it has been found regularly in the course of this study. Being small plants, of up to 3 cm in length, with leaves of approximately 0.25 mm it is likely that the bulk of its remains are washed through the coarse sieves used in macrofossil preparation but identifiable fragments do turn up, perhaps more frequently, on microfossil slides.

This small size and their obscurity as plants would certainly explain their relative rarity in palaeocontexts. Little is known of their ecology and possible role on mires but it has been suggested that they may help to protect exposed peat surfaces (A.C. Crundwell, pers. comm.) but because they also grow through lawns of *Sphagnum* (Smith, 1990) this is by no means always the case.

(iii) *Odontoschisma sphagnicola*

This distinctive plant, as its name suggests, is often to be found amongst *Sphagnum*. The round leaves, laterally opposed are borne almost dorsally, thus exposing the stem ventrally. It has been found only once in this study, just below the surface of Shaw Moss. It is unlikely that this species will be present in deeper layers of peat.

2.4.5 Monocotyledonae

Only three species within one monocotyledonous family, the Cyperaceae, are encountered in raised-bog peat deposits, *Eriophorum angustifolium*, *E. vaginatum* and *Rhyncospora alba*. A fourth, *Tricophorum caespitosum*, despite its contemporary abundance, is usually never met with and it is presumed to be the victim of preferential decay (Godwin, 1975) but no experimental studies have yet been undertaken to confirm or refute this.

Within the three species commonly encountered the following components have been recognised:

(i) *E. angustifolium*

Epidermis The sinuose cells (15-50μm x 15-25μm) are distinctive especially the invaginations between end walls from cells in the adjacent row. **Roots** These are easily identified because they retain their diagnostic pink coloration. Rhizome fragments are also included within this category. **Seeds** These do not appear to be found in palaeocontexts and perhaps their germination is such that a seed bank is not formed?

Ecology This species is indicative of wet mire conditions (Stace, 1991) and is a common component of bog pool vegetation (Rodwell, 1991). However its chronological position within the mire cannot be ascertained with exactitude from the distribution of roots or stem bases (Godwin, 1956), both of which are often exposed on the face of a core. These remains are identifiable in the field and separable from *E. vaginatum* as this species is more densely tufted, less longly rhizomatous and does not have the pink roots of *E. angustifolium*.

(ii) *E. vaginatum*

Epidermis The sinuose cells of this species lack the invaginations of *E. angustifolium* and are very much longer (35-100μm x *c.*13μm). **Nodes** These are often found in association with the epidermis and contain the banana-like **spindles**. **Roots** Distinctive in their black coloration they can be traced in peat faces to considerable depths below the hummock itself ≤50cm. Rhizome fragments are also included within this category. **Seeds** Like most members of the Cyperaceae the seeds are trigonous and usually coloured black in peat..

Ecology This species is ubiquitous in blanket and raised bog environments (Godwin, 1956) and where active bog growth has apparently ceased tussocks of up to 60cm high and wide are formed e.g. Féith Musach, Tomintoul. These dense tufts are often encountered on the open faces of peat cuttings or cores and are easily identified although their bulk and toughness makes them tiresome to dig or core through. It can be found from driest to the wettest parts of a mire even occurring in pools, usually as tussocks. I would suggest it competes most favourably where water levels are fluctuating or responding to drainage/climate change.

(iii) *Rhyncospora alba*

Epidermis The cells of this species are ± quadrate to shortly rectangular, in size around *c.* 25μm. The primary feature of distinction is that the end walls are plain whereas the lateral walls are deeply sinuose. **Seeds** Looking like a hybrid between a Gae Bolg and Sputnik satellite the seeds are unmistakable and once known, they are instantly recognised.

Ecology A characteristic species of wet, possibly inundated peat or *Sphagnum* (Godwin, 1956) where it forms spindly, open lawns.

In addition to the above species' components the following monocotyledonous components are also included in the diagrams:

(iv) Total monocots.

The sum of all monocotyledonous components.

(v) Monocot. roots

The sum of roots referable to *Eriophorum angustifolium* and *E. vaginatum* plus the unidentifiable residue attributable to these two species, *Rhyncospora alba, Tricophorum caespitosum* and towards the surface, *Molinia caerulea.*

(vi) Undeterminable monocots.

Usually epidermis that bears no distinctive cellular structure and cannot be included in any of the above components. Much of this sum is often referable to *E. vaginatum* remains which have become decomposed during the dry conditions apparently prevailing at this time.

2.4.6 Dicotyledonae

The Ericales predominate amongst the dicotyledonous plants found upon raised-bogs and it is fortunate that in such contexts all the species encountered are readily identified. Other species are occasionally encountered such as *Myrica gale* (Myricaceae) and the seeds of *Betula* spp. (Betulaceae) but the latter were not counted since their origin is usually outside the mire area, particularly on the lagg zone in contemporary times. The following species and components are recognised within this study:

(i) Ericaceous roots

Readily identified by their fineness and reddish-brown coloration. *Vaccinium oxycoccus* roots are typically more orange and may be identified separately but not perceiving a well marked discontinuity in variation I have not felt confident of this and instead lump all such roots together.

(ii) *Calluna vulgaris*

Branches Bearing imbricate leaves in four rows and where these have become dismembered the leaf scars remain visible. **Flowers/seed boxes** The 4-merous bell, 2-3mm long is dissected to the base. **Leaves** Small (1-2mm), ovate with strongly revolute margins. **Seeds** Yellowish with sigmoidal cells having sinuose walls. **Wood** Usually bearing bark which, when broken into with tweezers, reveals the reddish, fine grained wood.

(iii) Dicot. leaf unidentified

Separated from the Monocotyledoneae by the net venation. The single leaf attributable to this taxon was presumed to have derived from outside the peat environs.

(iv) *E. tetralix*

Flowers/seed boxes Bell shaped, 6-7mm long. **Leaves** 2-4mm long, linear, sometimes still bearing the marginal cilia or scars thereof. **Seeds** Orange with polygonal cells. **Stems** Usually distinct when still bearing leaves but more commonly the 4-whorled leaf scars serve as a mark of distinction.

(v) *Menyanthes trifoliata*

Seeds Bean shaped and light pink in colour, 3 mm to 4 mm in length.

(vi) *Myrica gale*

Catkins Recognised by the imbricating bracts and reference to comparative material is advised. Both male and female catkins may be found. **Leaves** 2-6cm oblanceolate, toothed apically; decompose to reveal net venation.

(vii) *V. oxycoccus*

Flowers 4-merous with reflexed petals, 5-6mm. **Leaves** 4-8mm, oblong-ovate with recurved margins. **Seeds** Contained in a fleshy fruit. I have not found them and perhaps their small size escapes attention; but it is also possible that no seed bank is set up? **Stems** These may retain their orangey coloration with distant leaf scars.

2.4.7 Charcoal and fungi

Only the larger pieces (*c.* 1mm+) of charcoal were recorded in order to take account of local fires only and exclude those that may have been peripheral with no direct effect on the raised bog vegetation. The black, globose resting spores of *Coenococcum*, an ericoid mychorriza typical of dry layers, were also counted.

2.4.8 Pollen

Pollen counts were used to date the upper layers of Deer Dyke Moss due to the availability of dated diagrams in the literature. In determining taxa the guide produced by Barber (1996) was found to be most useful as it encompassed all the necessary taxa for simple dating purposes and is also simple and easy to use. The more extensive works of Moore (1978) and Faegri and Iversen (1989) were also consulted. Final confirmation and initial investigations into this technique were facilitated by the reference collection of the Palaeoecology Laboratory, University of Southampton.

2.4.9 Testate amoebae

Analysis of the tests of these species is rendered problematic due to synonymy within the works consulted. The nomenclature of Woodland (1996) is followed since this is the standard adopted by the group under D.J. Charman at the University of Plymouth whose conversion factors are used within this study. For identification purposes, the scanning electron micrographs and descriptions of Ogden and Headley (1980) are found to be the most useful with reference also being made to the following works: Corbet (1973); Deflandre (1928 & 1929); Ellison & Ogden, 1987; Grospeitsch (1958); Heal (1961); Lee *et al.* (1985). The work of Wanner and Meisterfield (1994) adds a cautionary note to the identification of this group of organisms whose taxonomy is in need of revision (D. J. Charman, pers. comm.). Reference material was not available but the photographs taken by D. Mouquay for the Palaeoecology Laboratory at Southampton University were found to be very helpful.

2.4.10 Algae

Chains of algal cells are easily recognised in palaeoecological contexts but no attempt was made to identify the taxa present other than the instantly recognisable *Spirogyra* spp. whose diagnostic spiral chloroplasts were well preserved. In other species internal organelles had been lost reducing their identification to a knowledge of cell dimensions.

2.5 QUANTIFICATION OF PEAT COMPONENTS

2.5.1 Plant macrofossils

The Quadrat and Leaf Count (QLC), developed at the University of Southampton was used in the quantification of plant macrofossils. The method is as follows: the prepared sample is tipped into a trough so as to approximate to a monolayer and the peat components are then quantified as percentages or scores on a 5-point scale within fifteen, 1 cm^2 quadrats viewed at x10 magnification (Clarke, 1988). One hundred *Sphagnum* leaves are then removed and placed onto a slide for identification, counting and expression as percentages of the 'Total *Sphagnum*' score.

The two forms of quantification adopted pose problems for statistical analysis but are essential due to the nature of the plant remains within the peat. Percentages are used for those components which mix homogeneously throughout the trough (*i.e. Sphagnum,* leaves, roots and epidermis). These components and their sums are represented on the diagrams as histograms (Figures 4.1.1 to 4.1.1.9). A 5-point scale is used for the remaining, heterogeneously distributed or rare components (*i.e.* shrubby remains, the remaining bryophytes and seeds) and these are represented on the diagrams as bars. This approach is employed because aggregated, heterogeneously mixed parts like the wood, flowers, etc. do not always show up in a series of *random* palaeoquadrats. It is therefore deemed prudent to scan the entire trough and numerate on the 5-point scale what else is there lest it be missed and its ecological significance be unaccounted.

Sources of error in quantifying the vegetation components of the peat arise from;
(a) *The growth form. Vaccinium oxycoccus* is a particular case in point. Its two dimensional habit results in one or two leaves or maybe a single flower being included in the 4 cm^3 palaeoquadrats whereas the three dimensional habit of *Calluna* allows for a homogeneous rain of detritus and hence much greater inclusion within a palaeoquadrat. Additionally, the small size and elevation of *C.*

vulgaris parts probably ensures that they are more widely dispersed over the mire surface than say *E. tetralix* with its larger leaves and flowers or *V. oxycoccus* growing close to the ground.

(b) *Spatial distribution* This is closely related to (a) and is dependant upon the surface area of the plant and hence, the probability of that plant being incorporated into the acrotelm.

(c) *Differential preservation* Certain species may be preserved in an unrepresentative proportion [e.g. *Sphagnum* species (Clymo, 1965) or not all, e.g. *Tricophorum caespitosum* (Godwin, 1956)] due to the differential decay of plant remains.

These sources of error are impossible to predict or quantify and it was therefore considered prudent to avoid a spurious appearance of confidence by using the semi-quantitative 5-point scale to express the final results for the vegetation communities typified and described in this study.

It is commonly suggested that macrofossil studies reflect the *in situ* growth of species (Birks & Birks, 1980; Grosse-Bauckmann, 1986; Wasylkiowa 1986) but C.A. Dickson and J.A. McMullen (unpublished) found evidence for windblown *Sphagnum* leaves being incorporated into the midden material at the neolithic village, Skara Brae in Orkney. The prevalence and significance of this dispersion has not yet been addressed in the literature but it surely demands further study, perhaps in a manner similar to the pollen traps employed by palynologists. It does however suggest that the ecological information contained in a single core may reflect, to an uncertain degree, more than that of the microtope sampled.

Another feature of the macrofossil diagrams constructed from a single core is the apparent coming and going of taxa within a phase. For the vascular species, *C. vulgaris* and *Eriophorum* spp. this relates to their respective strategies of adventitious branching (Gimmingham, 1960) and plagiotropic rhizome growth (Wein, 1968) which allows them to maintain an upward rate of growth that matches that of the *Sphagnum* carpet. The sporadic occurrence of *E. tetralix* is probably related to its initial establishment in proximity to the core and subsequent maintenance there until its demise at an age of up to 19 years (Rutter, 1955). Further away from the core hole the relatively large, anatomical parts of this plant (*cf.* Bannister, 1958) preclude their dispersal over the vegetation surface and this can be impaired further by the development of a close *C. vulgaris* canopy. Amongst the Sphagna, the coming and going of certain taxa within a phase is probably related to small scale climatic shifts, stochastic influences and modification of the microtope by their own, respective growth forms (*cf.* van der Molen *et al.*, 1993). Accordingly species may be seen to come and go within a phase and this can offer some insight to the spatial arrangement of species within a community. This might be seen as a source of error but repeated sampling of the phase of a particular community, throughout time can be considered a substitution for the replicate samples taken in space by contemporary ecologists. Finally, some extreme but short-lived peaks may be due to amplified shifts occurring around the threshold value for a community and this *might* be seen within this study during wetter phases dominated by *S. auriculatum* and *S. cuspidatum*.

2.5.2 Pollen

One hundred, non-mire grains were counted and all tree taxa (exc. *Corylus*) were included in the pollen sum, of which the other taxa were expressed percentages in line with the work of Oldfield (1967) whose results were used for dating the upper 50cm of Deer Dyke Moss.

2.5.3 Testate amoebae

One hundred and fifty tests were counted per layer and the concentration of the tests determined by the following formula.

number of tests.cm^{-3} = *number of tests counted* **x** *number of* Lycopodium *spores counted / 1500*

The final counts are expressed as percentages in the format of a cornell condensed file and such data is then in a suitable format to use with the conversion factors for percentage moisture and depth of water table as per the requirements of Dr. D. Charman at Plymouth University. The results of these conversions are given with the 95% confidence limits corresponding to *c.* ± 4 cm with little variation and therefore this range is not reiterated throughout the remainder of the study.

As it turned out, the calculation of testate amoebae concentrations was not utilised in this study but this data is recommended by D. Charman (pers. comm.) to elucidate the source of apparently erroneous results.

2.6 STATISTICAL ANALYSES

The basic assumption of this study asserts that hydrology is the single most important variable in determining composition of the prevailing vegetation. Hydrology, usually measured as depth to the water table from the vegetation surface, has been shown to be of primary importance for contemporary vegetation in numerous studies (see references in Heathwaite *et al.*, 1993 for examples). A smaller number of authors have reported on the effect of hydrochemistry upon the vegetation of raised bogs (e.g. Koerselman & Verhoeven, 1992; Pakarinen, 1982, Proctor, 1992, 1994; Proctor & Maltby, 1998; Wind-Mulder *et al.*, 1996). In his study of 39 ombrogenous peatlands in Britain and Ireland Proctor (1994) suggests that the major, nutritional ions have little "*direct* influence" on ombrogenous vegetation communities and instead follow established topographic (= hydrological) and climatic gradients. Accordingly, the impact of hydrochemistry is ignored and the hypothesis proposed is that hydrology, determined as depth to the water table, is the single most important variable in raised bog ecology.

To ascertain validity of the hypothesis within this study a multivariate statistical technique, Detrended Correspondence Analysis (DCA) was utilised. The derivation and mathematical principles of DCA are to be found in the following works; Hill & Gauch (1980) and ter Braak (1986, 1987a & 1995) while Kovach (1996) and Shi (1993) both offer a good, general introduction to the subject from a palaeoecological perspective. Essentially, DCA analysis summarises the variability present within a multidimensional data set into the two axes of a scatterplot where the x-axis (DCA axis 1) encompasses the greatest amount of variability and the y-axis (DCA axis 2) the second greatest amount of variability. Further axes may be extracted and four are calculated by the computer program CANOCO (ter Braak, 1985b) used in this study. Confirmation or rejection of the null hypothesis is dependant upon the appearance, or otherwise, of a hydrological gradient on DCA axis 1.

Analyses were run using 5-point scale data for Arnaby Moss Regeneration Peat and percentage data for the remaining sites. It was considered desirable to use 5-point scale data for all of the sites and therefore gain the maximum amount of information by including all species. However, in practice this was found to be impractical since, with exception to Arnaby Moss Regeneration Peat, the resulting scatterplots were ecologically meaningless. The diversity of taxa at Arnaby Moss Regeneration Peat is relatively low and none were numerically rare whereas for the remaining sites the converse is usually true. It is therefore suggested that the presence of numerous, rare taxa, which have little or no apparent relationship to the axes, masks the inherent ecological relationships when the 5-point scale is used. In addition, the sporadic occurrence of certain peat components, related more to their stochastic preservation than ecological response, is suggested to be a further block to the elucidation of clear ecological relationships. The running of data quantified on percentage data alone removes this source of error since many of the taxa which occur sporadically (such as seeds, non-*Sphagnum* bryophytes and sometimes, aerial, ericaceous parts) are excluded. In addition, a greater amount of calculable variation exists within the expression of data as percentages which is consequently reflected in the dispersion of taxa along the DCA axes.

2.7 DESCRIPTION OF VEGETATION COMMUNITIES

The fundamental assumption made within this study is that the vegetation communities which occur on lowland raised bogs do so in distinct phases. This concept was first proposed in the writings of von Post, summarily discussed by Conway (1948) and proposed as the Phasic Theory of bog growth. This theory was verified by Barber (1981) who also concluded that the raised bog surface responded to climatic change as a whole.

It is apparent within each phase that the abundance of individual species may vary according to environmental change or species dynamics, but the floristic composition does not alter markedly until a postulated threshold value for that community is reached (von Post in Conway, 1948). These threshold changes can be seen in the macrofossil diagrams as generally well marked and abrupt changes in species composition. The threshold value for a given community present on a raised bog is assumed to relate primarily to the depth of water table and this is in turn dependant upon the prevailing climatic regime.

Determination of where a given phase starts and ends is usually a readily apparent feature of the macrofossil diagrams. However, the boundaries of some communities, particularly those where *Sphagnum* sect. *Sphagnum* species dominate over lesser representations of other taxa, are difficult to determine in the absence of a sustained appearance of their constituent species. In this instance division is made on the supporting evidence of shifts in the testate amoebae assemblage, collectively apparent in the water table constructions. Such divisions are possibly undesirable in that they impose upon the transitional nature of certain raised bog communities but some distinction can be made between a "pooly" or "hummocky" lawn and their corresponding water table depths.

The vegetation communities were defined according to the marked vegetational changes already indicated, throughout the stratigraphy of each raised bog and then cross matched between sites. A Twinspan (Hill, 1979) analysis (not presented) was also performed to compare against this subjective method. Unsurprisingly, the same communities were recognised but additional complexity was added to the interpretation by Twinspan segregating out short sections of stratigraphy representing ecological noise (e.g. the transitory occurrence of an *E. vaginatum* tussock). Accordingly, this analysis was abandoned on the grounds that it offered no advantage over the method used ultimately its apparent objectivity was questionable due to the subjective judgement required in disentangling the many stratigraphic sections it defined (even over a few iterations).

2.8 DATING METHODS

2.8.1 Radiocarbon dating

The radiocarbon dates obtained for this study help to elucidate two key points in the restoration of raised bog vegetation:

(i) Over what timespan will changes in the vegetation of a site become apparent following elevation of the water table?

(ii) Which species or communities most rapidly accumulate peat and accordingly, are those most suitable for the recolonisation of sites where restoration of an active acrotelm is desirable?

To facilitate determination of these rates bulk radiocarbon samples were taken on either side of a phase transition from cores which had been stored horizontally at 4°C. These bulk samples were of 8 cm stratigraphic length and of dimensions appropriate to obtain 100 g of wet peat material. Bulk radiocarbon samples incur a systematic error by the averaging of a large number of potential radiocarbon dates which, in the 8 cm stratigraphic samples used here, may span 3.3’ decades to 20.5 decades (according to the accumulation rates determined within this study). This source of error is particularly problematic for estimating the rates of transition between one community’s phase and the next. This is because in the averaged age from a stratigraphic section the mean value obtained will tend towards the centre of the section and not at the end closest to the transition. As a consequence of this, accurate rates of transition are not determinable but the presence of a continuum or hiatus may be discernible. In determining rates of peat accumulation, Shore *et al.* (1995) point out that different stratigraphic lengths, of a bulk radiocarbon sample, will lead to different results. However, this error is overcome to some extent by the replication of some dates for a given community between and in one case, within sites. Olsson (1986) additionally notes that where a bulk radiocarbon sample crosses a boundary the differences in accumulation rate may give rise to an incorrect radiocarbon determination because of the different rates of accumulation. This error may arise here because of the arbitrary placement of a transition based upon the 4 cm sampling interval rather than its true stratigraphic position.

The penetration of roots into lower peat layers has often been considered a source of error in radiocarbon dating by the introduction of young carbon into old. However the results of Kilian *et al.* (1995) proved surprising in the apparently greater age of peat containing ericaceous rootlet. This was related to their intake of ancient CO_2 derived from the oxidation of catotelmic methane (Shotyk, 1983). Recent work at Aberdeen University on carbon flux has indicated that mire waters can become supersaturated in CO_2 to values twenty times greater than that of the atmosphere (M. Billet, pers. comm.). However, dating of the of the ericaceous rootlets indicated that they were not necessarily the source of ancient carbon (Kilian et al., 1995) and it could therefore be suggested that the Sphagna perhaps exploit this ancient carbon source. This ancient carbon is attributed to a further source of error in radiocarbon dating known as the reservoir effect (Stuiver and Pollach, 1977) and it is present as the three fractions described by Shore *et al.* (1995), namely humin and the humic and fulvic acids. To increase the accuracy of bulk radiocarbon dating Shore *et al.* (1995) attempted to discern the best of these three peat fractions for dating but their results proved inconclusive and perhaps illustrate best the complexities of translocation with raised bogs.

Since the decay of radiometric particle obeys laws of probability an associated, statistical error value is included in the expression of a date by radiocarbon laboratories. This probability curve assumes a normal distribution (Olsson, 1986) and its extent is independent of the size of stratigraphic section sampled. The radiocarbon dates obtained for this study were subsequently calibrated using the OxCal program of Bronk Ramsey (1994) to derive the potential range of calendar years before present (BP) within 95.4% confidence limits (2 δ). The output from this program is expressed as a probability distribution curve which is derived from that of the radiocarbon date and the known decay rate of radiocarbon by calculation of the variance distribution (Bronk Ramsey, 1994). Selection of a date within the range proffered by OxCal is subjective and in this study the most central peak of probability was taken as the date for calculating rates of peat accumulation.

Due to financial constraints only three sites were selected for coring and these were chosen on the criteria selected below. The section from Arnaby Moss Regeneration Peat was not considered because of its modern origins.

(i) Mullenakill Bog: This site was chosen as representative for the Northern Ireland sites, both of which contained a similar, palaeoecological record although Ballynahone appears to have retained a consistently higher abundance of *C. vulgaris* throughout the late Holocene. Mullenakill Bog was selected on account of the management aim to encourage palaeoecological research upon the site and also for its commitment to education. It is therefore hoped that the radiocarbon dates obtained for this site will have wider educational implications than the confines of this study alone.

(ii) Cranley Moss: Cranley Moss and Coalburn Moss are very similar stratigraphically and the former was selected for radiocarbon dating on the basis of its greater, palaeoecological biodiversity. There is little else to choose between the sites although Cranley does already have radiocarbon dates from the study by Dumayne (1992). Unfortunately, these have no application within this study because of the need for calibration using pollen data not collated in this study.

(iii) Arnaby Moss: A high degree of variability was apparent in the Cumbrian sites but this raised bog was selected on the basis of the dry, heathy phase present in its palaeoecological profile between 196 cm and 124 cm. This phase appears analogous to the vegetation communities present on many badly damaged raised bogs, particularly in the absence of a continuous *Sphagnum* lawn. In addition, the communities present at the other Cumbrian sites are to some extent replicated within the palaeoecological profiles from Mullenakill Bog and Cranley Moss, as well as Arnaby Moss.

2.8.2 Pollen dating

Date (A.D.)	Event
1540	An increase in weed and bracken frequencies as mixed farming replaced pastoral.
1700	An increase in agricultural pollen types and an accompanying decrease in wood- and wasteland taxa as agriculture expands.
1800	Primarily, the decline in hemp pollen frequencies following closure of the local monastery with a lesser decrease in the pollen of *Artemesia* related to the "New Husbandry" of the Agricultural Revolution (Oldfield, 1963).
1860	Extrapolation of the peat accumulation rates and the absence of post 1870 changes in the pollen profile.

Table 2.1 Outline of the chronology proposed for Deer Dyke Moss by Oldfield (1969). Based on a comparison of documented changes in land use with palynology.

Pollen analysis was undertaken on the top 38 cm of peat from Deer Dyke Moss in order to date recent changes in the peat profile. Referral was made to the work of Oldfield (1969) who proposed a "tentative scheme" of chronological events in the vicinity of Deer Dyke Moss with particular reference to the area now included within the boundaries of Roudsea Wood. The dates proposed by Oldfield (1969), are based on documented, historical changes in land use and their palynological characteristics are summarised above, in Table2.1.

3. SITE DESCRIPTIONS

Figure 3.1 Distribution map of the study sites.

* Duddon Mosses; Arnaby Moss Regeneration Peat, Arnaby Moss and Wreaks Moss.

3.1 BALLYNAHONE BOG, CO. LONDONDERRY

Ballynahone Bog, situated near Magherafelt, (Grid ref: Sheet 78 8698), like many loughs and wetlands in the north of Ireland, is impounded within a matrix of drumlin like hills descriptively known locally as "eggs in a basket". In this instance, the drumlins are composed of glacial, yellow and brown sands and blue, brown and grey clays (Double, 1954). Initially the site developed as a basin mire (Double, 1954), a term still applicable to its physiography but upon which an undated, ombrotrophic surface subsequently developed. At the time of Double's observations in the early 1950's the margins of this ombrogenous area had apparently been cut away but the central area of dome was considered to be intact when assessed by the Northern Ireland Peatland Survey in the late 1980's and to cover some 244 ha in extent (Cruickshank and Tomlinson, 1988). This is one of the largest remaining areas of continuous peatland in Northern Ireland, of which some 105 ha are considered to represent original surface (Shaw, 1993).

Biological and physiographic interest in Ballynahone Bog is very strong and it was assessed to be one of the top ten lowland raised bog sites in terms of conservation importance by Leach and Corbett (1987). This interest relates to the size of the site, its hummock-hollow topography and the consequently rich wetland flora and fauna that this supports including some rare and notable species. The anthropogenically disturbed areas also contain much diversity and the following habitats are present; poor fen, scrub, woodland, grassland and heath. On the main area of uncut, ombrogenous peat, the nationally scarce *Sphagnum pulchrum* and provincially rare *Andromeda polifolia* are to be found in addition to the rich flora of typical, ombrogenous species. The diverse vegetation in turn provides a home for many insects and a number of breeding or wintering bird species, some of which are nationally scarce or rare.

Damage to the site in more recent times has mainly focused around the interests of

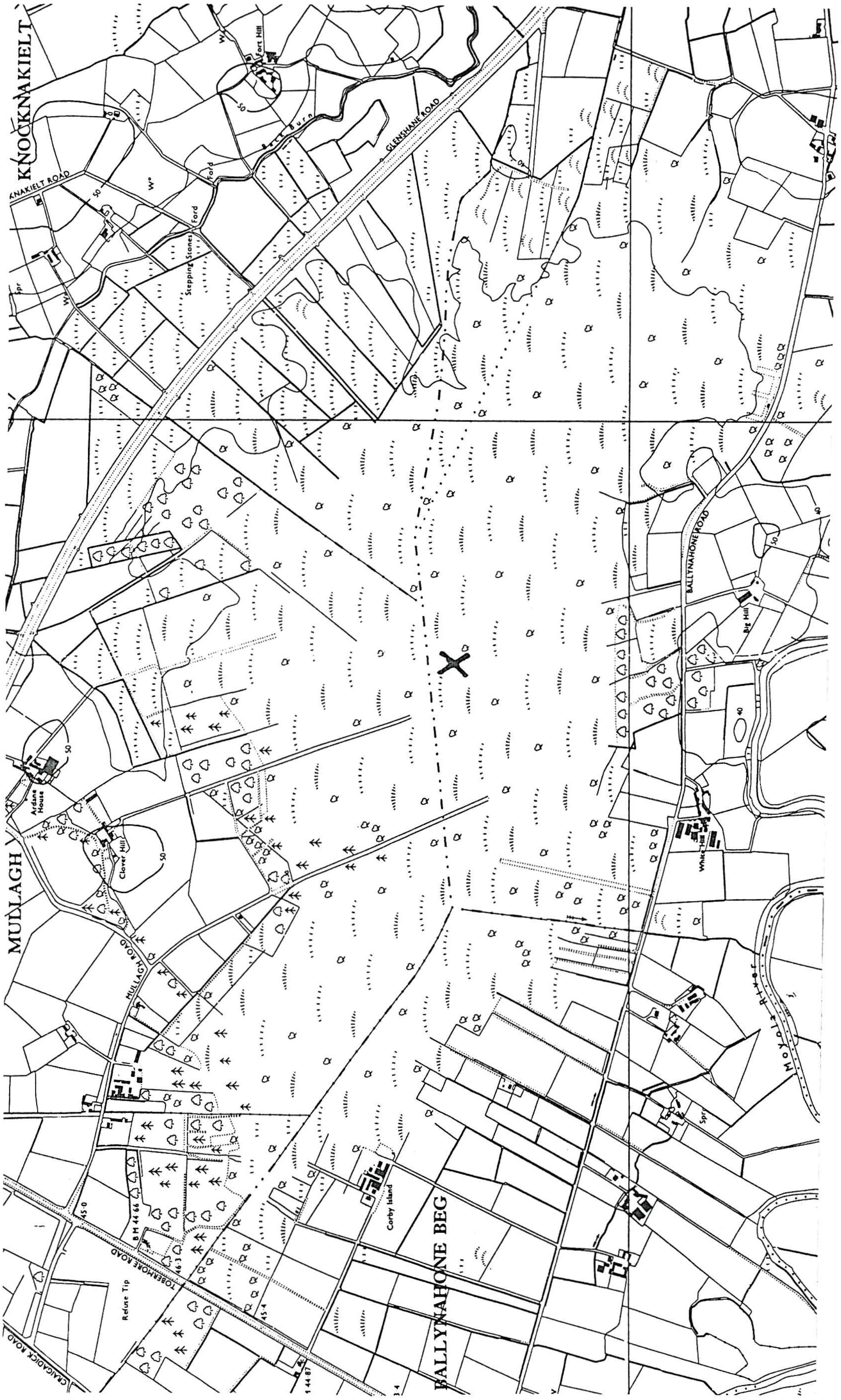

Figure 3.2 Map of Ballynahone Bog ("X" indicates the approximate core location).

Bulrush Peat Company (now Levingtons) who installed drains on the northern half of the bog in preparation for peat extraction. This followed the planning consent granted in 1988 after a lengthy, public enquiry. Local people, alarmed at the prospect, formed Friends of Ballynahone Bog and set in process a legal challenge against the government, urging them to revoke the planning permission and instead to confer mandatory, protective legislation upon the bog. The basis for this action revolved around the apparent negligence by government ministers who had not granted the bog protective status as either an ASSI or Special Area of Conservation, the latter being mandatory under the European Habitats Directive. Ultimately, campaigners won the right to take the Government to court over this apparent negligence but before their hearing the Northern Ireland Office confirmed in October, 1994 that it would undertake to confer protective legislation and revoke the planning permission granted to Bulrush (*http://www.foe.co.uk:8070/wildplaces/s_bally.html*). This action was to prove costly since, although the site itself was purchased by Northern Ireland's Environment and Heritage Service for the nominal sum of 5p, compensation and court cost claims by Bulrush and its parent company Pindstrup Moseburg A/S ran respectively to £2 million and £1 million pounds (*http://alexandra14.nio.gov.uk/press/970725b.htm*).

Following the Northern Ireland Office's declaration to protect the site in October, 1994 the Friends of Ballynahone Bog undertook to dam all drains on the site, five years after they were incised. Shortly after this, on the 25th January, 1995, ASSI status was conferred upon the site which is now also a NNR. At the time of my visit in September 1997 the bog appeared to be in healthy condition with bog pools in evidence and rafts of vegetation developing within the now flooded drains. No hydrological monitoring has been implemented but damming operations certainly appear successful. Also encouraging was the fact that no signs of recent burning were evident, a feature noted by Cruickshank and Tomlinson (1988) on their visit prior to Bulrush's drainage scheme.

3.2 COALBURN MOSS, LANARKSHIRE

Situated in the Upper Clyde Valley, Coalburn and Cranley Mosses are the highest sites in this study, at an altitude of 210 m. Rainfall, measured at Carnwarth (NS 974464, 220 m alt.), respectively, 14 km north-east and 5 km east, of Coalburn and Cranley stands at *c.* 805 mm.annum^{-1}. This contrasts with the north-west of England sites which have developed in low altitude, estuaries and areas of higher rainfall (900 - 1400 mm.annum^{-}).

The central area of the 196 ha Coalburn Moss (Grid ref: Sheet 78 8698), is bounded by two railway lines which, it has been suggested, limit water loss from the site. Recent work by SNH has shown that the peat is in fact continuous below these lines (L. Buckle, pers. comm.) but their hydrological impact is still not clear. A number of old drains dissect the site and some of these are still active, particularly the main drain running across the Moss north-west/south-east. Despite all of this, the water table is still apparently close to the surface.

Peat cutting has taken place to the south of the site leaving a small, *c.* 1 m step. This area currently retains standing water and lagg vegetation has recolonised, undoubtedly helping to buffer the water table in the main area of ombrogenous peat. The flora of this small area has presumably arisen from the remaining sections of lagg vegetation that still discontinuously border the Moss. Most anthropogenic utilisation of the Moss has focused on the reclamation of agricultural land for grazing. The remnant area of Moss is consequently bordered by a series of reclaimed wet and dry fields, some of which are included within the SSSI boundary offering scope for further hydrological restoration. Additional damage to the site includes the presence of grip drains on the south-west segment of Coalburn Moss, defined by the railway and main drain. Here there is also evidence of burning, probably exacerbated by drainage.

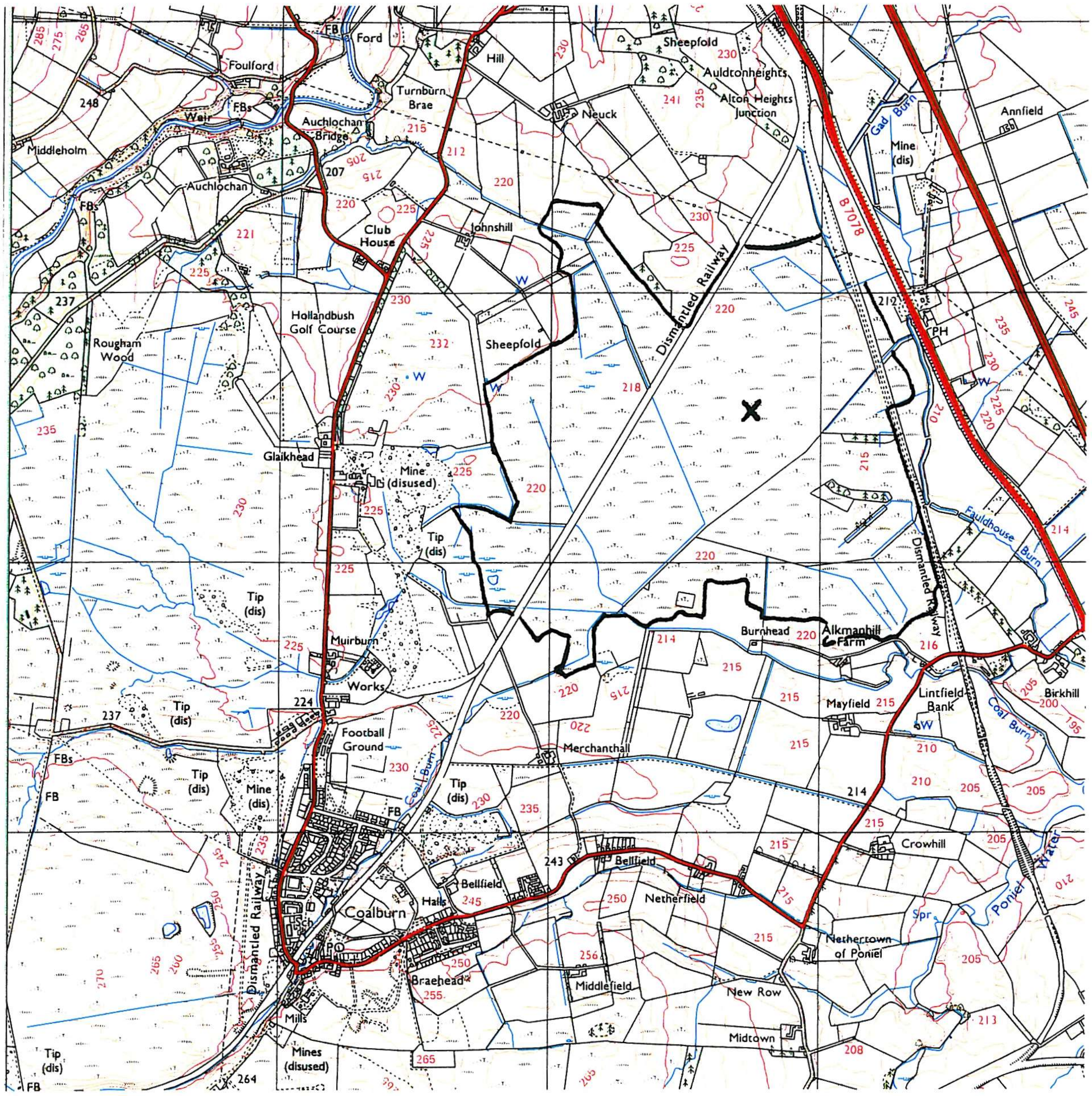

Figure 3.3 Map of Coalburn Moss ("X" indicates the approximate core location.)

The surface of the mire retains a high proportion of continuous *Sphagnum* vegetation put at 45% in the Nature Conservation Review Confirmation. The topographically diverse vegetation is dominated on the lawns and low ridges by *S. capillifolium* and *S. magellanicum* with *S. tenellum* becoming common in the wetter hollows. The hummocks are colonised by *C. vulgaris*, *A. polifolia*, *E. tetralix* and *E. vaginatum* with an understorey of hypnaceous mosses, most commonly *H. cupressiforme*. The other Sphagna recorded are *S. auriculatum*, *S. compactum*, *S. cuspidatum*, *S. imbricatum* and *S. papillosum*. The *Sphagnum* cover becomes discontinuous in those areas where damage has ensued from the presence of moor grips and burning but the surface in both cases remains wet and capable of supporting *Sphagnum* growth.

3.3 CRANLEY MOSS, CLYDESDALE

Cranley Moss lies some 6 km north-east of Lanark and 15 km, in the same direction from Coalburn Moss. The vegetation is similar to that found on Coalburn Moss with *S. capillifolium*, *S. cuspidatum*, *S. magellanicum* and *S. papillosum* most dominant amongst the Sphagna which are extensively present. The same vascular species are encountered as at Coalburn Moss but by comparison, *A. polifolia* is a rare species here. A small number of *Pinus sylvestris* are sporadically located across the mire surface and a number of these appeared to be succumbing to waterlogging. It is unlikely therefore that they will pose a problem and at present they serve as perches for raptorial bird species whose pellets were not uncommon around the bases. No signs of burning were noted during the time of survey and this is probably a consequence of Coalburn Moss's relative isolation within an area intensively utilised for agriculture. However, cutting of this mire has left a large step of 2 m to 3 m, down to the Mouse Water but this reconformation of the mire has not led to a marked decrease in surface wetness, as evidenced in the luxuriance of Sphagna to within tens of metres from this feature. By contrast, the cut-over area has become colonised by a

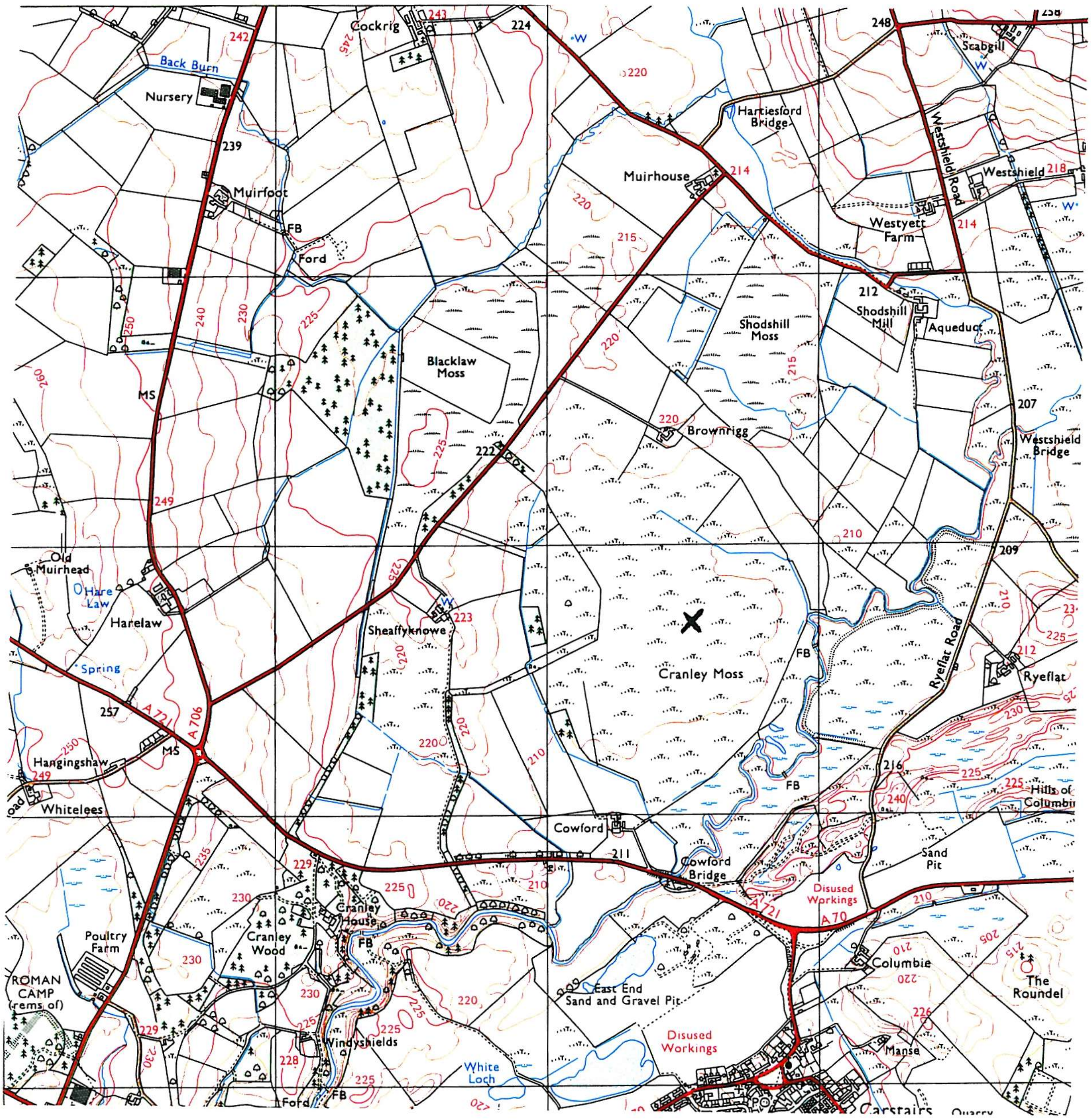

Figure 3.4 Map of Cranley Moss ("X" indicates the approximate core location.)

xeric, tussock forming community dominated by *C. vulgaris*, *Deschampsia caespitosa* and *Pleurozium schreberi.*

The relatively few drains that were cut into the main expanse have now all been blocked (in 1991) and a water table monitoring regime has been set up (L. Buckle, pers. comm.). The lagg stream which drains into the Mouse Water retains some of its characteristic vegetation but has been modified for drainage not only of the mire but also the surrounding agricultural land.

3.4 DEER DYKE MOSS, CUMBRIA

Deer Dyke Moss (Grid ref: SD 3382), situated on the eastern shore at the head of Morecambe Bay at 9 m alt., represents a similar situation to that found at the Duddon Mosses. At one time the Moss would have formed part of an extensive, estuarine mire system that has become fragmented through peat cutting and reclamation for agricultural land. Currently the Roudsea Woods and Mosses NNR encompasses two discrete areas of extant peatland; Deer Dyke - Fish House Moss and to the south, White - Ellerside Moss. Deer Dyke Moss and Fish House Mosses are separated by a mutual lagg, the Otter Dyke Burn and they therefore comprise two distinct areas of peat. Rainfall in the area is slightly less than that found at Duddon Mosses, Clothier and Newson (1996) giving an estimated figure of 1350 mm.annum^{-1}. This is slightly higher than that given in the Roudsea Mosses and Woods Management Plan which suggests an unsourced figure of 1171 mm.annum^{-1}, 30% of which falls in the period October - December.

The period of most intensive peat cutting spans, as at Duddon, the eighteenth and nineteenth centuries but this was restricted to marginal areas. Most of the extant drains were incised during the post- war period in preparation for cutting of the entire moss. Fortunately this

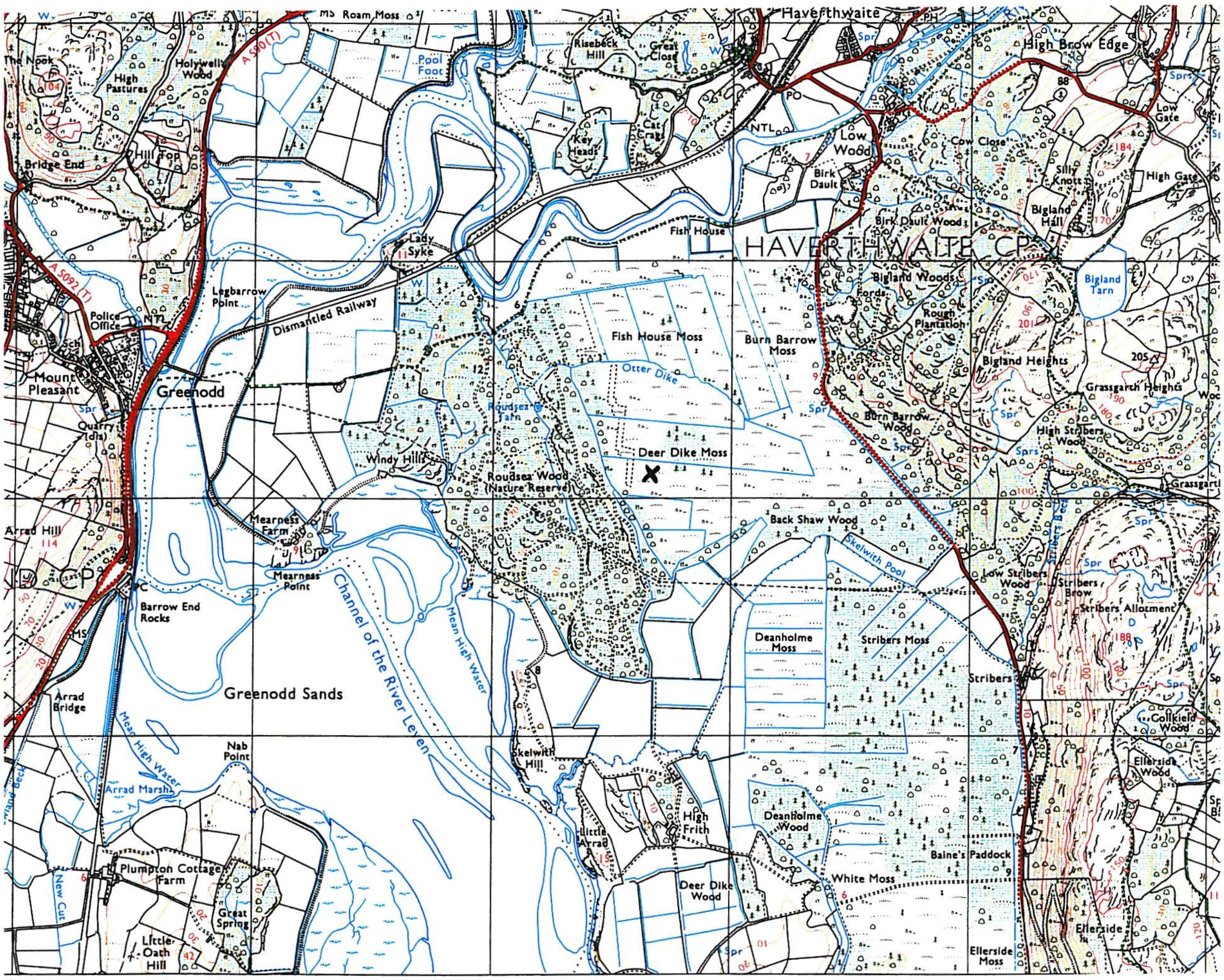

Figure 3.5 Map of Deer Dyke Moss ("X" indicates the approximate core location.)

intention was not realised but because the area was initially acquired for conservation on account of the woodland no remedial action was taken until 1984. At this time scrub development was extensive, forming an almost continuous canopy of *Betula*, *Pinus sylvestris* and *Rhododendron* and it was an impressive undertaking by the NNR staff to remove and dispose of this both on Deer Dyke Moss and the neighbouring Fish House Moss. Dams were subsequently put in place and on Fish House Moss alone 6000 of these structures were put in place using a combination of plastic sheeting and peat. Current hydrological restoration focuses upon the area surrounding the peatland, most of which is excluded by the NNR and SSSI boundaries. This includes Burn Barrow Moss which is contiguous with the eastern margin of both Deer Dyke and Fish House Mosses. In addition, agricultural land to the south of Deer Dyke Moss retains active drains which carry water into the Skelwith Pool. Clothier and Newson (1996) therefore recommend that control is gained over these areas in order to further enhance the hydrological integrity of this peatland.

Vegetation on Deer Dyke Moss reflects this history of hydrological perturbation and scrub encroachment with an abundance of *E. vaginatum* and *C. vulgaris*, often in association *with H. cupressiforme* that is currently kept in check by yearly mowing. The decrease in shade and increase in moisture levels has allowed *Sphagnum* to begin spreading more widely in the form of low hummocks of *S. capillifolium, S. magellanicum* and occasionally, *S. subnitens*. In the areas of open water created by ditch blocking *S. cuspidatum* is common and forming rafts stable enough for colonisation by *S. capillifolium* and *S. magellanicum*. Other vascular species present include *A. polifolia*, *D. rotundifolia*, *E. tetralix*, *E. angustifolium*, *M. caerulea*, *Myrica gale*, *Rhyncospora alba*, *T. caespitosum*, and *V. myrtillus*. *Betula* appears to be re-establishing itself but it is hoped, as at the Duddon Mosses, that increasing water tables may eventually overcome this undesirable development.

3.5 THE DUDDON MOSSES, CUMBRIA

The Duddon Mosses, which flank the Duddon Estuary south of Broughton in Furness of north-west England, are now represented by 8 discrete peatland units totalling 356.2 ha. Two discrete areas are recognised within this complex, Arnaby/Shaw Moss which lies to the west of the estuary and the Broughton Mosses (including Wreaks Moss) which are located to the east. These estuarine mires developed upon deep deposits of mud and clay deposited prior to the eustatic rise which followed the last glaciation when the area was subsequently inundated at a depth up to 7m (Gresswell, 1958). Prior to anthropogenic perturbation the Duddon Mosses would have formed part of an ecological continuum ranging from salt marsh to the wooded higher ground such as upon Woodland Fell behind the Broughton Mosses (Lusardi, 1993). However drainage and peat cutting fragmented the complex as a whole to its contemporary state of isolated units within a complex of improved, agricultural grazing land. The history of this exploitation stems back to at least the medieval period but reached its zenith in the eighteenth and nineteenth centuries, particularly the early part of the latter when a litter works was functional at White's Moss, one of the Broughton Mosses. Exploitation virtually ceased by 1945 and the spontaneous regeneration seen to have occurred since then bodes well for rehabilitation of the sites, if not their restoration.

Situated on the coast, west of Cumbria's mountain core, these mosses have the highest level of precipitation recorded for Cumbrian mires, 1400 $mm.annum^{-1}$ (Clothier and Newson, 1996). Clothier and Newson (1996) also calculate a potential evaporation of 471.5 $mm.annum^{-1}$ which illustrates an obvious surplus but as these workers go on to point out, mire ecology is dependant upon the timeliness of rainfall and calculate a possible summer deficit of 36.5 mm. Their usage of Smith's (1976) correction factors for evapotranspiration, which are altitude dependant, may imply that Arnaby Moss which reaches 30m on the uncut dome may suffer less of a deficit than the lower lying Wreaks Moss at 10 m.

MAP OF THE DUDDON MOSSES

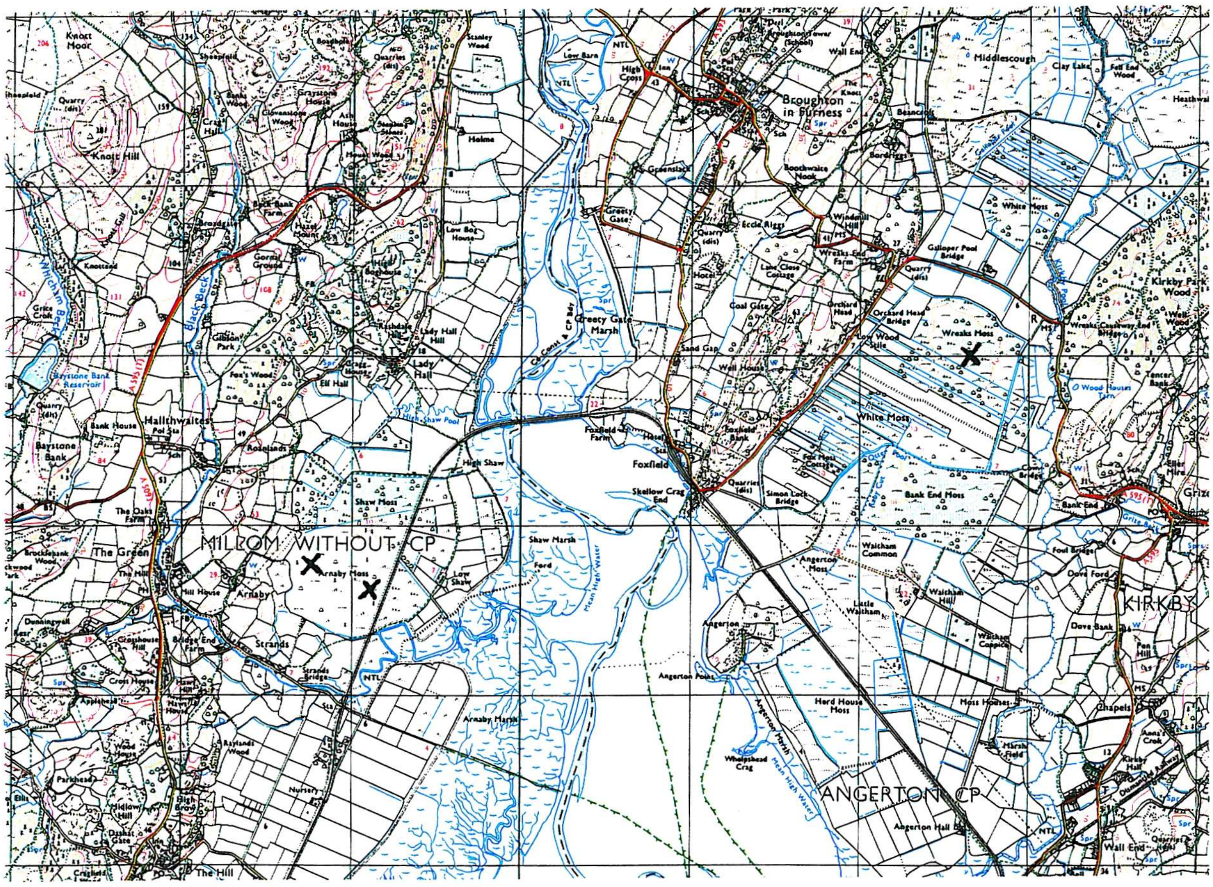

Figure 3.5 Map of the Duddon Mosses ("X" indicates the approximate core location.)

3.5.1 Arnaby Moss and Arnaby Moss Regeneration Peat

Arnaby Moss (Grid ref: SD 1984), is a heterogeneous area of peatland in which Lindsay (1978) recognises nine communities of which only two are considered within this study; namely his *Sphagnum/Vaccinium/Eriophorum* and *Calluna/Erica/Rhyncospora* communities from both of which cores were obtained. The remaining communities are geographically peripheral to and inferior by comparison to these mire communities in terms of their potential for rehabilitation to raised bog and inherent palaeoecological record.

The *Sphagnum/Vaccinium/Eriophorum* community is a secondary one developed directly upon fen peat (personal observation). Impoundment downslope of this community is derived from passage of the Greenod - Foxfield railway constructed in *c.* 1880 (Mr. Wearing, pers. comm.) and it is this feature to which the regeneration presumably owes its origins. It would appear that some amount of time elapsed however before the accumulation of water reached its contemporary surficial levels since Lindsay (1978) notes that the area was grazed up until *c.* 1960 when it then became too wet for cattle. This may suggest a change in vegetation since there is currently little fodder amongst the community currently present. Further changes in the vegetation are noted from the time of Lindsay's (1978) survey since at the time of my visit, in comparison to his notes, the extent of low hummocks had diminished, *Juncus effusus* and *Sphagnum cuspidatum* had virtually disappeared and the bryophytes *Aulacomnium palustre* and *Polytrichum commune* had increased greatly in extent. Consequently the vegetation is dominated by *S. recurvum* var. *mucronatum* with varieties *tenue* and *amblyphyllum* occasional. The most striking feature is still the abundance *of Vaccinium oxycoccus* which carpets most of the area and the only remaining phanerogams are *Eriophorum vaginatum* and occasional *C. vulgaris*, *Empetrum nigrum*, *E. tetralix* and *E. angustifolim*. This area, which represents the most active section of mire growth in the Duddon Mosses borders into an area of wet woodland from which *Pinus sylvestris* and *Betula* are spreading perhaps, in time, to be followed by their understorey of hummocky *Molinia*. It may be hoped that if this should not occur the mire may eventually succeed to an ombrogenous state.

The *Calluna/Erica/Rhyncospora* community is located upon the only remaining area of uncut, ombrogenous surface within the moss. It is now very hummocky with an amplitude of up to *c.* 75 cm and despite the recent removal of invading trees has changed only a little since Lindsay's (1978) survey. The vegetation may be described as of two types, that dominating the hummocks composed primarily of *C. vulgaris*, *E. vaginatum* and *Hypnum cupressiforme* and that of the hollows which is dominated by *Sphagnum* species, including *S. recurvum*, in response to the increased mineral status resulting from wastage of the massif. *S. cuspidatum* also occurs in these hollows and in the lawns of *S. capillifolium*, *S. magellanicum* and *S. papillosum* developing there is to be found an abundance of *E. tetralix* and *N. ossifragum*. It would appear that the hollows are in a state of active growth hastened by the removal of planted *Pinus*. *M. caerulea* occurs sporadically throughout but most notably upon the hummocks.

3.5.2 Wreaks Moss

Wreaks Moss (Grid ref: SD 2286), has historically suffered from marginal peat cutting which created a series of steps down to the bordering agricultural land. Only limited drainage has taken place on the moss itself and these drains are now mostly grown over. Greater concern has been expressed about drainage of the bordering fields. Investigations by Heathwaite & Baird (1995) and Clothier and Newson (1996) consequently recommend acquisition of and management in these fields and if possible, hydrological linkage of Wreaks Moss with White/Bank End Moss.

Scrub encroachment has taken place on the Moss since at least 1945 when the centre bore a large clump of *Rhododendron*, 30m in diameter and a thin covering of *Betula* scrub, the latter of which subsequently spread over the mire surface and consolidated into complete cover between 1972 and 1983 (Newlands and Thompson, 1987). This mode of colonisation is unusual because as all surveyors have noted, the crown of Wreaks Moss is the wettest area because, as shown by Heathwaite & Baird (1995), the modelled water table at least recedes towards the mire margin. This dry, marginal area strangely resisted colonisation (Newlands and Thompson, 1987) despite its proximity also to the *Betula* fringe growing on the peripheral, cut surfaces. All scrub was removed from the site in 1993 but at the time of my visit in late August, 1996 a number of healthy *Betula* seedlings were noted that may yet be overcome by a recovering water table. Despite these perturbations Wreaks Moss retains one of the least anthropogenically disturbed areas of peatland within the Duddon Mosses.

The vegetation of the mire lacks extensive *Sphagnum* cover and it is presumed that this is a consequence of shade from the encroachment of scrub and the extant, leggy *C. vulgaris* found particularly towards the drier margins. *E. vaginatum* also becomes commoner towards the drier margins, except towards the western edge where it is replaced by *M. caerulea*. This situation has persisted since Lindsay's survey (1978) and may be slow to recover following scrub encroachment for reasons discussed in section 4.6. A good diversity of *Sphagnum* species is retained with the typical species *S. capillifolium*, *S. cuspidatum*, *S. magellanicum*, *S. papillosum* and *S. recurvum* forming a functional acrotelm on the crown but as increasingly isolated patches towards the margin. Hummock/hollow topography is not particularly well developed. Open, bare patches of peat, not colonised *Cladonia* by spp., are currently being invaded *S. tenellum* except where they are created by Roundup™ treatment of *Rhododendron* which bear a flora of small acrocarps (*Aulacomnium palustre*, *Campylopus introflexus*, *Dicranella heteromalla*, *Funaria hygrometica* and *Polytrichum juniperinum*) and *S. compactum*. Vascular species are those typical of bog vegetation that has been modified to wet heath and includes an abundance of *C. vulgaris* with other associates such as *E. tetralix*, *Tricophorum caespitosum* and *Vaccinium myrtillus*.

3.6 MULLENAKILL BOG AND PEATLANDS PARK, CO. ARMAGH

Mullenakill Bog lies within Peatlands Park (Grid ref: H 8961; (figure 3.7) , Dungannon, an area of low, wooded drumlins interspersed by raised bogs all of which have seen some degree of anthropogenic disturbance through local and/or regional factors. Within the diverse vegetation of the 280 ha Peatlands Park, Mullenakill Bog retains the only uncut peatland surface of only 22 ha in extent and this area plus the neighbouring, deciduous woodland comprise the Annagarriff and Mullenakill NNR (Stanfield, 1997). Much of the current interest in Peatlands Park is a legacy of its past as a sporting estate with other, more damaging forms of exploitation accordingly restrained. Consequently, peat cutting was kept to marginal areas until 1901 when the estate was purchased by the Irish Peat Development Company who carried on commercial extraction until the late 1960's (*http://www.nics.gov.uk/doe_env/peatland.htm*).

The Peatlands Park was set up in 1978 through the realisation that although peatlands where represented within NNR designation for the province of Northern Ireland no such sites were included in the Country Park series. The area of cut-over and intact raised bogs, low, wooded drumlins and oligotrophic lakes was targeted primarily for conservation with public education and recreation taking second and third priorities, respectively (Stanfield, 1997).

The drainage system installed by the Irish Peat Development Company led to water level drops within the Peatlands Park area of up to 3m. This far reaching perturbation to the system is revealed most cogently by the disappearance of Annagarriff lake under a mantle of fen vegetation by the 1960s and shrinkage of the originally 19.8ha Derryadd Lake to 9.75ha by 1990 (Peatlands Park Management Plan). This lake later emptied into the peatland massif in 1992 where the water is suspected to still reside since no signs of it have been evident in the surrounding, largely agricultural area (K. Stanfield, pers. comm.). Conservation management has therefore sought to restore and maintain appropriate hydrological conditions across the peatland areas which continue to undergo anthropogenic water loss through marginal areas of contemporary peat cutting, drains and a regional water table drop in the Lough Neagh area of an average 2.3 m between 1858 and 1959 (Peatlands Park Management Plan). Recharge to the site is predominantly atmospheric but runoff enters at two points containing road and agriculturally derived pollutants.

In the area of commercial peat workings up to 2m of peat has been removed leaving depths of up to 10m and resulting in a typical, anthropogenic topography of baulks and ditches which were levelled the summer after the main drains were dammed in 1984. The water table has subsequently risen by 1 - 1.5m to seasonally lie at bank-full or above 20 - 50 % of the bare, peat surface and is assisted in this by the construction of small dams (Shaw, 1993). This hydrological variation across the site is caused by a fall of 1-2m over the peat surface, a relic of past peat extraction. Wetter conditions exist in the former area of Derryadd Lake where efforts were made to impound water prior to its abrupt disappearance into the peat massif. These measures included levelling the area in 1984 and the building of a peat bund in 1988/9 to maintain a water depth of *c.* 30cm (Shaw, 1993).

The vegetation of these areas appears to have retained the same species composition during the time intervening Shaw's visit (1993) and mine in September, 1996 with perhaps only changes in scale occurring over this period. Those areas of the former commercial peat extraction that lie well above the water table are most notable for their expanse of bare peat interspersed by isolated phanerogams; in order of decreasing cover, *Calluna vulgaris*, *Eriophorum angustifolium*, *Erica tetralix*, *Myrica gale*, *Molinia caerulea*, *E. vaginatum*, *Holcus lanatus* and isolated tufts of the mosses *Aulacomnium palustre*, *Brachythecium rutabulum*, *Campylopus introflexus* (common), *Polytrichum juniperinum* and occasionally, the minerotrophic *Sphagnum girgensohnii* which undoubtedly indicates the mineralisation occurring in these desiccated areas. In the wetter areas liable to inundation for at least four months of the year *Sphagnum cuspidatum* forms mats or rafts that in the lake area may seasonally attain 75% cover (Shaw, 1993). Within these mats and rafts *S. magellanicum* and *S. papillosum* are colonising. Shrubby ericoids are much less dominant in these areas, especially *C. vulgaris* and *E. vaginatum* succeeds *E. angustifolium* which remains present. *Rhyncospora alba* becomes present in these areas where, as Shaw (1993) also notes it is capable of colonising bare peat.

Mullenakill Bog, as stated, retains the only intact surface within Peatlands Park and it was from this area that the core was taken. This intact surface represents only one third of the former extent of this raised mire and the remaining fraction is still being worked for peat both commercially and privately. Further hydrological perturbation occurs at the site thorough the presence of a nineteenth century drain which dissects this uncut area and previously, peripheral dams along the southern edge which were dammed in 1990 with the consequence that this portion of the bog is wettest (Shaw, 1993). Burning has also been noted as a detrimental factor upon the site by Shaw (1993). The result of these perturbations has been the colonisation by woody species such as *Rhododendron*, *Betula* and planted *Pinus*. Despite removal of these species some individuals linger on around the margins and juvenile *Betula* and *Pinus* were seen to be recolonising in September, 1996.

The remnant mire vegetation does however show healthy signs of recovery, most notably the Sphagna which currently cover over 50% of the mire surface. Rank *C. vulgaris*, often with *Myrica gale* or *M. caerulea* dominates those areas that have suffered from burning and drainage where *Sphagnum* cover remains sparse. Over the rest of the Mullenakill Bog *C. vulgaris* is abundant amongst a *Sphagnum* rich vegetation of *S. capillifolium*, *S. magellanicum*, *S. papillosum*, *S. tenellum* and encouragingly, wet lawns of *S. cuspidatum.*. Other common phanerogams include; *E. tetralix E. angustifolium*, *E. vaginatum*, *Narthecium ossifragum*, *Rhyncospora alba*, *Tricophorum caespitosum* and occasional *Vaccinium oxycoccus.* The provincially very rare *Andromeda polifolia*, erroneously recorded from only two of the province's five counties in Hackney (1992) survived desiccation of the site upon railway baulks and is now recolonising Mullenakill Bog.

3.7 WEDHOLME FLOW

Wedholme Flow SSSI (Grid ref: NY 2253), covers some 780 ha and it is situated at the head of the Solway Firth at an altitude of 13m where rainfall stands at some 900 mm.annum^{-1} with a potential evapotranspiration of 471 mm.annum^{-1} (Clothier & Newson, 1996). Ownership is fragmented with individual plots varying from 0.45 ha to 251.4 ha and this has resulted in security for some areas of the bog which is currently undergoing peat extraction by Levingtons. Historically, peat extraction on the site goes back to the mid nineteenth century with the inception of a drainage system. Extraction has tended to cut across the site resulting in the isolation of uncut surfaces in two discrete lobes; to the north, Moss Side, Newton Arlosh and Kirkbride Awards and in the south, the so called, South Lobe. In this investigation the South Lobe was chosen for coring because it uniquely offers the opportunity to explore the vegetation changes of a peatland undergoing continued extraction.

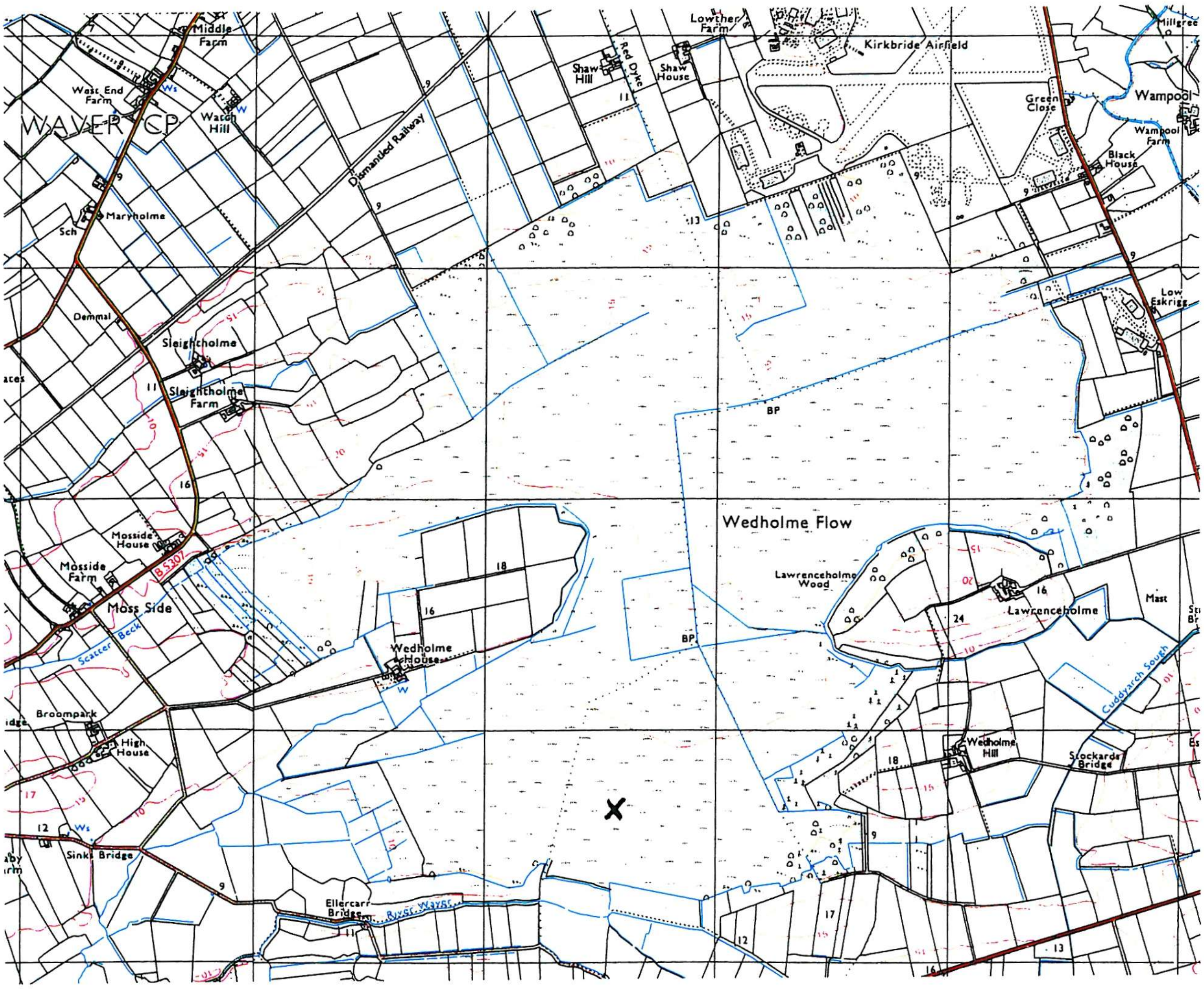

Figure 3 .8 Map of Wedholme Flow ("X" indicates the approximate core location.)

Unfortunately the conformation of the peat massif and the underlying sediments at the Southern Lobe do not bode well for practical management or predictive modelling and this is further complicated by ongoing peat extraction along its northern margin (Bragg, 1991). Consequently, a possibly unsatisfactory arrangement has been made with Levingtons to leave a stepped margin here, falling by 1 m in every 20 m. Monitoring of the water table in 1990 showed that it then fluctuated between 7 cm and 55 cm below the peat surface, with extremes of up to 1m (Bragg 1991). Under continued extraction these fluctuations are liable to both increase in magnitude and sink deeper into the catotelm, resulting in further changes to the micro-structure of the peat and larger scale conformation of the South Lobe. Bragg (1991) accordingly draws two extreme scenarios, of the worst and best outcomes for the Southern Lobe which, situated close to the centre of the original basin is dependant upon the Flow as a whole for its hydrological integrity. Bragg's (1991) predictions are that further extraction will cause the water table to fall asymmetrically by several metres or more leading to slumping of the peat massif that may, at best, conform to the new ground water mound or, at worst, lead to catastrophic failure of the whole.

The current vegetation of the South Lobe of Wedholme Flow is in an apparently healthy state with almost continuous *Sphagnum* cover interrupted only by low hummocks dominated with such species as *C. vulgaris*, *E. tetralix*, *E. vaginatum* and *V. oxycoccus*. The *Sphagnum* vegetation is rich as well as extensive with the following species occurring commonly as lawns and low hummocks; *S. capillifolium*, *S. cuspidatum*, *S. magellanicum*, *S. papillosum and S. tenellum*. In the wet lawns *E. angustifolium*, *N. ossifragum* and *R. alba* are present. Insectivorous *D. anglica* and *D. rotundifolia* are present and the north American native, *Sarracenia purpurea* has been introduced, currently present as a few small colonies but, as at Rannoch Moor, Argyll, it may be unlikely to become a serious pest and could most fruitfully regarded and retained as an interesting curio. The remaining areas of raised bog vegetation have been described in the Nature Conservation Review (1985) as "the most important raised mire surfaces left in England".

4. RESULTS

4.1 MACROFOSSIL STRATIGRAPHY

4.1.1 Introduction

In this section the macrofossil diagrams constructed for each study site are described as a series of stratigraphic sections. The horizontal lines dissecting the diagrams in Figures 4.1.1 to 4.4.9 do not accord strictly to the limits of each stratigraphic section, indicated in the margin of the relevant text, but to phases of the vegetation communities described later in this chapter (section 4.3). This is to permit the description of distinct but sub-threshold changes in the vegetation (*sensu* Conway, 1948) and an extra, *E. vaginatum* dominated phase that is not described as a discrete palaeovegetation community in section 4.3. This is because of its occurrence at the dynamic transition between two discrete communities and the fact that it therefore has no constant, definable characteristics other than the abundance of *E. vaginatum*. When such a phase appears it is apparent that *E. vaginatum* is dominant but this is simply a consequence of the volume in a tussock of this species dominating two, or rarely more, successive palaeoquadrats. The response of this plant to fluctuating water tables is however of interest and it may be considered as a useful indicator of a bog on the verge of suprathreshold change.

The sequence of phases in the sub-sections below is chronological and each site is therefore described from the bottom upwards. Reference is also made to the testate amoebae derived water table models (Figures 4.4.1 to 4.4.18) so that changes in the vegetation can be directly related to those in the groundwater mound and these models are discussed more fully in section 4.4. Radiocarbon dates, where available, are also indicated in the text in relation to known climatic changes but rates of development and transition are discussed more fully in section 4.5.

4.1.1 Arnaby Moss Regeneration Peat

72 cm - 78 cm

This initial phase of growth here occurs during the colonisation of exposed fen peat revealed by extensive cutting. A mosaic of hummocks and hollows is indicated in what is primarily a minerotrophic community with oligotrophic, ombrogenous elements. *S. palustre* is the main hummock forming species and it supplies a substrate for *C. vulgaris* and the bryopsid mosses, *Dicranum* sp., *Hylocomium splendens*, *Pleurozium schreberi*, *Pohlia* sp. and *Rhytidiadelphus squarrosus*. Lawns of *S. palustre* probably also supply a locus for the *Polytrichum* spp. (curiously including the woodland, *P. formosum*) and *Aulacomnium palustre*. although these may extend into wetter areas of low elevation. The hollows appear consistently wet enough for the presence of *S. cuspidatum* and its associate *Drepanocladus fluitans* accompanied by the single occurrence of *Phalaris arundinacea*. The high values for Unidentifiable Organic Matter within this phase are probably the sum of algal mud from the pools and decomposition within the hummocks.

A continuous rise in the water table is recorded throughout this phase by the testate amoebae derived water table model (Figure 4.4.2), from -12.0 cm to -4.4 cm at the 72 cm transition. At this point the hydrological threshold of this community is surpassed and/or the hummocks are swamped by accelerated growth of *S. recurvum* which subsequently becomes dominant.

0 cm - 72 cm

This marks one rather homogenous phase that is dominated throughout by varieties of *S. recurvum* (sensu Hill, 1978) following the retraction of *C. vulgaris* above 72 cm stratigraphic depth to isolated hummocks from where it is recorded only as readily dispersed seeds. Presumably *S. palustre* is still the plant responsible for formation of these hummocks.

This transition may be dated to one of two events. Primarily, the construction of a railway embankment downslope of the Moss in the 1880s may have led to the impoundment of run-off that eventually accumulated to the surficial levels under which *S. recurvum* is currently dominant. The second event of note is recorded by Lindsay (1978) who describes how prior to the 1960s, cattle were grazed on the moss but an increase in the water table at this time meant that the surface became too wet for such a practice which was then abandoned. It would appear that there is little evidence within this *S. recurvum* dominated phase to suggest a sufficiency of fodder for cattle and it is tentatively suggested that the transition at 72 cm depth is therefore dated to the 1960s although it may actually have been construction of the railway embankment which led to the initial, sub-threshold impoundment of water. Accordingly, we see, by comparison to Grosvernier, *et al.* (1997), a not improbable growth rate of *c.* 2.4 cm.annum^{-1} and as much as a century of slow peat accumulation under the preceding phase, until the impoundment of water reaches a point where *S. recurvum* can vigorously outcompete the other species present.

The flora is thus limited to species whose vertical or plagiotropic growth can match that of *S. recurvum*. These species include, *Calliergon stramineum*, *D. fluitans*, *R. alba* and the currently extant *P. formosum* and *Eriophorum* spp. The presence of all these taxa is sporadic, indicative of their distribution over the palaeosurfaces. The only species, other than *S. recurvum*, present at consistently high values is, *V. oxycoccus*, particularly in the upper levels which may be a reflection of differential preservation.

At 8 cm depth, upwards, there is a fall in the water table, as indicated by the testate amoebae data, from near surficial levels to *c.* -3 cm. This change in hydrology leads to the extinction of *S. cuspidatum* and the expansion of *A. palustre* which can currently be seen forming extensive lawns on the Moss. It will be interesting to see if this drop in water table is perhaps the first step in a shift of the community to ombrogenous conditions.

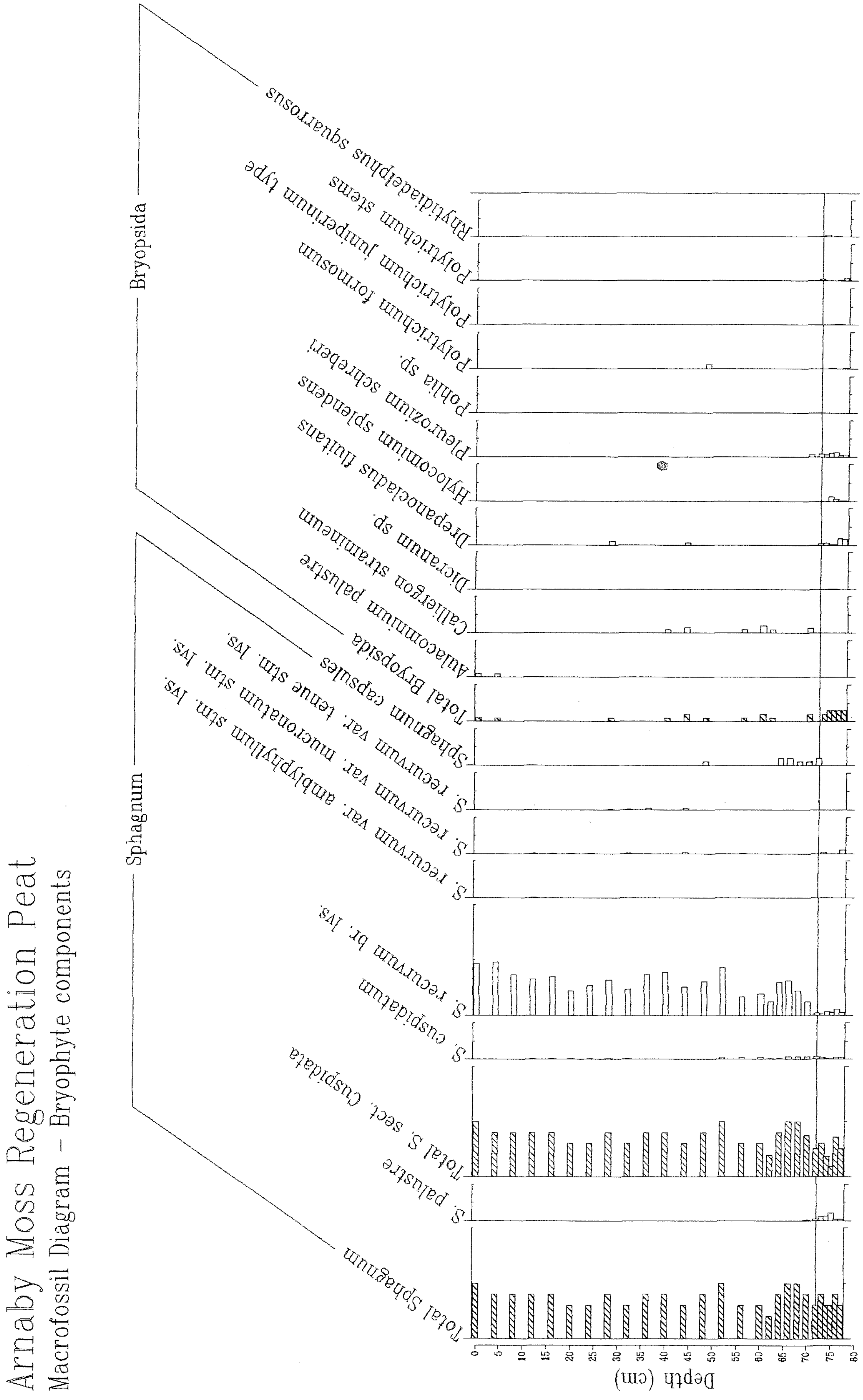

Figure 4.1.1a Arnaby Moss Regeneration Peat macrofossil diagram. Bryophyte components.

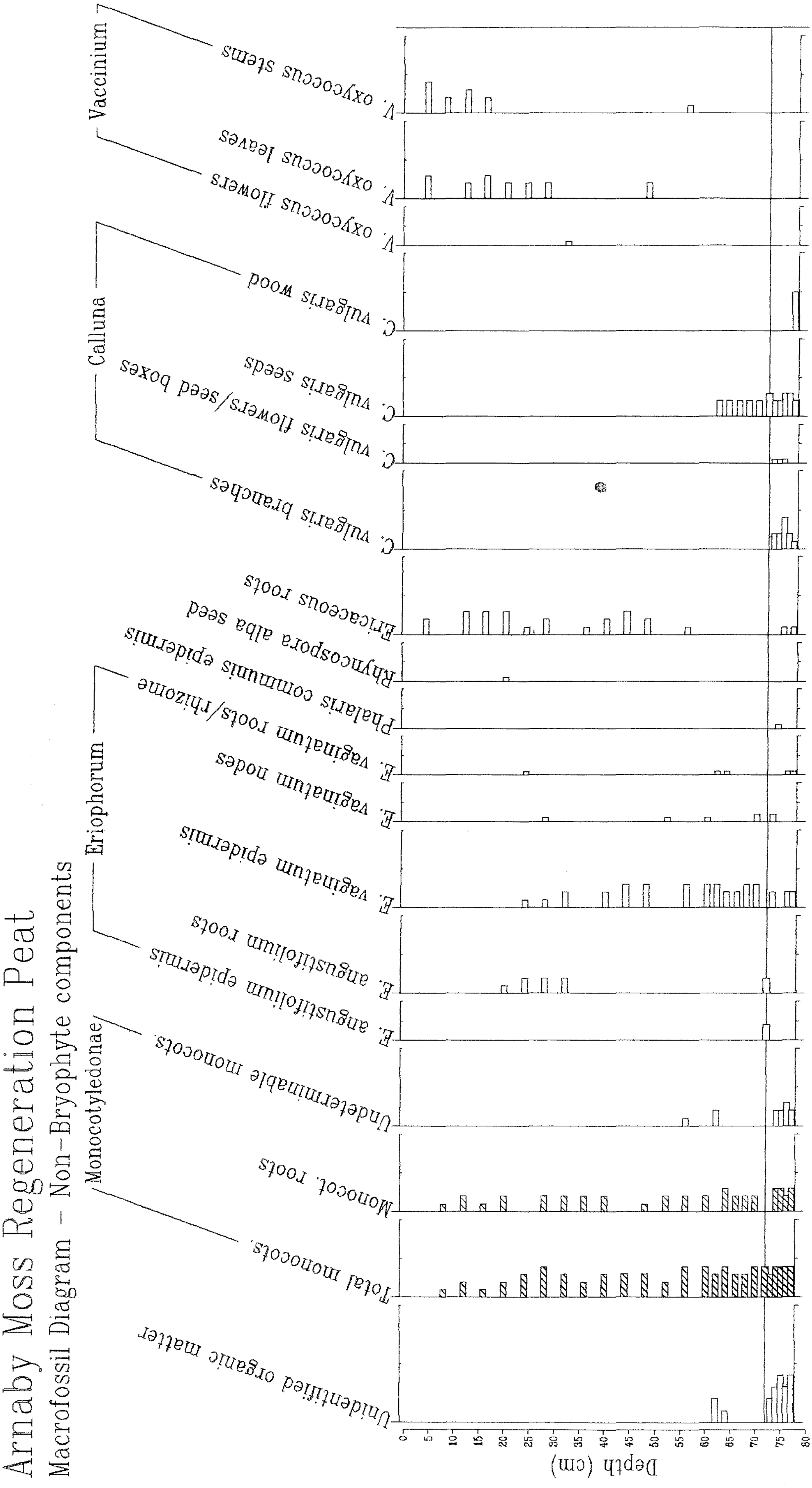

Figure 4.1.1b Arnaby Moss Regeneration Peat macrofossil diagram. Non - bryophyte components.

4.1.2 Arnaby Moss

226 cm - 236 cm

This phase is marked by a low (-14.7 cm) water table according to the testate amoebae derived water table model (Figure 4.4.4) and an almost complete dominance of Monocotyledonae all of which is probably referable to *E. vaginatum*. *Sphagnum* cover is minimal and probably restricted to the hollows between tussocks of *E. vaginatum*. A charcoal layer marks the upper end of this phase whose xeric nature indicates the relatively dry conditions prevailing throughout NW Europe at this as revealed in the stratigraphy of other peatlands (Casparie, 1972; Gear & Huntley, 1991; Tipping, 1995)

198 cm - 226 cm

This is a dynamic vegetation phase, the inception of which succeeds a charcoal layer and plausible climate change. Initially, it is marked by the expansion of *S. imbricatum* under an increased water table (- 4.2 cm to -7.3 cm) accompanied by *C. vulgaris*, *E. vaginatum*, *Myrica gale* and *Polytrichum* spp.. This community is checked by a further charcoal layer which sees the local extinction of *C. vulgaris*, *E . vaginatum*, *M. gale* and the hypnaceous mosses. *S. auriculatum* then comes to dominate under an apparently decreased water table (*c*. -14.0 cm). These two features probably indicate ponding of water on the charred mire surface during periods of rainfall interspersed by longer periods when the water table was lying deeper within the peat massif.

A wet climatic shift is known at this time from the work of Hughes (1997) and Mauquoy (1998) and the fact that the water table remains low suggests that the pyrogenic compaction of upper peat layers has led to an increase in surface run-off. This is indicated further by the presence of poikylohydric *S. auriculatum.*

126 cm - 198 cm

The inception of this phase is marked by the extinction of *S. auriculatum* which is proceeded by the establishment of a community dominated by hummocks *C. vulgaris* in association with various hypnaceous mosses and *E. vaginatum*. *Sphagnum imbricatum* maintains a low abundance and other Sphagna; *S. capillifolium, S. cuspidatum* and *S. fuscum* occur sporadically, all presumably interspersed amongst the apparently dominant hummocks. The derivation of this community from the preceding phase would appear to be the result of vegetation dynamics since the testate amoebae derived water table model remains unchanged at *c.* -14 cm.

The reappearance of a dry climatic phase (Barber, *et al.* , 1994; Tipping, 1995; Mauquoy, 1997) coincident with the transition to this phase suggests the origins of this community to be based in such. A contemporary decline in sea level change of some 50 cm (Zong, 1998) also accounts for this shift by lowering the regional water table upon which the groundwater mound of the raised bog is dependant. This cautions against the use of coastal sites in climatic reconstruction since it the relative influence of each factor is indeterminable.

Towards the end of this phase water tables appear to rise, fluctuating between *c.* 4.0 - 11.0 cm as the effective precipitation increases (Dubois and Ferguson;, 1985; Barber *et al.* , 1994; Mauquoy, 1997) . The *Sphagnum* vegetation apparently responds to this but maintains low values and the hypnaceous mosses become extinct. This state arises at cal. 3 280 BP and persists until cal. 2 870 BP when the Sphagnum vegetation attains its rational limit (sensu Smith and Pilcher, 1973), thus marking the end of this phase (with the extinction of *C. vulgaris*). This apparent lag of 410 years may be attributable to confinement of *Sphagnum* by the hummocks of *C. vulgaris* and *E. vaginatum* the latter of which is extinct before the end of this phase. In addition, the influence of a reduced sea level is known to persist throughout this phase and from its timing it is suggested that the initial *Sphagnum* response is due to an increase in effective precipitation but that it does not expand to dominance until the sea level returns to its original level. A number of fire events occur throughout this phase but appear to have no long term effect upon the vegetation

58 cm - 126 cm

S. imbricatum maintains almost complete cover throughout this phase under the control of a water table that is at times, almost surficial but occasionally falling to -7.0 cm. As the water table approaches the surface small peaks of the aquatic *S. auriculatum* and S. *cuspidatum* occur. Other, vascular species are of sporadic occurrence and at low abundance values indicating that the homogeneity of this vegetation was interspersed only by occasional, low hummocks. The end of this phase is marked by the occurrence of *S. auriculatum* and *S. cuspidatum* at high values. A number of known climatic shifts, both wet and dry have been recorded by other researchers within the duration of this phase but the *S. imbricatum* monoculture encountered here appears to be insensitive to them.

10 cm - 58 cm

This phase is marked by a high water table that only falls to below 2.0 cm at its periphery. Accordingly the vegetation contains the aquatic species *S. auriculatum* and *S. cuspidatum* and the originally dominant *S. imbricatum* which latterly becomes replaced by *S. papillosum*. As in the preceding phase, vascular species remain sporadic throughout indicating the presence of low hummocks and also in this phase, by comparison to that preceding, shallow hollows amenable for colonisation by *Rhyncospora alba* are present.

This phase, the end of which is undated due to its modern origins, covers a period of climatic change noted by Mauquoy (1997) as variable and this may be seen in the interplay of the constituent species.

0 cm - 10 cm

This last phase of bog growth represents the regeneration now occurring at Arnaby Moss after what must have been a long hiatus resulting from severe peat cutting operations over the last two centuries. The bottom of the phase may be dated to the 1960s or 1993 when invading scrub and plantation were removed and the groundwater mound rose sufficiently to allow growth of hydrophilous *S. recurvum*. This species is probably favoured over other Sphagna by the release of minerals accompanying wastage of the bog .

This core was taken from a hollow wherein *Narthecium ossifragum* also grew but as is typical, none of its remains appear to be preserved, even over this short timespan. However, the inclusion of *Hypnum cupressiforme* and *C. vulgaris* from the neighbouring hummock vegetation illustrates that macrofossil evidence may include more than just *in situ* material.

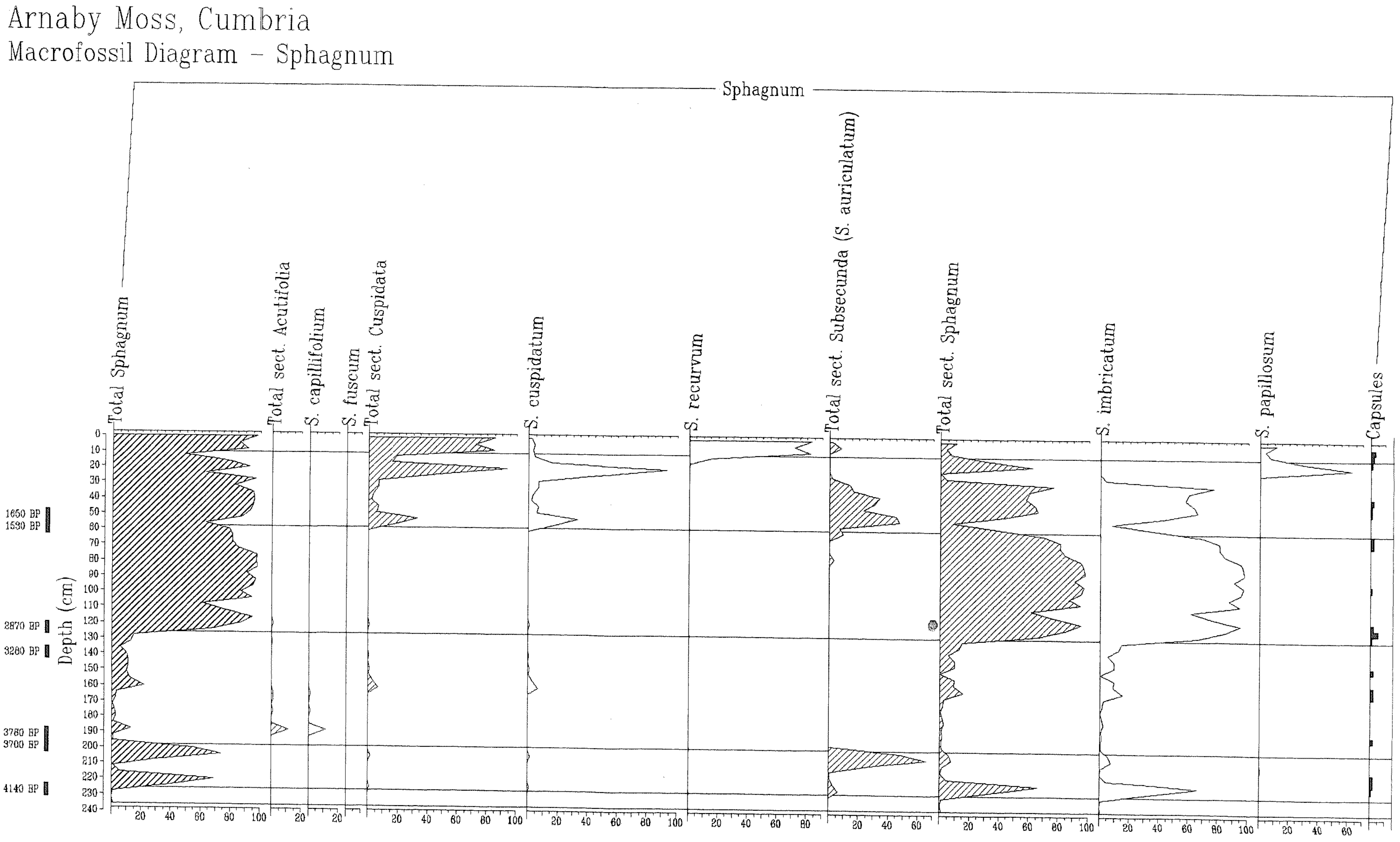

Figure 4.1.2a Arnaby Moss macrofossil diagram. *Sphagnum*..

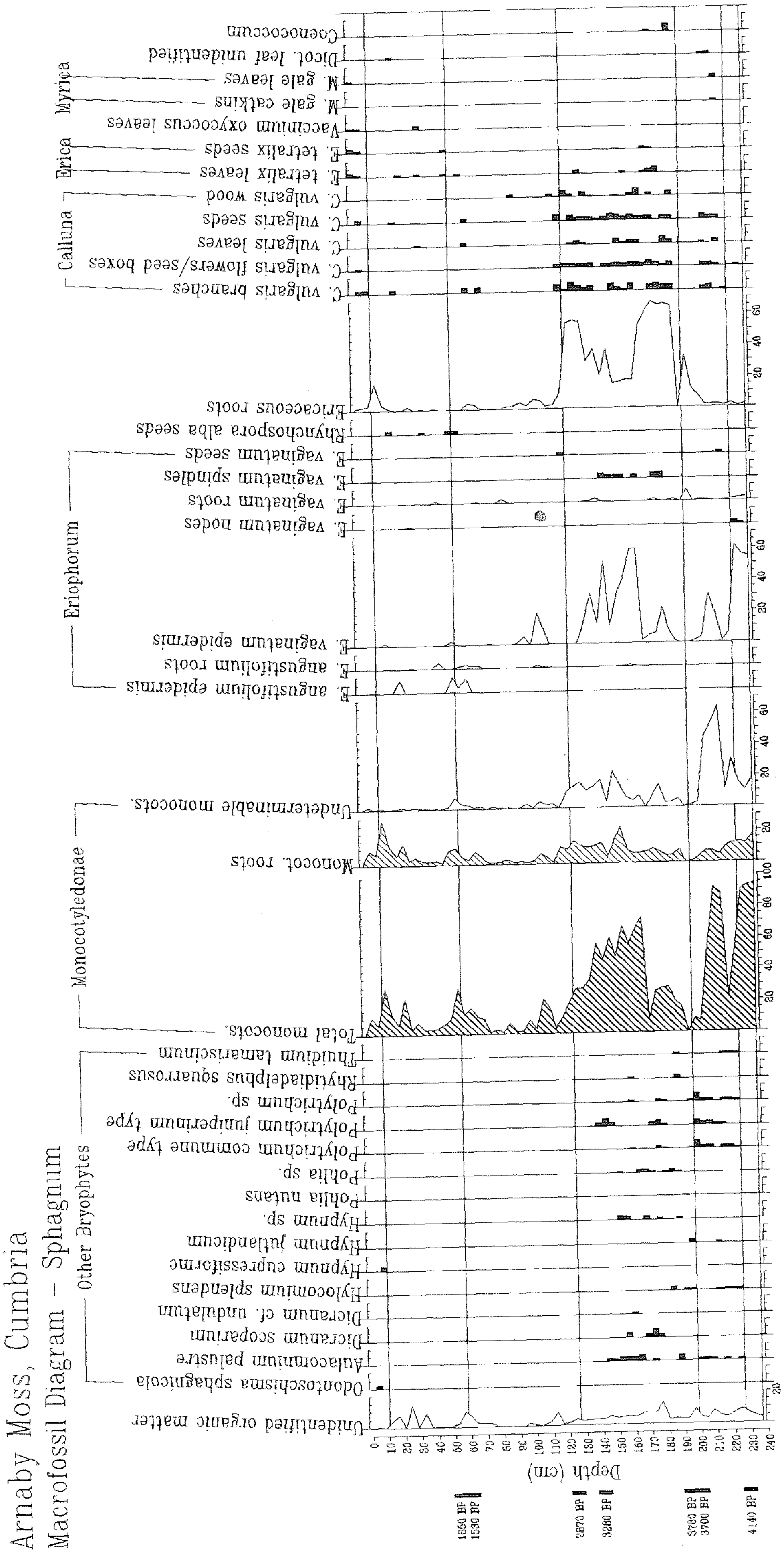

Figure 4.1.2b Arnaby Moss macrofossil diagram. Non - *Sphagnum* components.

4.1.3 Ballynahone Bog

298 cm -300 cm

This phase is represented by only 2 cm of stratigraphy in which *E. vaginatum* is dominant. This probably indicates that the full late Holocene sequence is contained within this core since *E. vaginatum* is the dominant species throughout much of the mid-Holocene.

246 cm - 298 cm

A heterogeneous raised bog surface is indicated throughout this phase with the temporal and spatial interspersion of wet and dry species. The water table model (Figure 4.4.5), derived from the testate amoebae data indicates that the water table is variable too, ranging between - 3 to +2 cm. These features probably record the expansion and contraction of microtopes according to short term, sub-threshold changes in the effective precipitation. *S. cuspidatum* dominates the pools, fringed with *S. tenellum* and *S. capillifolium*, the latter ranging onto the hummocks. These hummocks bear *C. vulgaris* which may also be accompanied by *S. fuscum*. *E. vaginatum* may locally form hummocks and *R. alba* is to be found also, probably fringing the pools of *S. cuspidatum* where *E. tetralix* and *Kurzia* spp. may also be expected to occur. The end of this phase is marked primarily by the extinction of *S. cuspidatum*. and its more hydrophilous associates.

242 cm -246 cm

This phase marks a short, transitional occurrence of *E. vaginatum,* probably due to water table fluctuations as the bog recovers the equilibrium of its hydrology.

126 cm - 242 cm

During this phase the water table, as revealed by testate amoebae data, falls consistently to below the vegetation surface, in the range -2.3 to -8.0 cm. Under this hydrological regime a complete cover of *S. imbricatum* develops in which *C. vulgaris* , *E. tetralix*, *E. vaginatum*, *R. alba*, and *V. oxycoccus* are rooted. *S. capillifolium*, *S. cuspidatum* and *S. tenellum* are still present but only sporadically indicating a loss of heterogeneity from the preceding phase. The two small peaks of *S. auriculatum* may indicate short-lived pooling of water on the mire surface, probably under short lived periods of unusually high summer rainfall. *C. vulgaris* and *E. tetralix* are seen to diminish from the mid point of this phase onwards and this may be due to their being overcome by the upward growth of Sphagna.

98 cm - 126 cm

This phase marks an even more homogenous phase than that preceding as indicated by the extinction of Monocotyledonae, most of which is probably attributable to *E. vaginatum*. Low amounts of *S. cuspidatum* are still present but the dominant species is clearly *S. imbricatum* which maintains a palaeoquadrat cover of over 90% throughout. The water table, as indicated by the testate amoebae, during this phase approaches to within -2.6 cm from the surface but is typically lower than this in the range of -4 cm to -7 cm.

62 cm - 98 cm

The beginning of this phase is marked by the emergence of *S. capillifolium* as an important constituent of the vegetation. The absence of *C. vulgaris* and shallower water table (-2.1 to -3.4 cm) than that preceding would suggest that this species initially formed low hummocks sparsely topped by *S. fuscum*. Now, *S. capillifolium* appears to be forming lawns of low elevation in which the more xerophilous raised bog species cannot subsist. *S. subnitens* accompanies *S. capillifolium* here as low mats or in juxtaposition attesting further to the development of a dominant lawn microform with wetter hollows. *S. imbricatum* maintains its numerical dominance within this community, particularly towards its later stages after which it becomes extinct, to be superseded by *S. papillosum* with which it associates throughout this phase.

54 cm - 62 cm

E. vaginatum attains a short period of dominance. This can be attributed to a rise in water table from the previous phase into the next during which time it is plausible that the mire's hydrology was unstable and favourable to this species.

30 cm - 54 cm

During this phase we return to the species composition encountered between 246 cm and 298 cm. However, in this instance we find that conditions are apparently more stable with *S. magellanicum* and *S. papillosum* maintaining a constantly low abundance while the aquatic species *S. auriculatum* and *S. cuspidatum* dominate. *S. cuspidatum* predominates initially but as it declines in abundance *S. auriculatum* increases to a short-lived peak prior to the next phase. This probably indicates seasonal drying within the hollows previously dominated by *S. cuspidatum* in association with *E. angustifolium*. The presence of *R. alba* seeds at this time also indicates that this species moved into the hollows as they became exposed to summer drying. *S. tenellum* occurs at a low abundance throughout, probably at the margins of these hollows.

The return of *C. vulgaris* is indicative of drier hummocks interspersing the *S. cuspidatum* dominated hollows although this former species does not become consistently present until at least seasonally drier conditions prevail, as indicted by the replacement of *S. cuspidatum* by *S. auriculatum*. towards the end of this phase. A change in groundwater mound levels is not recorded by the testate amoebae which suggest that it remains relatively constant throughout this phase (-1.7 to 2.1 cm). *E. tetralix* increases in abundance at the same time as *C. vulgaris* and this is a common feature of this former species which my be slower to colonise than the latter.

The end of this phase is marked by the extinction of aquatic Sphagna, *C. vulgaris* and the emergence of *S. magellanicum* as a dominant species.

14 cm - 30 cm

S. magellanicum dominates here and would appear to form a low lawn as is its common habit. *C. vulgaris* maintains its presence but presumably only as scattered individuals because only wind blown seeds and no vegetative remains are recorded throughout this section of stratigraphy. Hydrologically no marked change is observed over the boundary of this layer and that preceding and the two water table depths calculated for this phase are widely divergent at -1.9 and -6.7 cm.

The boundaries of this phase are marked by the sharp rise and fall of *S. magellanicum.*

0 cm - 14 cm

This phase is antecedent and very similar to the contemporary vegetation of Ballynahone Bog. *S. magellanicum* and *S. tenellum* occur co-dominantly amongst the Sphagna with a small, sporadic occurrence of *S. subnitens*. *S. cuspidatum* and *S. papillosum* increase towards the end of the phase and this increase in diversity and abundance is maintained in the contemporary quadrat data. *C. vulgaris* becomes less abundant during this phase to become indicated only its seeds and this may be, in part, a response to the decreasing depth of the water table as recorded by the testate amoebae (-4.9 to -3.8 cm). Charcoal is found consistently in these upper layers and fires may have also effected the decrease of *C. vulgaris* but *E. tetralix* does not appear to be so affected and maintains a high degree of presence throughout. The liverwort *Odontoschisma sphagni* is also recorded from these recent layers.

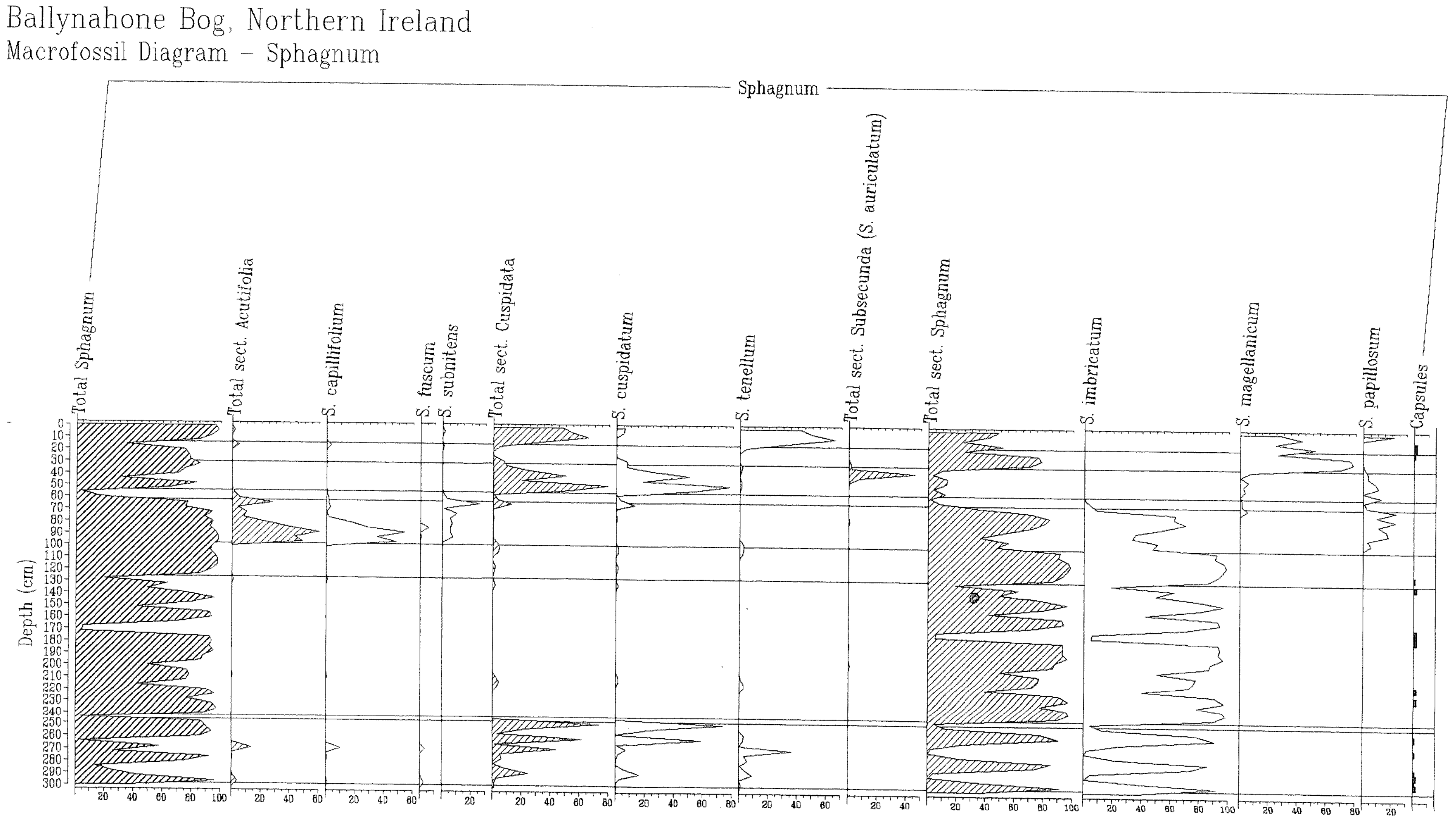

Figure 4.1.3a Ballynahone Bog macrofossil diagram. *Sphagnum*.

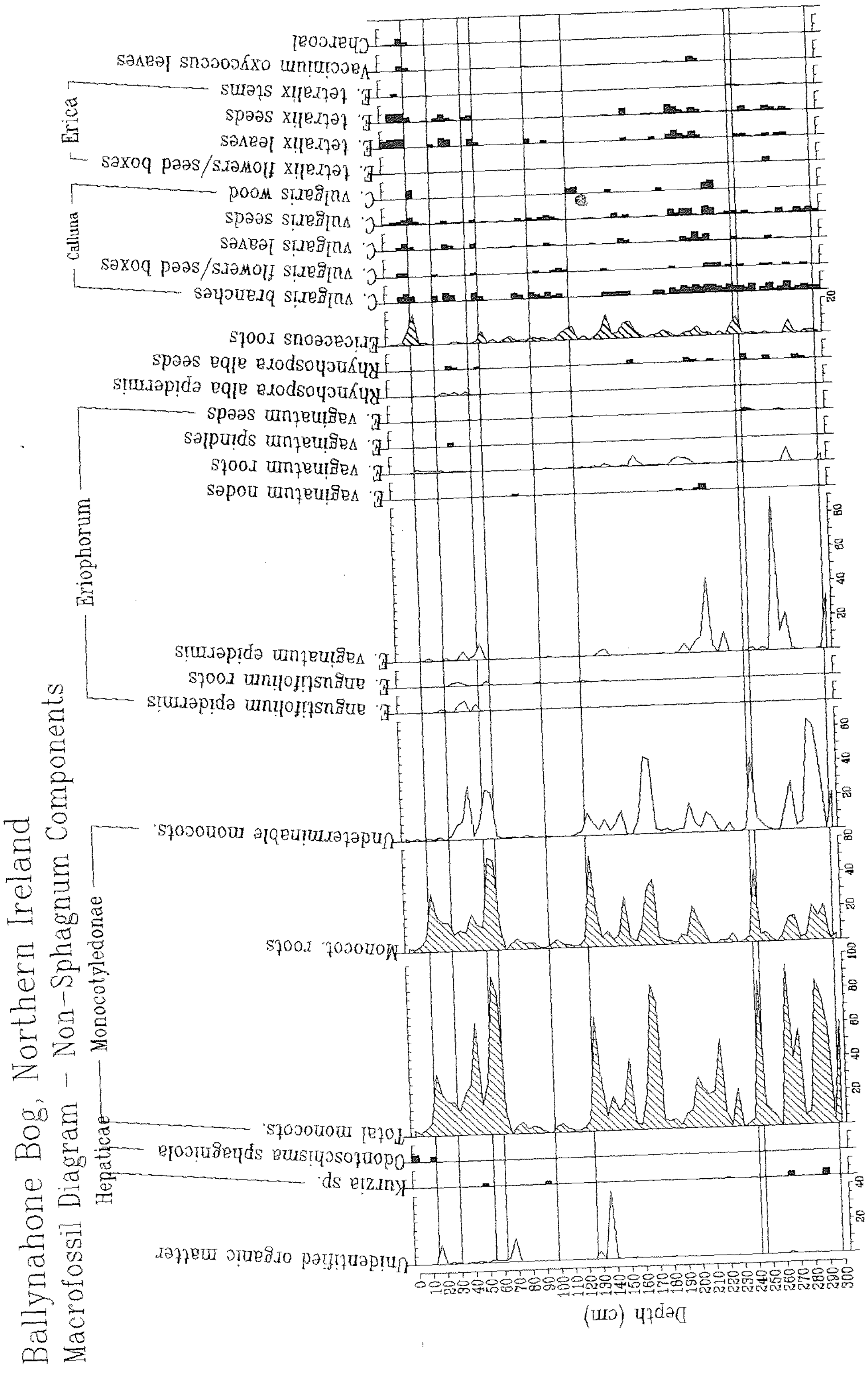

Figure 4.1.3b Ballynahone Bog macrofossil diagram.Non - *Sphagnum* components.

4.1.4 Coalburn Moss

256 cm - 300 cm

This phase of bog growth must have been a striking , visual component of the upper Clyde landscape with its coloration derived from the dominant red and brown of *S. capillifolium* and *S. fuscum*. *C. vulgaris* and *E. tetralix* are apparently sparse, particularly after the charcoal layer at 292 cm. The fire that produced this charcoal layer was at least locally hot enough to carbonise leaves of prostrate *Vaccinium oxycoccus*, remains of which are not usually recovered from such deep layers. Fire damage to the tussock species *S. fuscum* may also be apparent in the shape of its sharp decline but Jasieniuk & Johnson (1982) have observed this species to readily regenerate following a fire. Whatever the cause, this species steadily diminishes throughout the phase to apparent extinction as it is replaced by *S. capillifolium* at least in the proximity of the borehole.

S. cuspidatum, occurs towards the end of this phase, perhaps stimulated by an increase of the testate amoebae derived, water table model (Figure 4.4.7) to -2.2 cm from a constantly increasing -7.4 cm at the start. This species, preferential to stable pools, is latterly replaced by *S. auriculatum* indicating that the water table possibly began to fluctuate towards the end of this phase and this is supported further by the subsequent shift to a transitional, *E. vaginatum* dominated vegetation type. The currently rare *S.* (cf.) *balticum* occurs here and was probably present as isolated shoots or patches in the localised lawns of *S. papillosum* and maintained by the absence of a complete sub-shrub layer.

256 cm - 242 cm

This phase of *E. vaginatum* dominance was accompanied by sparse *C. vulgaris* and the continued growth of Sphagna at low values (*c.* 20%).

142 cm - 242 cm

Throughout this phase the formerly dominant sect. *Acutifolia* species are subordinate to *S. imbricatum* but may intermittently assume greater dominance within the vegetation. Hydrophilous *S. cuspidatum* and *S. balticum* both maintain a low, sporadic presence initially suggesting the continued presence of localised wet hollows or shallow pools. These wetter areas and the most sustained occurrence of *S. capillifolium* subsist under a relatively shallow water table fluctuating between -4.9 cm and -8.9 cm according to the testate amoebae derived water table model. Following subsequent water table draw down to the range of -11.2 cm to -15.2 cm *S. imbricatum* dominates although a small peak of *S. cuspidatum* occurs once more at the end of the phase as the water table rises again, to a value of -8.4 cm. Despite these low water tables *C. vulgaris* and *E. vaginatum* remain very sporadic and it may be suggested that theses species were outcompeted by the faster growing *Sphagnum* carpet but in the absence of radiocarbon dates for this section of stratigraphy no firm assumptions may be made.

The end of this phase is marked by the extinction of *S.* section *Acutifolia* species and vicarious rise of *S. imbricatum* to sustained, high values.

58 cm - 142 cm

This phase presents a much more homogenous, *S. imbricatum* dominated vegetation than that which preceded although the same species remain present. *S. capillifolium* and *S. fuscum* occur sporadically and at low values throughout the phase. *S. cuspidatum* and *S. tenellum* are restricted to the opening stages when the water table increased from the relatively low values prevailing under the previous phase to an apparent, -8.4 cm. Following this point the phase is hydrologically indicated by an apparently unstable water table.

E. vaginatum continues its sporadic appearance but *C. vulgaris* increases its abundance to become consistently present at low values. This increase may be related to the continued presence of fire events but it is unclear whether the carbonisation of *C. vulgaris* remains favoured their preservation within the peat, that the fires encouraged vegetative proliferation of this species or, that they offered it some other competitive advantage such as an increase in nutrient supply.

The end of this phase is marked by the extinction of *S. imbricatum* and a sharp rise to dominance by *S. cuspidatum*.

46 cm - 58 cm

Marked expansion of *S. cuspidatum* is the primary feature of this phase where the water table rises to *c.* -4.4 cm. Initially this species reaches almost complete dominance with its common associate *E. angustifolium* but *S. tenellum* and *S. papillosum* soon colonise and the rise to dominance of the latter marks the end of this phase.

C. vulgaris maintains itself in this apparent pool vegetation so it may be assumed that hummocks of *S. papillosum* supported this species at least locally. The *S. tenellum* already noted and *E. tetralix* probably formed the transition between these two extremes with mats of *V. oxycoccus* spreading from here on to the infilling pools.

30 cm - 46 cm

This phase of *S. papillosum* dominance is associated with low values of *S. cuspidatum* which may have grown as isolated shoots within developing lawns or as discrete areas of pool vegetation. The water table under this phase is amenable to the continued growth of *S. cuspidatum* as it occurs at or around the vegetation surface (in the range -2.0 to +1 cm) which appears also to cause the extinction of *C. vulgaris*. This species is seen to recover from the mid-point of the phase onwards as its seeds are recorded in the stratigraphy suggesting its survival upon isolated hummocks.

The end of this phase is marked by a species shift from *S. papillosum* to *S. magellanicum*.

18 cm - 30 cm

A fall in water table to -5 cm appears to stimulate a shift in species from *S. papillosum* to *S. magellanicum* which is associated with low values of *S. tenellum* that uncharacteristically become more prominent towards the end of this phase as the water table continues to fall (to -9.1 cm) in the next phase. *C. vulgaris* becomes re-established on the lawns and low hummocks of *S. magellanicum*. during this period of water table recession.

0 cm - 18 cm

This final phase of growth sees the extinction of *C. vulgaris* as the water table rises to -4.8 cm from -9.1 cm before recolonisation reoccurs above 8 cm stratigraphic depth by which time the water table again falls, this time to -8.3 cm for the surface sample. Associated with these water table dynamics is another species shift in *Sphagnum* with *S. papillosum* now replacing *S. magellanicum*. This replacement appears to be stimulated by the upward movement of the water table at 8 cm stratigraphic depth to -4.8 cm. Throughout this phase *E. tetralix* remains constant in its appearance and amongst the sub-shrubs, it attains greater dominance than *C. vulgaris*, particularly after the upward, water table shift at 8 cm.

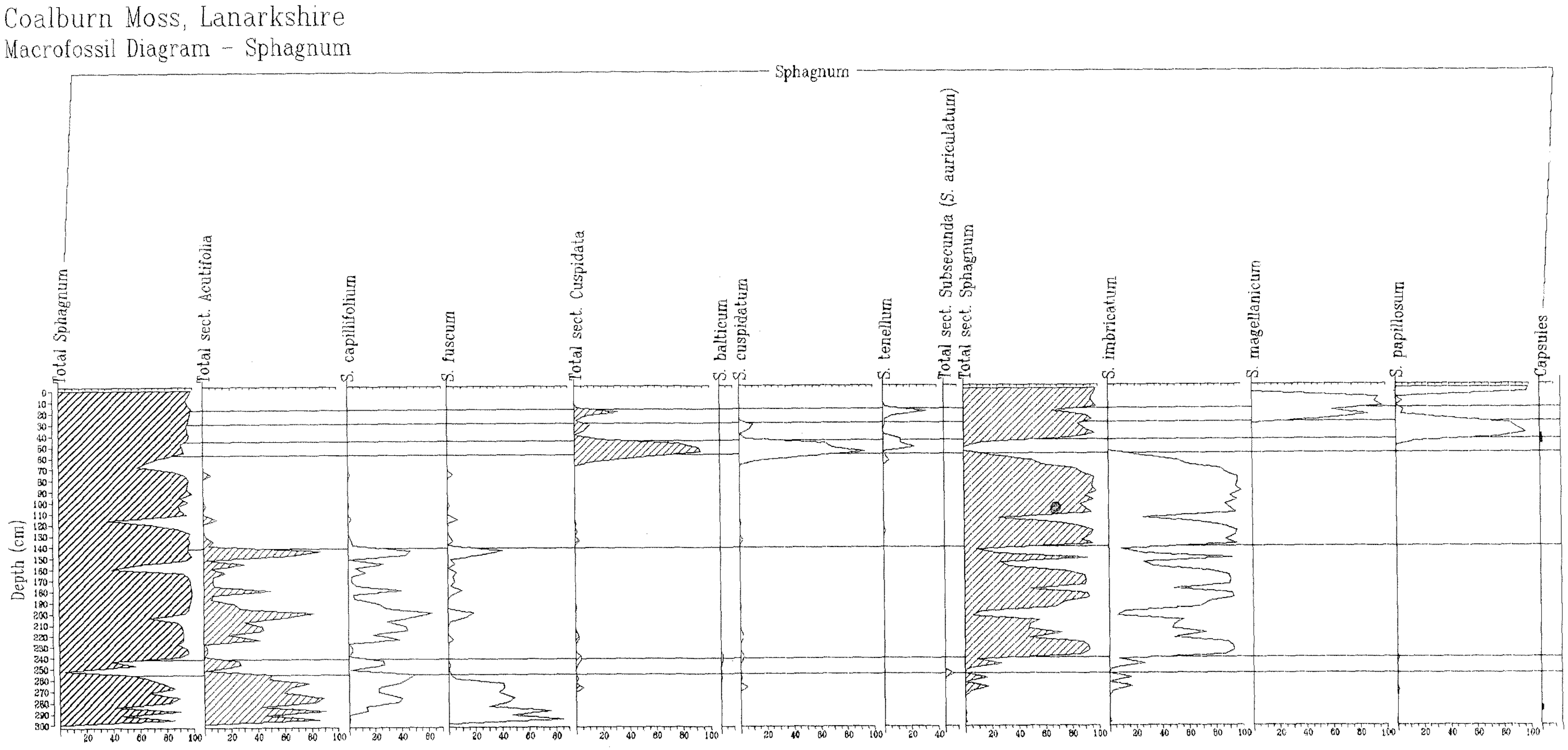

Figure 4.1.4a Coalburn Moss macrofossil diagram. *Sphagnum*.

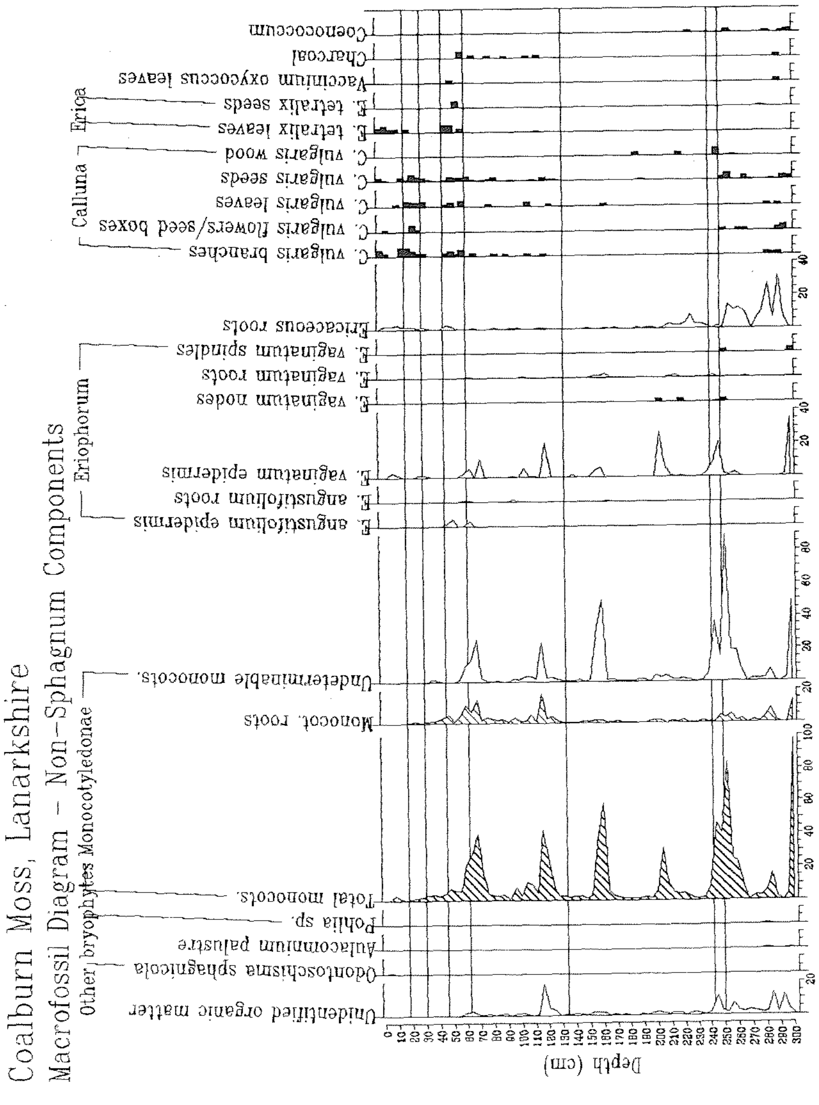

Figure 4.1.4b Coalburn Moss macrofossil diagram. Non - *Sphagnum* components.

4.1.5 Cranley Moss

214 cm - 300 cm

The start of this phase is not dated until 282 cm because the relationship of the communities on either side of this point is not clear although it would be reasonable to assume that the large amount of Monocotyledonae below 282 cm is referable to a static tussock of *E. vaginatum* and the low amount of *C. vulgaris* recorded perhaps referable to this phenomenon. From 282 cm onwards the community is very similar, if not contemporary, to that described from Coalburn Moss between 256 cm and 300 cm. However, an absence of *S. fuscum* is evident and *S. capillifolium* almost exclusively dominates. Other species are occasionally present in a diverse assemblage including; *S. auriculatum, S. balticum, S. cuspidatum, S. imbricatum, S. molle, S. subnitens* and *S. tenellum*. This assemblage persists under a statistically more stable water table than that at Coalburn although the mean depths of the water tables are roughly comparable; Coalburn Moss -5.6 cm ± 2.1 SD (Figure 4.4.7); Cranley Moss, -5.5 cm ± -1.5 SD (Figure 4.4.9).

The apparently greater abundance of *C. vulgaris* here than at Coalburn Moss is probably a real rather than spatial feature because of its consistency. This is because plagiotropic (upward but at an angle) growth of *C. vulgaris* in *Sphagnum* dominated environments, in stratigraphic section, would allow for movement of plants in and out of range of the palaeoquadrat and for the abundance to be averaged out through these movements, over time. This is also the case for *E. vaginatum* which, in this phase, maintains constantly low values showing none of the occasional peaks attributable to a plagiotropically growing plant crossing directly across the path of a core.

The fire event centred on 264 cm causes a major perturbation to the system that appears to damage the acrotelm to the complete, local extinction of *S. capillifolium* and absence of some *C. vulgaris* components. In replacement, *S. auriculatum* rapidly attains high values that span some decades, before yielding to a return by *S. capillifolium* to its original dominance. Some degree of water ponding and or exposure of bare peat on the surface apparently persists after the recession of *S. auriculatum* as seen in the sustained appearance of *S. tenellum* and *E. tetralix*. This latter species becomes extinct following a second, less serious fire event at 234 cm that bears less impact upon *C. vulgaris* and the vegetation as a whole.

Termination of this phase is marked by the extinction of *C. vulgaris*, the rapid decline of *S. capillifolium* to very low values and its subsequent replacement by *S. imbricatum*. The end of this phase is dated at cal. 3320 BP, the start of the next at cal. 3480 BP. This would indicate that the vegetation shift is a continuous event with no cessation of peat growth.

84 cm - 212 cm

S. imbricatum dominates this phase throughout in an almost complete monoculture until the latter stages when peaks, probably attributable to *E. vaginatum* appear amongst the Monocotyledonae. Following its rapid decline from the previous phase *S. capillifolium* persists at low values for the initial *c*. 30 cm of stratigraphy, accompanied by *S. fuscum*. Both of these species appear to become extinct when the water table drops from its moderate values in the range of -3.9 cm to -6.7 cm, down to -10.6 cm. Small amounts of *S. auriculatum*, *S. molle*, *S. tenellum* appear sporadically throughout as do short-lived peaks of the previously noted section *Acutifolia* species. *C. vulgaris* appears very rarely and *E. tetralix* remains apparently extinct.

The water table of this long lived phase is variable, in the range of -3.9 cm to -14.5 cm. The general trend is one of a fall in water table but towards the end of this phase the water table rises sharply to -1.7 cm, just before the upper boundary when *S. auriculatum* becomes more consistent within the vegetation. The end of this phase is then marked by the inception of consistently high *S. auriculatum* values.

78 cm - 84 cm

This is a short phase of high *E. vaginatum* values as is common at the boundary of many vegetation transitions within this study. The large discrepancy in the radiocarbon dates bounding this transition, of some 420 years, suggests that such phases may also instigate a hiatus in peat development by virtue of the relative accumulation rates under *E. vaginatum* compared with those of a *Sphagnum* dominated community.

34 cm - 78 cm

A wet lawn prevails throughout this phase in which *S. auriculatum* and *S. imbricatum*. are co-dominant. This expansion of aquatic Sphagna was probably stimulated by the onset of a wetter climatic period identified by Aaby (1976), Blackford and Chambers (1991) and Stoneman (1993). That some of these pools may have been relatively stable at least initially, is attested to by the presence of *S. cuspidatum*, albeit at low figures. *S. tenellum* is also present, probably fringing these wetter areas and growing into the lawns of *S. imbricatum*, possibly in association with *S. capillifolium* which appears very sporadically throughout this phase. In addition, ericaceous components are almost totally absent with only a small amount of sporadic root material recovered indicating their infrequency across the mire surface.

The modelled water table values for this phase describe well the presence of *S. cuspidatum*. Initially they are high, at -2.0 cm, but fall to a low of -9.5 cm before rising to a sustained high at or around the vegetation surface from 48 cm depth, when *S. cuspidatum* returns to the vegetation. The interim period of absence shown by *S. cuspidatum* is probably related to the presence of a drier phase recognised by Barber (1981), Stoneman (1993) and Mauquoy (1997) between cal. 1300 BP and cal. 1150 BP. During this phase it is considered that the ponding of meteoric water at Cranley Moss was an ephemeral event and therefore *S. auriculatum* came to dominate over the less poikylohydric *S. cuspidatum* which was then excluded from the vegetation by either competition or an incapable physiology. The return of *S. cuspidatum*, within the limits of the age - depth model, is at a time when a number of authors (Aaby, 1976; Barber, 1981 & Stoneman, 1993) indicated a return to wetter conditions at *c*. cal. 1000 BP.

The end of this phase is marked by the extinction of *S. imbricatum* at which time *S. auriculatum* attains numerical dominance among the Sphagna. This species is quickly replaced however by *S. cuspidatum* in almost complete monoculture, marking the start of the next phase.

18 cm - 34 cm

During this phase the water table is lying at or close to the vegetation surface (> -1.5 cm) and this favours, almost exclusively *S. cuspidatum*. *E. tetralix* is present initially, perhaps on residual hummocks of *S. imbricatum* but is soon absent from the stratigraphy. The only other associates are, *E. angustifolium* of which a small amount of root was recovered, *S. recurvum* and *S. tenellum*. This phase ends sharply with the replacement of *S. cuspidatum* by *S. magellanicum*.

0 cm - 18 cm

S. magellanicum rapidly forms an almost complete cover in this phase while *C. vulgaris* and *E. vaginatum* colonise after a short period with *E. tetralix* and *V. oxycoccus* typically entering the diagram a little later. This lag in the colonisation of vascular species is probably a consequence of instability in the *S. magellanicum* lawn which overlies a wet *S. cuspidatum* pool of indeterminable extent. It would appear that despite drainage, Cranley Moss has retained a healthy carpet of Sphagna through to contemporary times when damming of the drains was instigated.

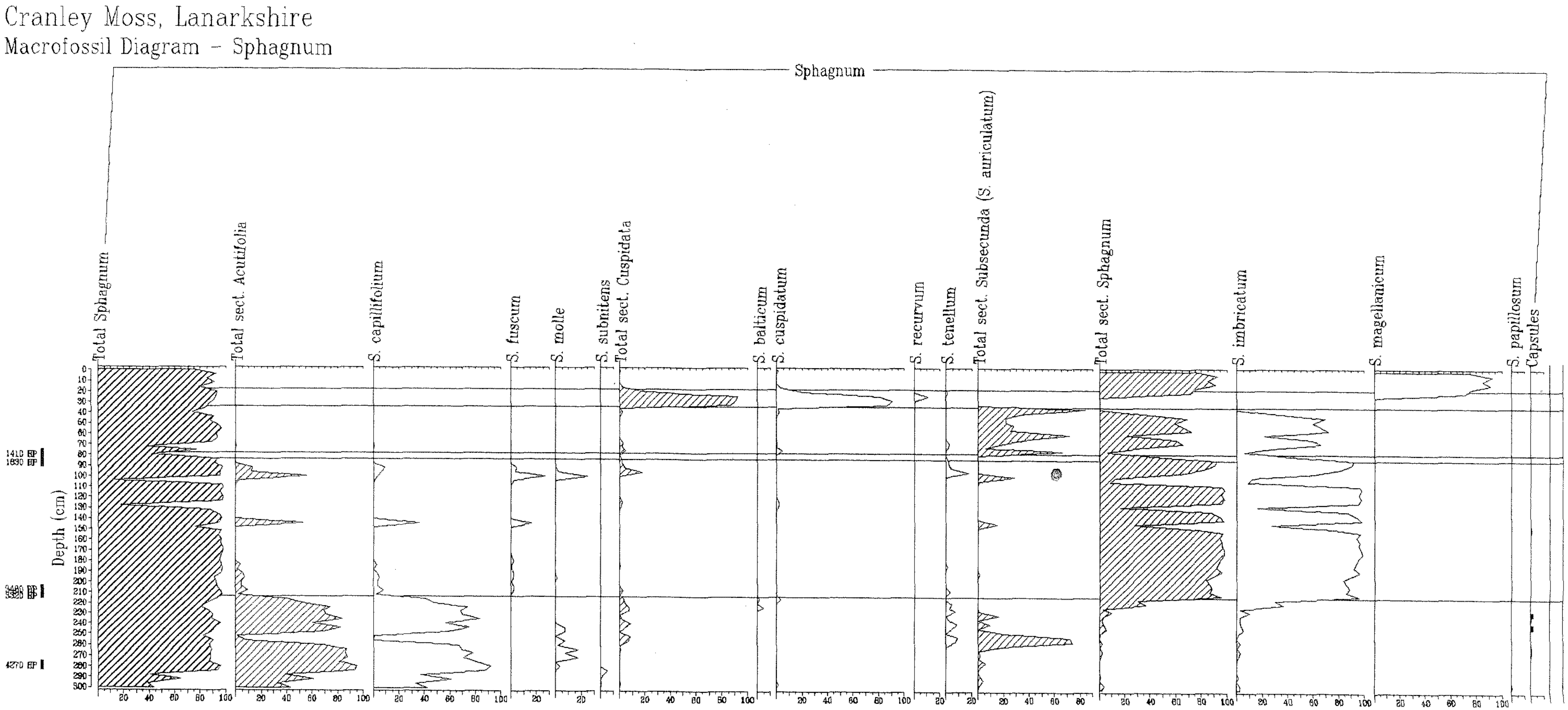

Figure 4.1.5a Cranley Moss macrofossil diagram. *Sphagnum.*

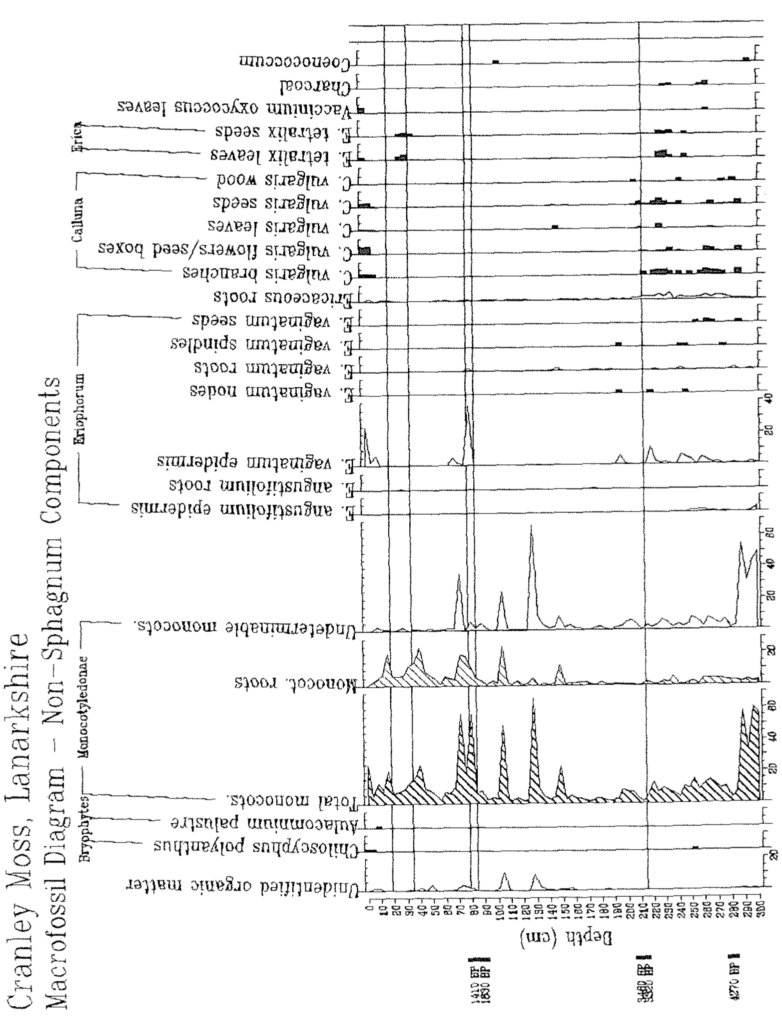

Figure 4.1.5b Cranley Moss macrofossil diagram. Non - *Sphagnum* components.

4.1.6 Deer Dyke Moss

274 cm - 300 cm

This phase is a degenerative phase as described above for Cranley Moss, 78 -84 cm. It is predominantly composed of Unidentified Organic Matter and the remains of Monocotyledonae including or wholly composed of *E. vaginatum*. . *S. imbricatum* occurs consistently, but at low values throughout whereas *S. papillosum* and *S. tenellum* also occur sporadically, possibly as isolated pockets amongst *E. vaginatum* hummocks. *C. vulgaris* and *E. tetralix* perhaps share more open areas with the Sphagna since their decline is in line with that of *S. imbricatum* . The lone *R. alba* seed at the top of this phase seems out of place unless shallow, open pools formed and it may have become incorporated from the phase above.

The water table model derived from the testate amoebae data (Figure 4.4.12) is probably too high in this case, giving values in the range -2.5 to -4.0 cm. This may be a feature of the unusual dominance of *E. vaginatum* tussocks supplying the necessary ecological conditions for the dominant testate amoebae species; *Amphitrema flavum*, *A. wrightianum*, *Assulina muscorum and A. seminulum* which are most abundant in wet, hummock environments (Woodland, 1996).

26 cm - 274 cm

The water table of this phase fluctuates within the narrow limits of -3.5 cm ± 1.9. This suggests, in conjunction with the limited floristic changes, that the whole stratigraphic section of 24 cm to 274 cm could be treated as one continuous phase showing a remarkable degree of apparent stability throughout a series of climatic shifts recorded in the stratigraphy of other raised bogs in the area. Uniquely amongst the sites studies here, the topography and possibly, the woodland vegetation of the surrounding land may be responsible in maintaining an apparently insensitive water table. Run-off from the high ground bordering Deer Dyke Moss presumably maintains a high, local water table. Additionally, the proximal presence of high ground limits run-off from the Moss to only the north, where it is bordered by Fish House Moss, and the south, towards Skelwith Pool. These same, wooded slopes, may also have maintained a still, moist microclimate limiting evapotranspirative losses from the surface of the mire.

The corresponding vegetation shows no dramatic shifts and *S. imbricatum* is dominant throughout. Isolated occurrences of *S. capillifolium*, *S. cuspidatum* and *S. tenellum* appear, the former particularly abundant towards the end of the phase. Cyperaceae are represented by the sustained occurrence of *E. angustifolium* and *E. vaginatum* and *R. alba* is sporadically present usually to the accompaniment of *S. tenellum*. *C. vulgaris* and *E. tetralix* occur for intervals that possibly correspond to isolated plants moving n and out of range of the palaeoquadrat. Overall, this long section gives the impression of a spatially and temporally continuous *S. imbricatum* lawn with low hummocks (*C. vulgaris*, *E. vaginatum* and *S. capillifolium*) and shallow pools (*E. angustifolium*, *E. tetralix*, *R. alba*, *S. cuspidatum* and *S. tenellum*).

Also of note is the catastrophic fire event at 46 cm to 64 cm, stratigraphic depth which significantly reduces the *Sphagnum* cover to the accompaniment of a sharp rise in Unidentified Organic Matter over 12 cm of stratigraphy indicating that the fire burnt to some depth into the peat. This event apparently causes extinction of the previously sparse *C. vulgaris* and *E. tetralix* and results in the absence of above ground *E. vaginatum* components.

6 cm - 26 cm

This pronounced peak of Unidentified Organic Matter presumably corresponds to slumping of the peat massif in response to the efficiently organised drainage system imposed in the 1950's. However, marginal peat cutting occurred on Deer Dyke Moss prior to this date and Oldfield (1969) suggests that there has been a hiatus in peat growth since *c.* 1850.

0 cm - 6 cm

This current phase is an encouraging one marking the return of *Sphagnum* under a water table of -5.1 cm. The two species involved, *S. magellanicum* and *S. tenellum* are accompanied by an apparent return of *C. vulgaris*, *E. tetralix* and *E. vaginatum* but the prior existence of these plants cannot be attested to because of the breaking down of macrofossils in the preceding phase to Unidentified Organic Matter. It would seem reasonable to assume that the *Sphagnum* spp. and *E. tetralix* maintained themselves in and around the ditches whereas *C. vulgaris* and *E. vaginatum* would be capable of maintenance upon the dried out baulks.

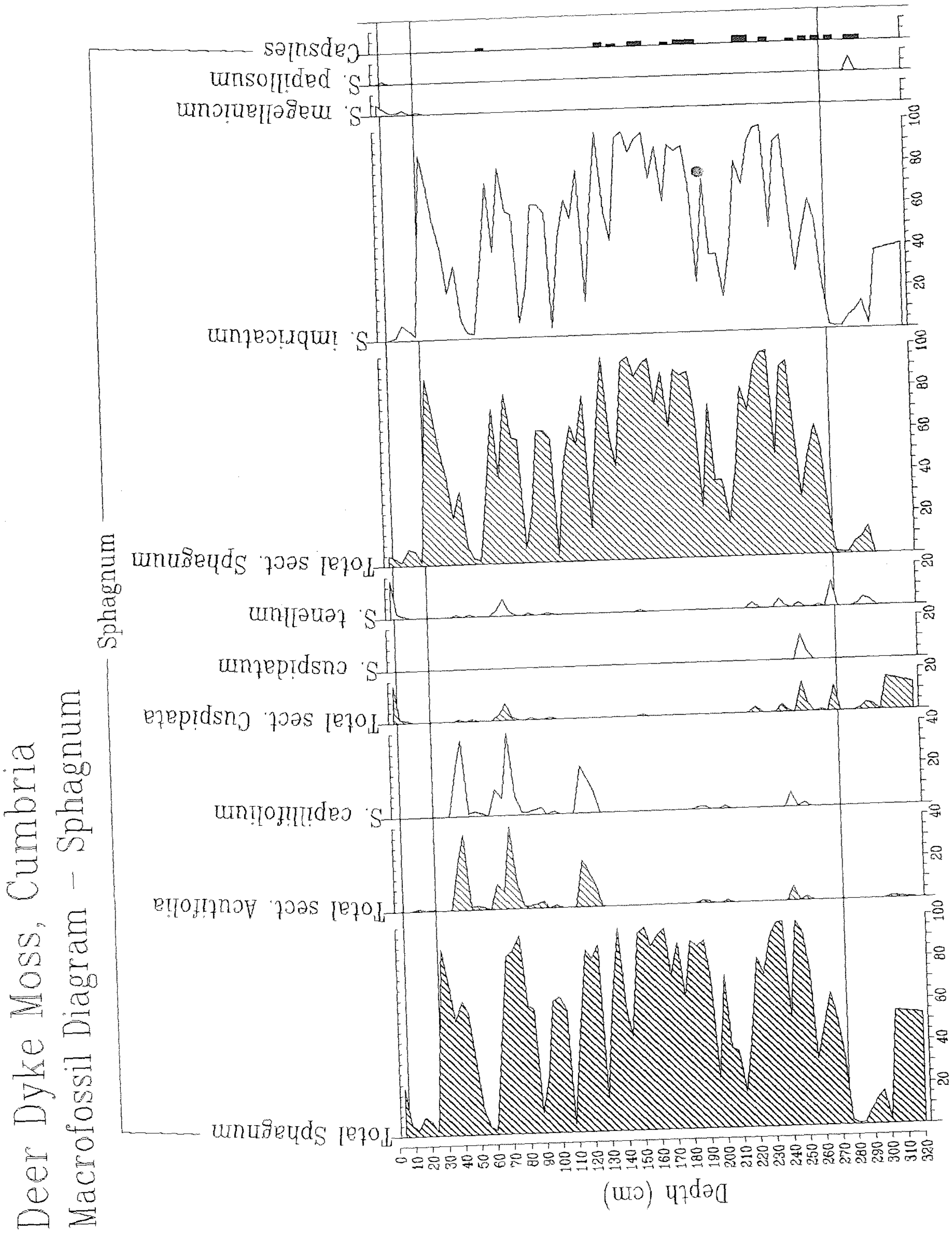

Figure 4.1.6a Deer Dyke Moss macrofossil diagram. *Sphagnum.*

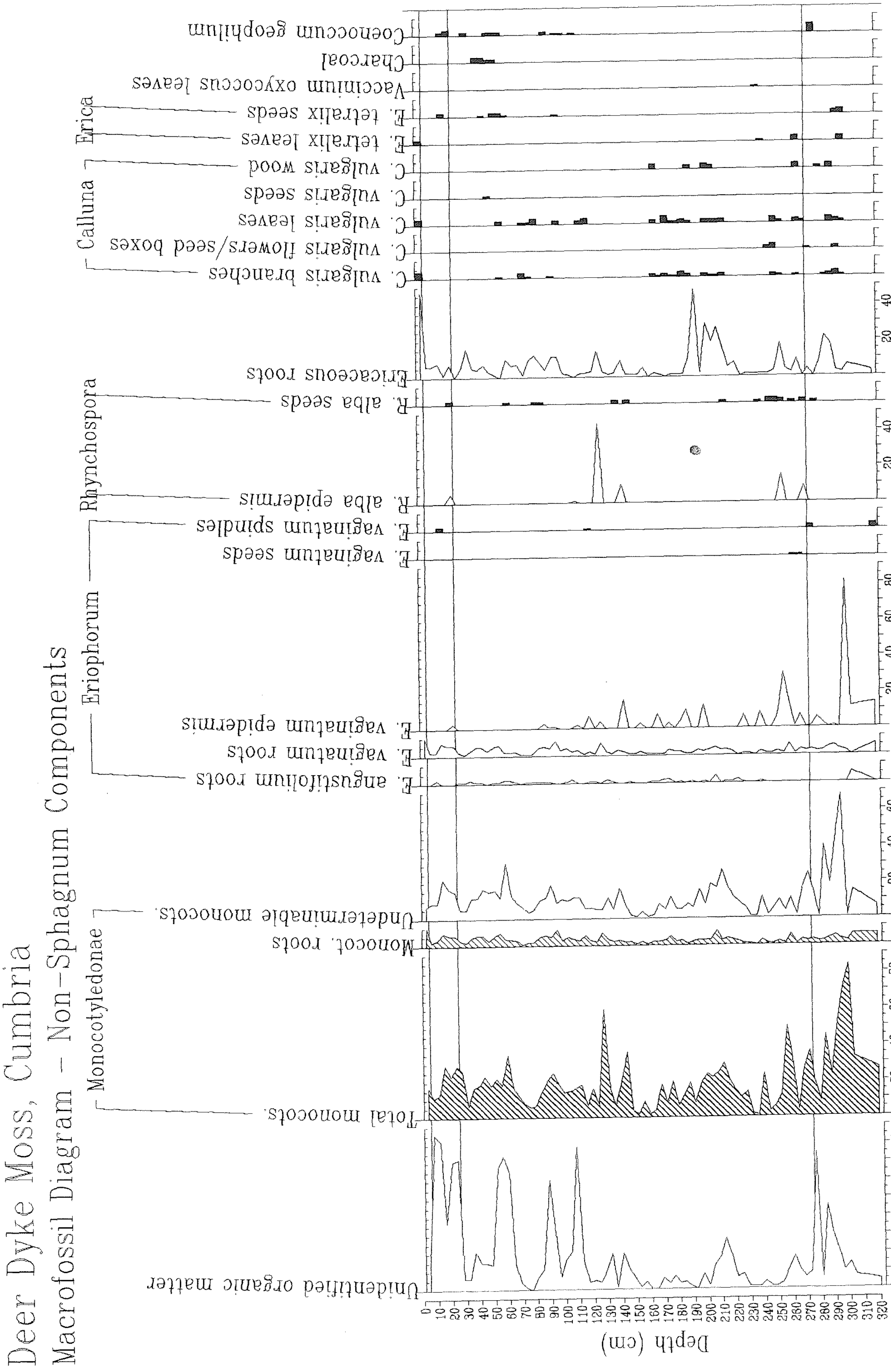

Figure 4.1.6b Deer Dyke Moss macrofossil diagram. Non - *Sphagnum* components.

4.1.7 Mullenakill Bog

270 cm - 300 cm

This phase of bog growth, dominated by an almost complete monoculture of *S. imbricatum*, took place under a relatively high water table (-0.6 to -0.2 cm) that becomes apparently superficial at 280 cm stratigraphic depth. This sharp increase in the modelled water table (Figure 4.4.14) gives rise to short-lived peaks of *E. tetralix*, *S. auriculatum* and *S. cuspidatum*. *E. vaginatum*, by comparison becomes extinct at this point and *C. vulgaris* maintains a sporadic presence throughout.

The end of this phase is marked by a sharp fall in the water table from +1.3 cm to -2.0 cm at which point *S. capillifolium* and *S. tenellum* become consistently present in a less homogenous assemblage.

206 cm - 270 cm

The timing of the onset of this phase is radiocarbon dated to cal. 2775 BP a time when, there is much evidence to indicate a widespread, climatic deterioration throughout NW Europe (Godwin & Willis, 1960; Tallis & Switsur, 1973; Barber, 1982; Charman, 1990, 1995) indicate a climatic deterioration. The emergence of *S. cuspidatum* in the phase would be consistent with this but overall, the DCA plot of the Axis 1 scores for the species and samples indicates no change in hydrology (in balance with the simultaneous emergence of less hydrophilous species). Additionally, the testate amoebae derived water table model indicates a fall in the water table of 3.3 cm. In response to this climate shift the vegetation appears to have developed a more heterogeneous topography supporting a more diverse community of plants. The testate amoebae may indicate a consistent fall in the water table due to the greater prevalence of hummock species now amongst their community such as; *Assulina* spp., *Difflugia pulex* and *Nebela militaris* present in hummocks of *S. capillifolium* and possibly, *S. imbricatum* . Wet indicators, most notably *Amphitrema flavum*, remain present and perhaps overall the fauna indicates the relative proportion of hummock to hollow.

S. imbricatum remains the dominant species throughout the phase with *S. capillifolium*, *S. cuspidatum* and *S. tenellum* constantly present at low, but increasing values, *S. fuscum* occurring as one, short-lived peak. The development of lawns as well as hummocks and hollows is evident from the presence of *Polytrichum juniperinum* type remains between 228 cm and 248 cm. *C. vulgaris* is present at low values throughout the phase but *E. tetralix* and *V. oxycoccus* do not become present until 228 cm. The end of this phase is marked by the extinction of *C. vulgaris*, *E. tetralix* and the diverse *Sphagnum* community.

166 cm - 206 cm

The start of this phase is marked by the return to a homogenous *S. imbricatum* lawn, the transition occurring between the radiocarbon dates cal. 2265 - 2520 BP. This shift occurs under the onset of drier conditions as indicated by the testate amoebae derived water table model. These values fall from the range -1.1 cm to 4.3 cm, down to -8.2 cm. Following this decline the values steadily return to a value around - 4 cm by the end of the phase which is marked by a sharp decline in *Sphagnum* abundance at cal. 1900 BP.

150 cm - 166 cm

This phase, the boundaries of which are dated at cal. 1680 BP and cal. 1900 BP marks peaks of Unidentified Organic Matter, Monocotlyedonae (probably *E. vaginatum*) and an ericaceous rooting zone. No recognisable above ground remains are recorded from any grouping and this is thought to be an indication of the dry conditions prevailing. Mauquoy (1997) and others cited there suggest this to be a period of wet shifts but this author also draws attention to invalidated, "inferred periods of dryness". The dates obtained here suggest this to be a prolonged period of low precipitation. Under these climatic and vegetative conditions however it is interesting to note, by reference to the age-depth model (Figure 4.5.3), that there is no decrease in the rate of peat accumulation.

38 cm - 150 cm

This phase sees a return to the vegetation found between 206 cm and 270 cm under similar, hydrological conditions within the range, -3.3 cm ± 1.5 compared to 3.1 cm ± 1.3. The initial presence of *Racomitrium canescens* is indicative of bare patches of peat which are rapidly colonised by *S. imbricatum* as it returns to dominance within the vegetation. The initial presence and possible persistence of bare peat possibly assists the emergence of colonist *S. molle* which maintains itself throughout the phase at low values. This persistence of a shade tolerant species is aided by the very sporadic occurrences of *C. vulgaris, E. angustifolium, E. vaginatum*, and *E. tetralix* indicating their scarcity within this community. *R. alba* is now absent, perhaps becoming severely restricted during the preceding phase and incapable of expansion to exploit the now prevailing conditions, although it is currently common on the mire. Ultimately, the over all impression given is that of an undulating *Sphagnum* lawn with a diverse community of *S. capillifolium*, *S. cuspidatum*, *S. fuscum*, *S. imbricatum* and *S. tenellum* with a scarcity of higher plants.

The inception of this community, dated at cal. 1680 BP and its termination at cal. 795 BP encompasses a number of known climatic shifts to which Mullenakill Bog shows little response. The end of the phase is marked by the extinction of *S. imbricatum*, the subsequent rise of *S. cuspidatum* and emergence of *S. magellanicum*.

14 cm - 38 cm

This phase is marked initially by a sharp peak of *S. cuspidatum* that soon falls to co-dominance with *S. magellanicum*. The vegetation throughout this phase appears to be almost wholly *Sphagnum* based with only one level of *C. vulgaris* and *E. tetralix* present and *E. vaginatum* sporadic in appearance at very low values.

This phase of *S. cuspidatum* dominance occurs at a time when Barber (1981) considered an increase in summer precipitation and Aaby (1976) a change in the humification values of his stratigraphy of Draved Mose, both indicating a wet shift. Such a shift was also recorded by Stoneman (1993) but conversely, Tallis (1995) and Mauquoy (1997) consider a time of drier phases also. The reasons for this are unclear but in this instance a wet shift is evidently recorded.

The end of this phase is marked by almost complete disappearance of the Sphagna and the appearance of a monocotyledonous rooting zone.

2-14 cm

This phase is initially marked by a sharp increase in Monocotyledonous roots and those of the Ericaceae and both components are probably indicative of the species colonising this phase otherwise dominated by Unidentified Organic Matter. A feature of diminished water tables, the amount of Unidentified Organic Matter in this phase case is probably due to local and regional drainage. Drainage of the Lough Neagh area commenced in 1859 and persisted until 1956 (K. Stanfield, pers,. comm.). On the bog itself a drainage system was installed by the Irish Peat Development Company after purchase in 1901 (*http://www.nics.gov.uk/doe_env/peatland.htm*). This phase can therefore be crudely dated to somewhere around this time with uncertainty imposed additionally by the absence of data on how much of the stratigraphy may have been lost during this period. The first record of *Campylopus introflexus* from Ireland is 1942 and this species was present around the Lough Neagh area by 1964 (Richards & Smith, 1975) thus supplying a crude date for the upper layer of this phase. This colonist species indicates the existence of open, bare patches of peat.

The end of this phase is marked by the rapid return of a *Sphagnum* dominated vegetation type.

0 cm - 2 cm

This rapid return of *Sphagnum* can probably be ascribed to hydrological management in the park during the early 1980's which locally raised the water table by 1.0 - 1.5 m (Shaw, 1993). Clearance of *Pinus* and *Rhododendron* also took place around the periphery of Mullenakill Bog thereby reducing evapotranspirative losses. *S. magellanicum and S. tenellum* are now recolonising rapidly with perhaps, a greater abundance of *C. vulgaris* than previously but this may diminish again as water tables continue to rise. The lowering of the regional water table around Lough Neagh may however result in the persistence of this species. The continued existence of bare patches is seen in the continued presence of *C. introflexus*.

Increases in water table are reflected in the testate amoebae derived water table model that shows figures recovering to the range of typical values. It is also encouraging to see that the contemporary vegetation of Mullenakill Bog is similarly found on the much less perturbed Ballynahone Bog indicating once more the resilience of these ancient monuments in maintaining homeostasis.

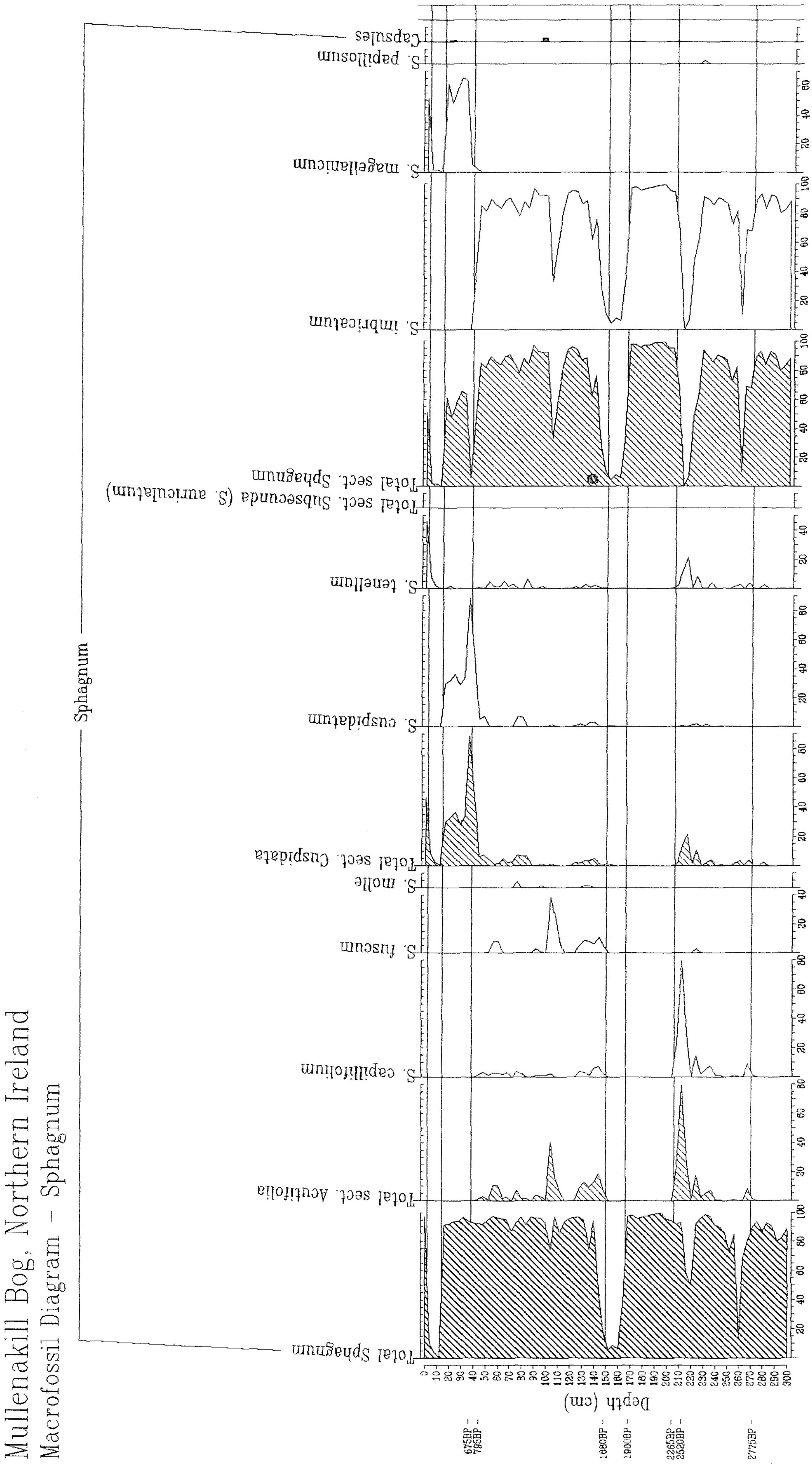

Figure 4.1.7a Mullenakill Bog macrofossil diagram. *Sphagnum*.

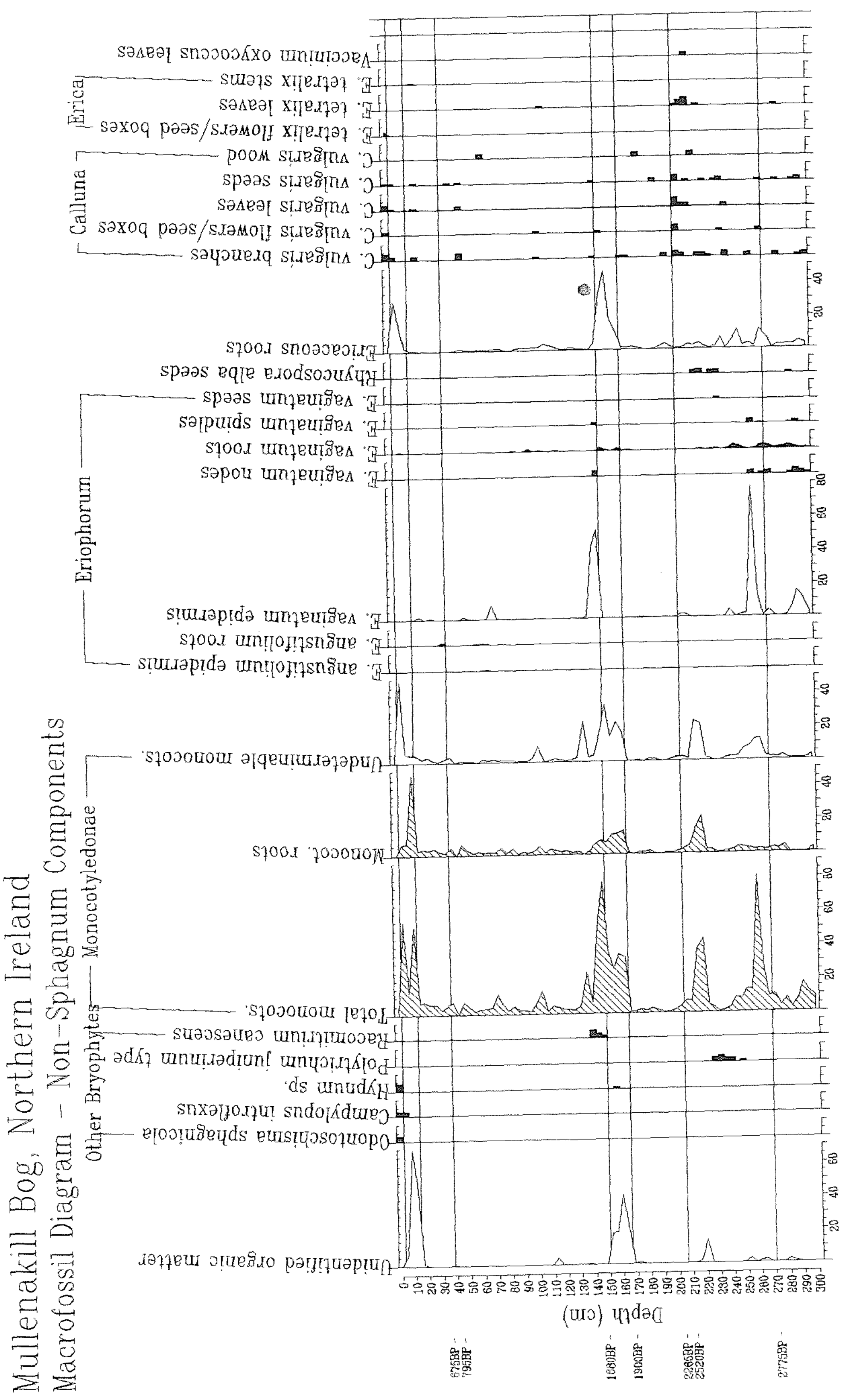

Figure 4.1.7b Mullenakill Bog macrofossil diagram. Non - *Sphagnum* components.

4.1.8 Wedholme Flow

286 cm - 300 cm

This stratigraphic section opens with a wet lawn phase dominated almost exclusively by *S. auriculatum* and *S. cuspidatum* with a small amount of material referable to *S. imbricatum* and *S. papillosum*. *R. alba*, *E. angustifolium* and *E. tetralix* are present within this *Sphagnum* lawn which appears too wet for the growth of *C. vulgaris* after the coincident extinction of *S. papillosum*. In this instance we possibly see evidence for *S. imbricatum* forming lawns and with *S. papillosum* overtopping the former on hummocks within the limits of *C. vulgaris* tolerance.

Throughout this phase the modelled water table rapidly falls to - 6.9 cm (Figure 4.4.16) by the start of the next and this probably explains the decline of *S. cuspidatum*, relative to *S. auriculatum*, in what probably became seasonal pools.

166 cm - 286 cm

The start of this phase is marked by the almost complete extinction of aquatic Sphagna and the sharp rise to dominance of *S. imbricatum* occasionally in association with *S. papillosum*. This lawn retains a low, sporadic presence of the aquatic *Sphagnum* species, *S. cuspidatum* and *S. balticum*, the latter probably favoured by the absence of a sub-shrub canopy. *S. auriculatum* remains consistently present throughout and indicates fluctuations in the water table also recorded by the testate amoebae which are modelled by the latter to be in the range of -0.9 cm to -9.4 cm.

Undoubtedly favoured by these fluctuating, hydrological conditions, *E. vaginatum* is the only vascular species consistently present throughout the phase. *E. angustifolium* is recorded sporadically as is *C. vulgaris* and *E. tetralix*, the latter pair from plants in seed shedding range of the borehole.

50 cm - 166 cm

This phase sees a return to the wet lawn community that marked the beginning of the stratigraphy (286 to 300 cm) under an apparently more stable hydrology than that preceding. *S. auriculatum* is now much more dominant than *S. cuspidatum* which is present in this phase as only one, short-lived peak. *S. imbricatum* is again co-dominant with this species, frequently with *S. papillosum*, prior to its extinction just before the end of this phase. This extinction of *S. imbricatum* at 60 cm sees the emergence of *S. magellanicum* as a prominent species. *S. balticum* does not appear present and the greater predominance of Ericaceae has presumably shaded it out.

An increase in topographical amplitude towards hummocks is also indicated by the appearance of the ericaceous species, particularly that of the relatively xerophytic *C. vulgaris* which appears more consistently once water levels apparently drop to below an average -2 cm. Thus, this phase sees an appearance of hummocks upon which *C. vulgaris* can persist and the presence of ephemeral, probably shallow, pools containing *S. auriculatum*, *E. angustifolium* and *R. alba*. Both of these microtopes would have intergraded with stable lawns, the development of which can be seen in the presence of *P. commune* type remains at 96 cm.

Towards the end of this phase the water table model falls to a predicted -8.2 cm at which point *S. auriculatum* and the now extinct *S. imbricatum* becomes replaced by *S. magellanicum* and *S. papillosum*.

22 cm - 50 cm

This phase sees the development of a *S. magellanicum* and *S. papillosum* dominated vegetation type in which *C. vulgaris* becomes extinct as the water table rises towards -0.8 cm. *E. angustifolium*, *E. vaginatum*, *R. alba* and *E. tetralix* persist throughout this phase in low numbers and the modelled water table values fall at the upper boundary to a value of -8.6 cm by the start of the next phase.

10 cm - 22 cm

A peak of Unidentified Organic Matter distinguishes this phase and its inception can probably be dated to the middle of the 1800s when intensive drainage of the Southern Lobe was implemented (F. Mawby, pers. comm.). How much of this phase is degraded material or peat accumulated under continued growth of the surface is unclear. The sparse remains of *S. auriculatum*, *S. cuspidatum*, *S. magellanicum*, *S. papillosum* and *E. angustifolium* are present as well as monocotyledonous roots. The aerial remains of monocotyledonous taxa were not well preserved under the prevailing dry conditions but those recovered are probably attributable to *Eriophorum* spp. but *M. caerulea* might also be expected. At the end of this phase we also see a marked peak of ericaceous roots which is derived from plants rooting on this surface.

The hydrology of this phase is dominated by a sustained fall to below -8 cm that, in light of the Unidentified Organic Matter accumulation, is perhaps an underestimation.

2 cm - 10 cm

An upturn in the water table model to an interpolated -7 cm is concomitant with the expansion of *S. tenellum*. This species is here seen in its pioneer role, colonising a wasted surface in response to more favourable hydrological conditions. *S. magellanicum* returns to high values after a brief lag and its rise to dominance marks the end of this phase.

0 cm - 2 cm

S. magellanicum attains dominance in this contemporary phase. The presence of low hummocks is indicated by the apparent expansion of *C. vulgaris* to unprecedented figures that probably reflect the area's recent history of disturbance and continued water table draw down. Here also is a marked expansion of *E. tetralix*. The contemporary vegetation data (section 4.6.9) indicates that *S. capillifolium* is on these hummocks and that shallow pools with *S. cuspidatum* and *S. tenellum* are still present.

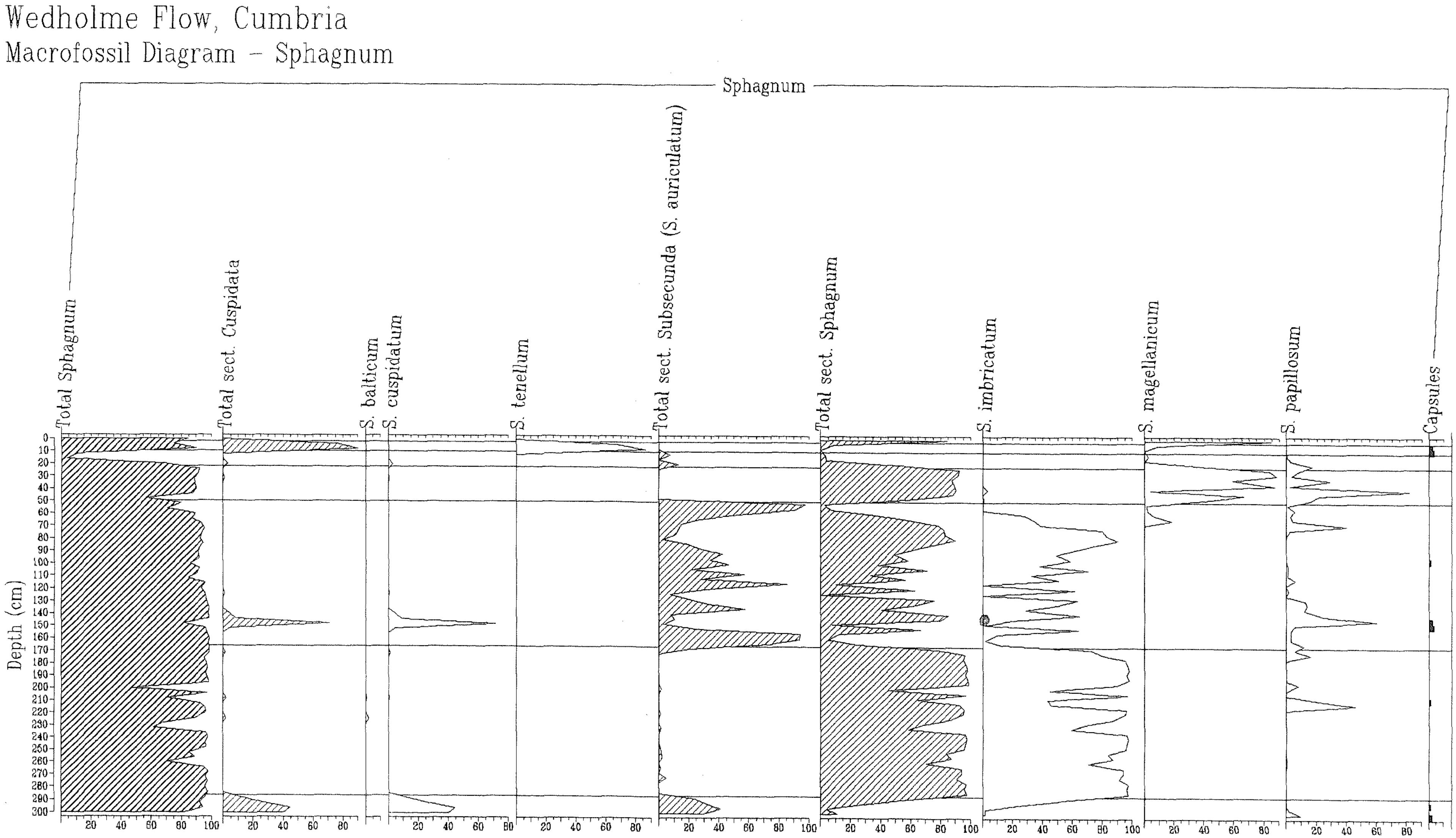

Figure 4.1.8a Wedholme Flow macrofossil diagram. *Sphagnum*.

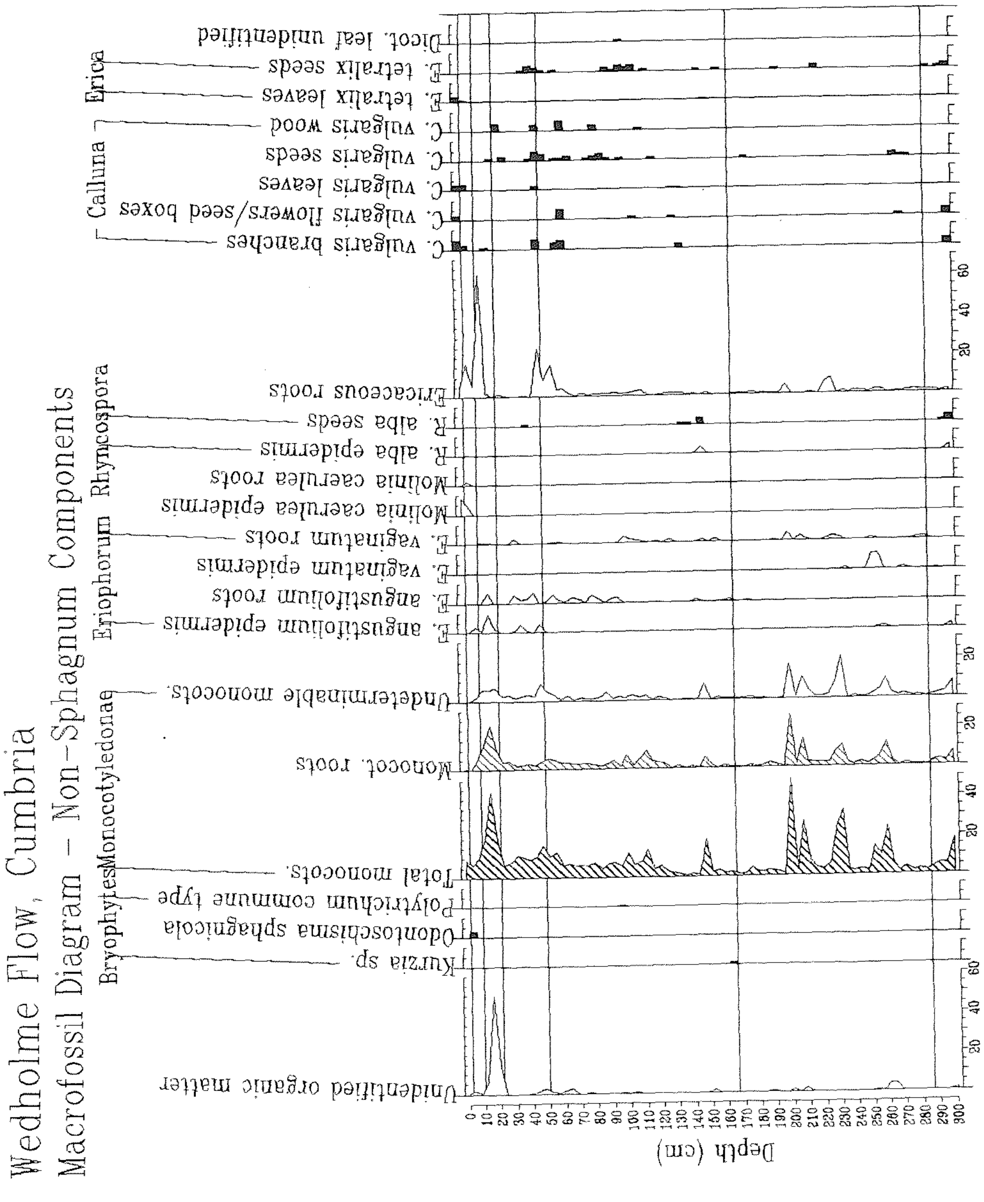

Figure 4.1.8b Wedholme Flow macrofossil diagram. Non - *Sphagnum* components.

4.1.9 Wreaks Moss

250 cm - 300 cm

Throughout this phase, a complete *Sphagnum* lawn is absent and areas of bare peat are indicated by the presence of *Campylopus* sp. and possibly *Kurzia* spp., the latter equally likely amongst *Sphagnum*. Isolated hummocks of *S. capillifolium*, *S. fuscum*, *S. imbricatum* and *S. papillosum* are present until at 272 cm the modelled water table (Figure 4.4.18) rises to *c.* -9 cm and this sees a small, accompanying rise of *Sphagnum*, particularly *S. imbricatum*. The recurrent fire events of this phase may have held the faunal and floral communities in check since an increase in the modelled water table and expansion of *S. imbricatum* are coincident with the cessation of the exogenous influence. However, a few bryophytes; *Aulacomnium palustre*, *Campylopus* sp., *Pohlia* sp. and *Kurzia* spp., do appear to benefit from opening of the vegetation and incineration of litter.

C. vulgaris remains the dominant species throughout this phase where its roots comprise most of the peat together with high amounts of Unidentified Organic Matter and the small amount of *Sphagnum* already noted.. Monocotyledonous roots also comprise a significant proportion of the peat and those aerial remains that survived the fire episodes can be identified as *E. angustifolium* and *E. vaginatum*.

At the end of the phase, the water table model falls to its original values in the range -12.0 to -14.0 cm. Times of higher, water table values appear associated with the fire events. This is possibly due to the presence of hydrophilous testate amoebae inhabiting ponds of water on the peatland surface instigated by the blocking of acrotelm pores with ash and fine charcoal.

246 cm - 250 cm

The significance of the small peak of charcoal at 248 cm is not clear. It may represent a "flash" fire of the *E. vaginatum* litter or have been of greater significance and actually been the genesis of this phase and the subsequent rise of *S. imbricatum*, perhaps facilitated by the reduction in *C. vulgaris* cover. Otherwise, *E. vaginatum* is dominant here, at the transition between two vegetation communities and its rise and fall indicate the boundaries of this phase.

194 cm - 246 cm

In the absence of a marked hydrological change recorded by the testate amoebae it is assumed that this *Sphagnum* rich community is, in the absence of fire, derived from that between 250 cm and 300 cm. The development of the *Sphagnum* lawn is possibly directed by the upstanding growth of *E. vaginatum* and *C. vulgaris* into a hummocky topography in which these species maintain their presence. The low, sporadic presence of hydrophilous *S. cuspidatum* and *S. tenellum* indicates the existence of wet lawns and possibly, shallow, waterlogged hollows. The single fire event at 220 cm appears to have no marked effect upon the vegetation although the appearance of a concomitant rise in Unidentified Organic Matter suggests that it was at least locally severe and probably burnt into the acrotelm.

This phase is terminated by the almost complete extinction of *C. vulgaris*, *E. vaginatum* and the appearance of *E. angustifolium*, as the water table rises.

142 cm - 194 cm

Under an increased water table, now in the range of -2 cm to -5 cm, the preceding *Sphagnum* lawn becomes much more homogenous with only low, sporadic values of *S. cuspidatum*, *S. tenellum*, *E. angustifolium*, *E. vaginatum* and *C. vulgaris*. This indicates extinction of the hummocks and expansion of the wet lawn/waterlogged hollow microtopes.

The end of this phase is marked by the return of *E. vaginatum* and the consistent emergence of aquatic Sphagna, primarily *S. auriculatum*.

50 cm -142 cm

During this phase of peat accumulation, the abundance of *S. auriculatum* suggests that precipitation and hence, the water table, may have become seasonally variable. This is indicated also by the presence of a charcoal layer in this hydrophilous community which suggests that summer drying may have occurred interrupted by periods where the water table rose sufficiently to permit the growth of *S. auriculatum*. This precipitation regime might explain the initial, insensitivity of the testate amoebae.

After the initial lag, a gradual rise in the water table is recorded by the testate amoebae to a sustained value of *c.* -1 cm from 112 cm onwards, when *S. cuspidatum* becomes present.. Once the water table reaches surficial levels at 72 cm it falls away to the range of values recorded at the start of this phase, (*i.e.* -3 cm to -5 cm) and *S. auriculatum* rises to high values vicarious to a decrease of *S. imbricatum*. The increase in the abundance of *S. auriculatum* and extinction of *S. cuspidatum* suggests that the water table may have returned to its variable state that marked the onset of this phase.

The development of occasional hummocks is apparent in the sporadic occurrences of *S.* sect. *Acutifolia*, *S. papillosum*, *C. vulgaris* and *E. vaginatum* within a lawn dominated by *S. imbricatum*. The low relief of these structures is indicated by the scarcity of *C. vulgaris* and the greater presence of *E. tetralix*, suggesting that these hummocks are possibly best described as areas of raised lawn. The hollows and their margins presumably bore the species *E. angustifolium* and *R. alba*.

38 cm - 50 cm

The opening of this phase is marked by the extinction of *S. auriculatum* and the emergence of the *S.* sect. *Acutifolia* species, *S. capillifolium* and *S. fuscum* with the continued presence of *S. imbricatum* at low values. The upward development of hummocks is shown by the presence of these species. The water table values remain consistent with those at the end of the previous phase and this is possibly indicative of a shift to a more sustained rainfall regime which allows this hummocks to develop, intercepting and retaining their own water. The appearance of *R. alba* in the last level of the phase indicates the continued existence of wet lawns throughout this phase.

The extinction of *C. vulgaris* and *E. tetralix* throughout this phase may indicate that the growing hummocks were too competitive an environment for these species, perhaps on account of the rate of upward growth. However, these species are presumably still present and perhaps their apparent scarcity is also due, in part, to the shedding nature of these hummocks which do not favour accumulation of macrofossils in the same manner as hollows.

The end of this phase is marked by a sharp decline of the *S.* sect. *Acutifolia* species and the onset of high values for Unidentified Organic Matter and Monocotyledonous roots. This is also the apparent extinction point of *S. imbricatum* although this species remains present into the next phase at very low values.

6 cm - 38 cm

This phase is dominated by high values for Unidentified Organic Matter and Monocotyledonous roots, most of which are probably referable to *E. vaginatum*, here represented mostly by the remains of its nodes. *C. vulgaris* and latterly, *E. tetralix* are also present within this vegetation type that sees the inclusion of *Sphagnum* at very low values, including the species; *S. auriculatum*, *S. cuspidatum*, ,*S. fuscum*, *S. magellanicum* and *S. papillosum*.

A fire event, indicated by the presence of charcoal at 20 cm to 28 cm is responsible for a gap in the presence of aerial *E. vaginatum* components and the carbonisation of *C. vulgaris* remains, thereby enhancing representation of this species within the stratigraphy. This fire event also appears to open up the vegetation with *R. canescens* indicating the presence of bare, probably burnt, peat. Additionally, *S. cuspidatum* becomes present and this species may be present in hollows rendered impervious by the clogging of acrotelm pore space with ash and charcoal.

From this stratigraphy, even with the inclusion of a clear, chronological sequence, it cannot be determined whether this is a period of peat accumulation or breakdown of the original layers stimulated by the severe perturbations this bog has suffered in its recent history. The indication of a high water table in the range, -0.8 cm to -3.9 cm would suggest the accumulation of *Sphagnum* peat under such a hydrological regime which has subsequently become degraded to high amounts of Unidentified Organic Matter following water table draw down. However, such modelled water table values are theoretically possible if water ponded on a surface rendered impervious by secondary mineralisation allowing for the colonisation of hydrophilous testate amoebae. At the end of the phase, a sharp fall in the water table to -12.0 cm at 8 cm is indicated by the testate amoebae data. This is accompanied by an increase in the abundance of *C. vulgaris* and *E. vaginatum.*

2 cm - 6 cm

This, short-lived phase reflects the usual appearance of *S. tenellum* as an intermediary point on the way to the development of a complete *Sphagnum* lawn. No definite water table depth is available for this phase which falls between testate amoebae samples but by comparison to the figures derived for 0 cm and 8 cm it may be assumed to be increasing, to -7.2 cm from a depth of - 12.cm.

0 cm - 2 cm

This phase is indicative of the contemporary vegetation on Wreaks Moss. The dominance of *S. papillosum* reflects only its admixture in the surface vegetation at the coring site since *S. magellanicum* is more abundant in the contemporary quadrat data for this site.

The consolidation of a *C. vulgaris* canopy is apparent in this phase and the preceding levels, latterly with the increased inclusion of *E. tetralix* and the emergence of *V. oxycoccus*. The current vegetation thus contains these species in a variable topography dominated by lawns and hummocks with the occasional presence of wetter areas colonised by *S. recurvum*, perhaps favoured by the increased nutrition prevailing from the high degree of mineralisation between 6 cm and 38 cm.

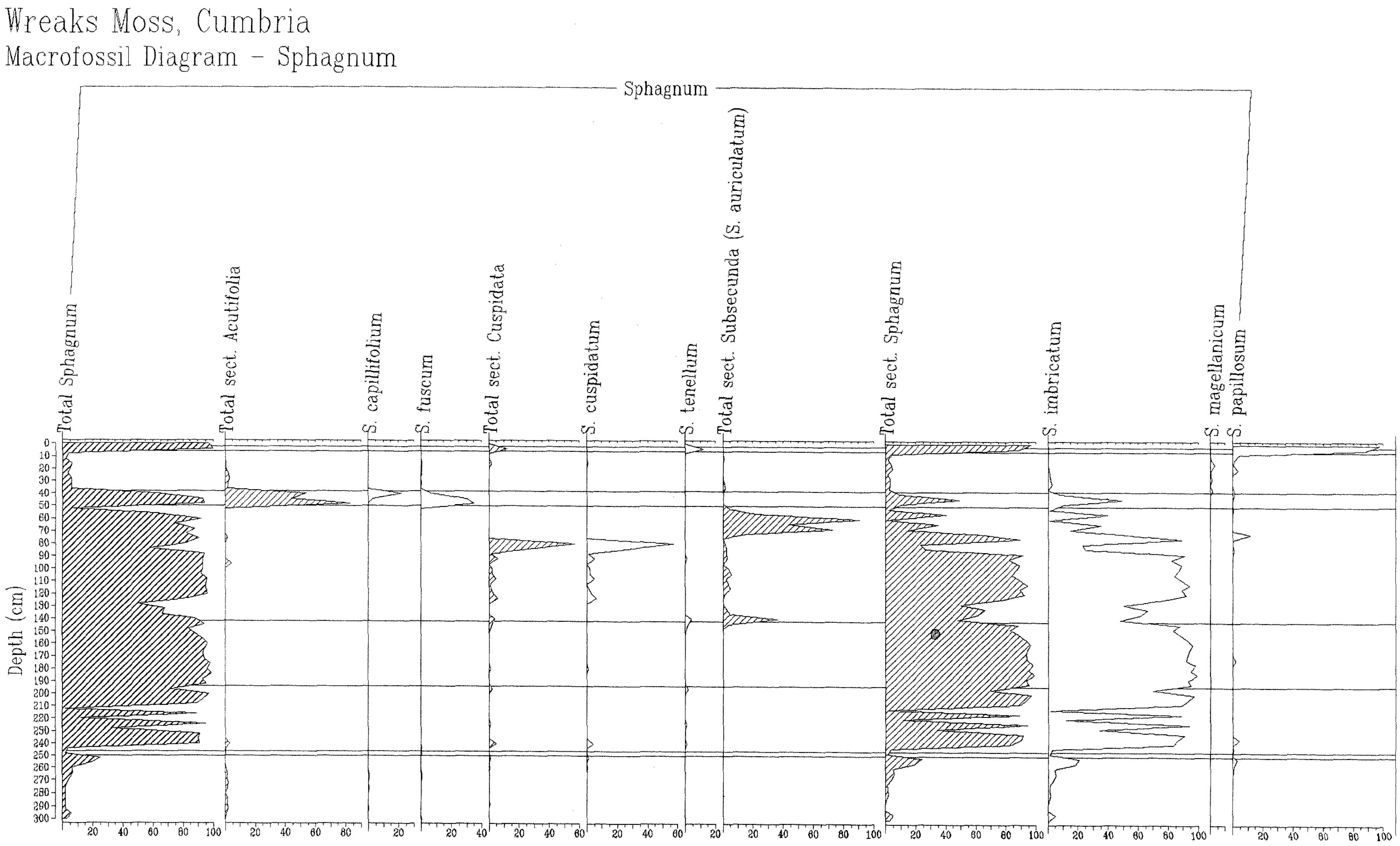

Figure 4.1.9a Wreaks Moss macrofossil diagram. *Sphagnum.*

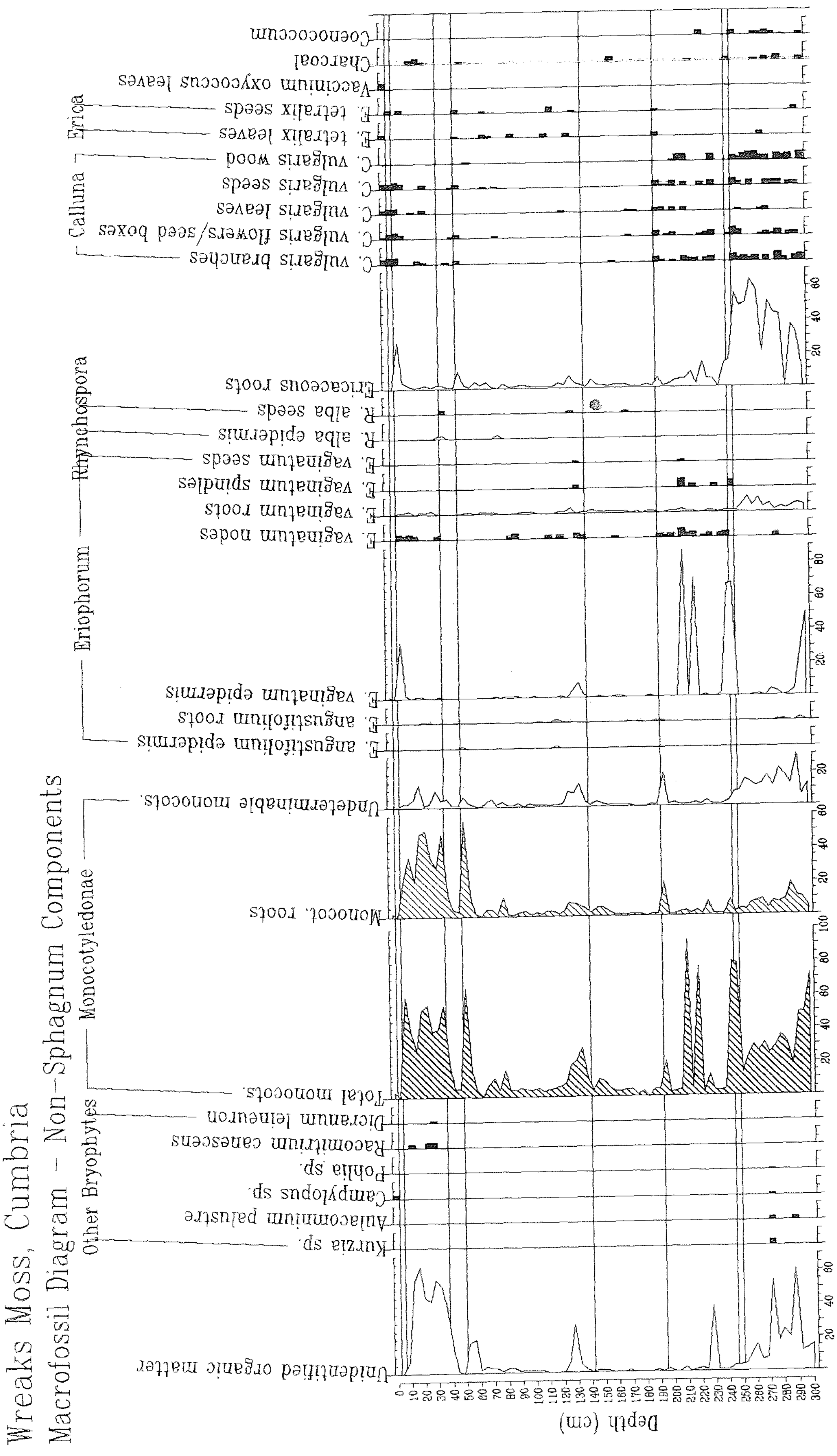

Figure 4.1.9b Wreaks Moss macrofossil diagram. Non - *Sphagnum* components.

4.2 DETRENDED CORRESPONDENCE ANALYSIS (DCA) RESULTS

4.2.1 Introduction

DCA analyses were run in order to confirm that hydrology is the primary ecological factor influencing the vegetation of raised bogs because this assumption forms the basis of this study. The hydrological axis of the DCA scatterplots was also plotted against the depth to yield a vegetation derived model for the prevailing hydrological state for comparison to those models derived from the testate amoebae data (section 4.4). In three of the analyses the direct hydrological gradient was relegated to the second DCA axis and in these instances, models derived from the two primary axes are presented.

4.2.2 Arnaby Moss Regeneration Peat

This DCA plot was derived from the 5-point scale data collated for the regeneration peat stratigraphy. The remaining sites were experimentally analysed on this basis also, by classifying their percentage data into the 5-point scale. However, the results for these analyses were ecologically meaningless and it has been suggested that this may be due to a consequent lack of variability in the classified data which cannot, therefore reflect the variability in the vegetation or be expressed in the analysis (D. Maddy pers. comm.).

The DCA Axis 1 .v. depth plot (Figure 4.4.2) for Arnaby Moss Regeneration Peat describes an approximately linear relationship with depth and this is assumed to reflect a temporal feature, namely succession. This is confirmed by reference to the scattergram (Figure 4.4.1) where the species and levels are seen to arrange themselves sequentially from right to left, according to their approximate positions in the stratigraphy. In conclusion, the DCA axis 1 .v. depth plot (Figure 4.4.2), with an eigenvalue of 0.413, reflects the inherent, vegetation dynamics of this regenerating peat. DCA Axis 2 has an eigenvalue of 0.161 and appears to have no ecological significance.

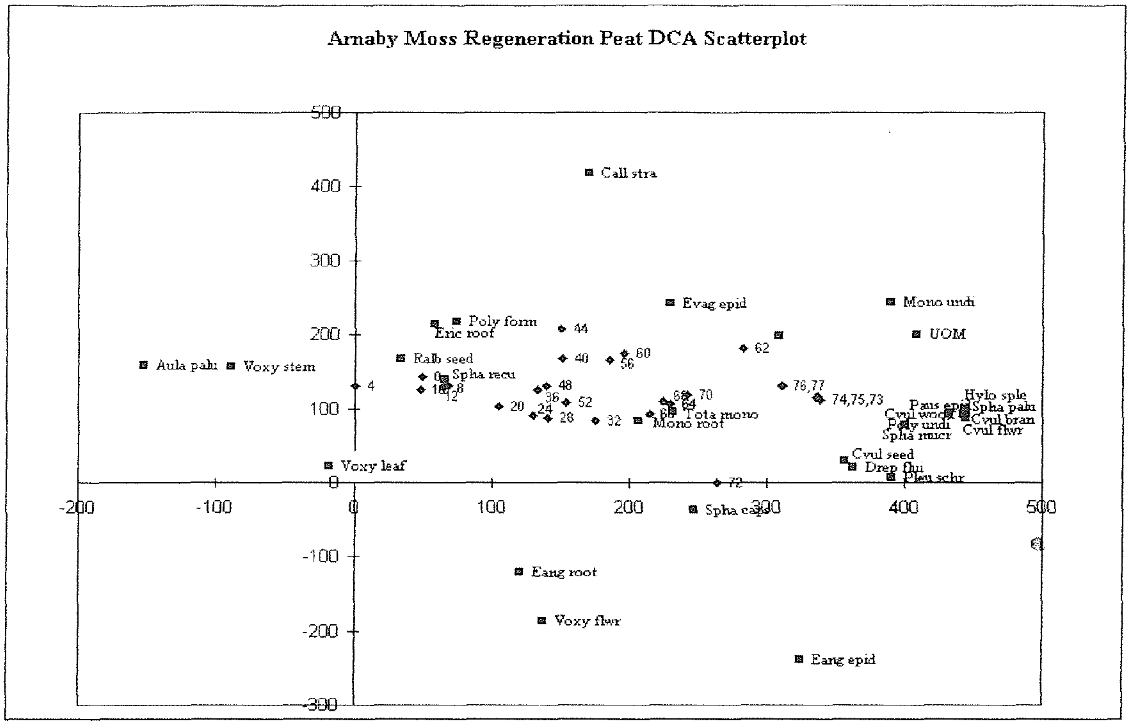

Figure 4.2.1 DCA scatterplot for Arnaby Moss Regeneration Peat macrofossils.

Key for Arnaby Moss Regeneration Peat's scatterplot: (Key: Aula palu, *Aulacomnium palustre*; Call stram, *Calliergon stramineum*; Cvul bran, *C. vulgaris* branches; Cvul flwr, *C. vulgaris* flowers; Cvulseed, *C. vulgaris* seeds; Cvul wood, *C. vulgaris* wood; Drep flui, *Drepanocladus fluitans*; Eric root, ericaceous roots; Eang epid, *E. angustifolim* epidermis; Evag epid, *E. vaginatum* epidermis; Evag root, *E. vaginatum* root; Hylo sple, *Hylocomium splendens*; Mono root, monocotyledous roots; Mono undi, Monocotyledonae undifferentiated; Pcom epid, *Phalaris communis epidermis*; Pleu schr, *Pleurozium schreberi*; Poly form, *Polytrichum formosum*; Poly unde, Polytrichum undeterminable; Ralba seed, *R. alba* seeds; Spha caps, *Sphagnum* capsules; Spha palu, *S. palustre*; Spha recu, *S. recurvum s.s.*; Tota mono, Total Monocotyledonae; Voxy flwr, *V. oxycoccus* flower; Voxy leaf, *V. oxycoccus* leaf; Voxy stem, *V. oxycoccus* stem.)

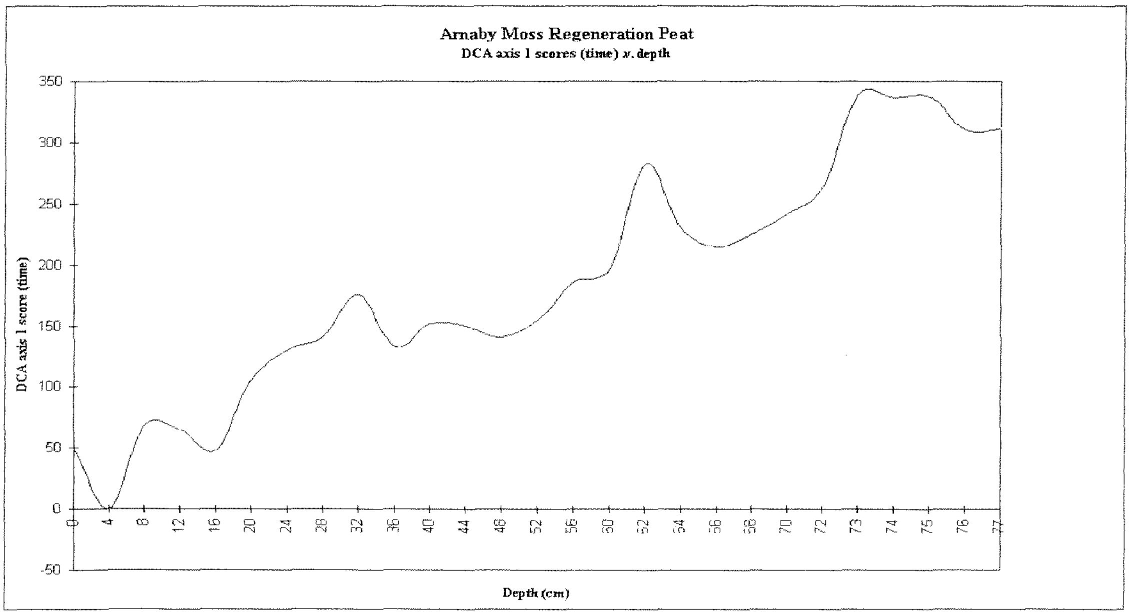

Figure 4.2.2 Time - depth model for Arnaby Moss Regeneration Peat. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

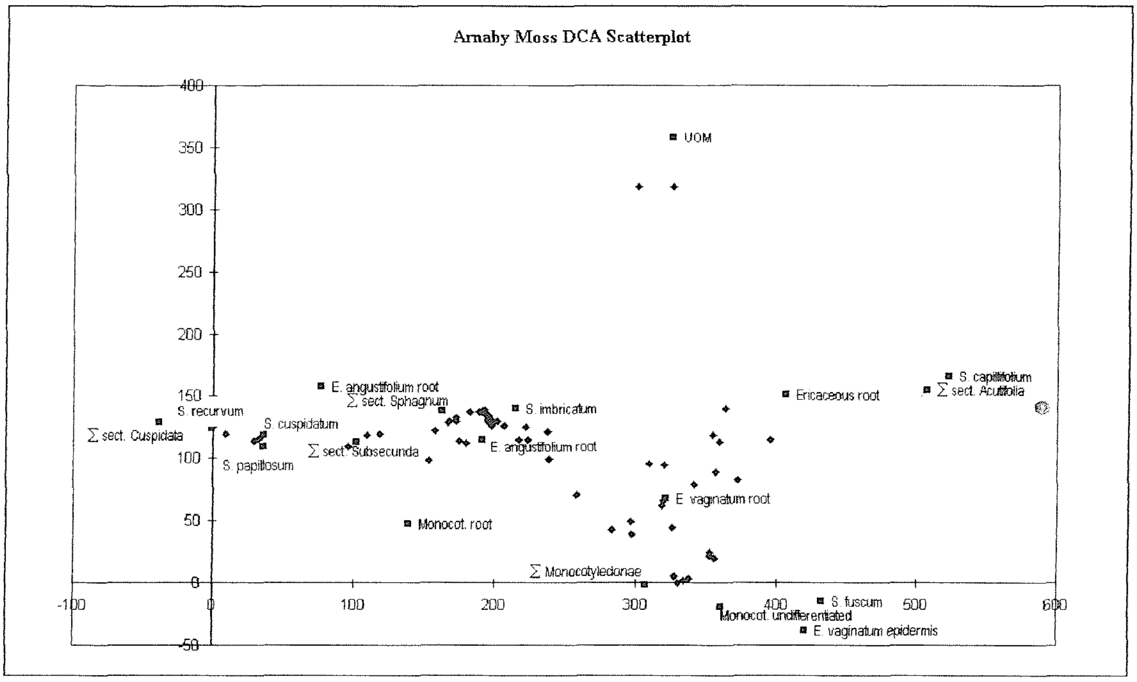

Figure 4.2.3 DCA scatterplot for the Arnaby Moss macrofossils.

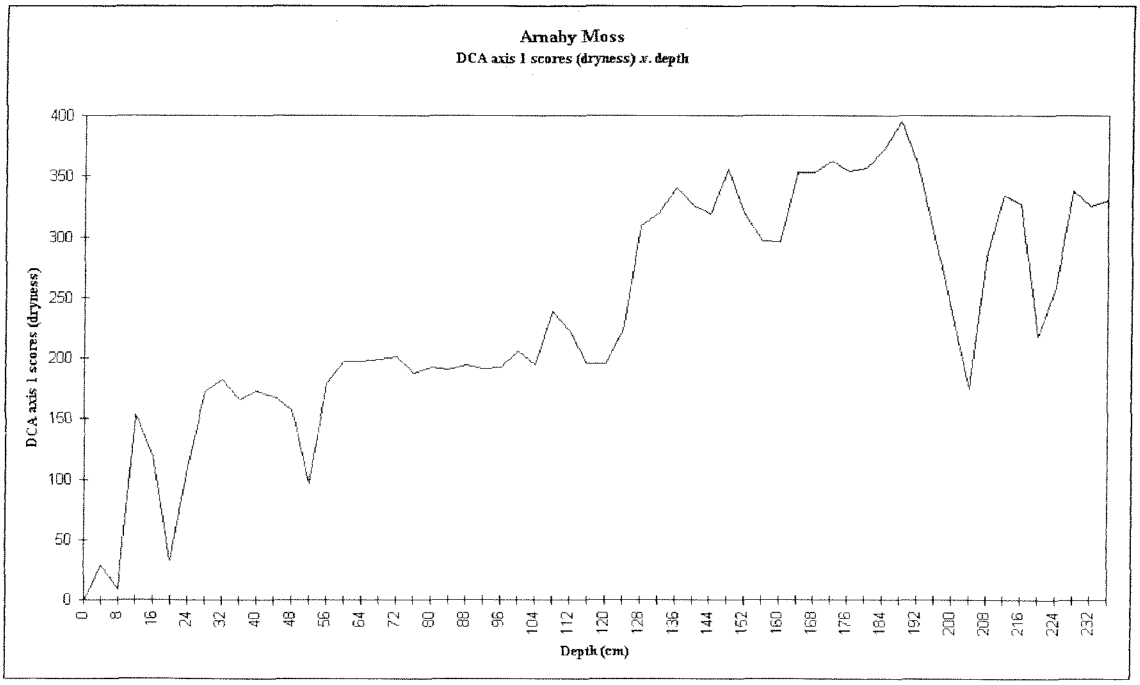

Figure 4.2.4 Surface dryness - depth model for Arnaby Moss. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

4.2.3 Arnaby Moss

The first axis of the DCA scatterplot (Figure 4.2.3) strongly reflects a water table gradient with the most hydrophilous species presented to the left hand side of the diagram. Reference to the macrofossil diagram suggests that the sequence of species and levels from right to left is also indicative of succession throughout the stratigraphy. The DCA Axis 1 .v. depth plot (Figure 4.2.4, eigenvalue 0.692) shows that both of these features are actually interrelated because the surface dryness so modelled is chronologically seen to fall in a series of steps. This trend is also apparent in the noisier testate amoebae derived water table model (Figure 4.4.4) but with a dip at the top of the stratigraphy. This is assumed to be erroneous since the presence of *S. recurvum* indicates what is probably the wettest phase of the stratigraphy. It is not unlikely that the close proximity of steep sided hummocks to the lawns of *S. recurvum* has led to the inclusion of their xeroindicative testate amoebae.

The relatively low eigenvalue of the second axis (0.371) and the short axial dispersal of the species and levels, with exception to the outlying Unidentified Organic Matter, attests further to the over-riding importance of hydrology on the past vegetation of Arnaby Moss which encompasses the two extremes of xeric Callunetum and mesic Sphagnetum.

4.2.4 Ballynahone Bog

The first axis of the Ballynahone Bog DCA scatterplot (Figure 4.2.5) is strongly indicative of a hydrological gradient although *S. fuscum* appears further to the left than one would expect. This is probably due to the occurrence of this statistically rare species in topographically diverse samples dominated by *S. cuspidatum*. *S. imbricatum* is indicated to be the second driest species, out on the right hand side of the diagram. This is perhaps indicative of a hummock forming habit being maintained by this species throughout most of the phase, as attested to by the abundance of *C. vulgaris* in the macrofossil diagram (Figure 4.1.3). The DCA Axis 1 .v. depth plot (eigenvalue, 0.576) therefore reflects

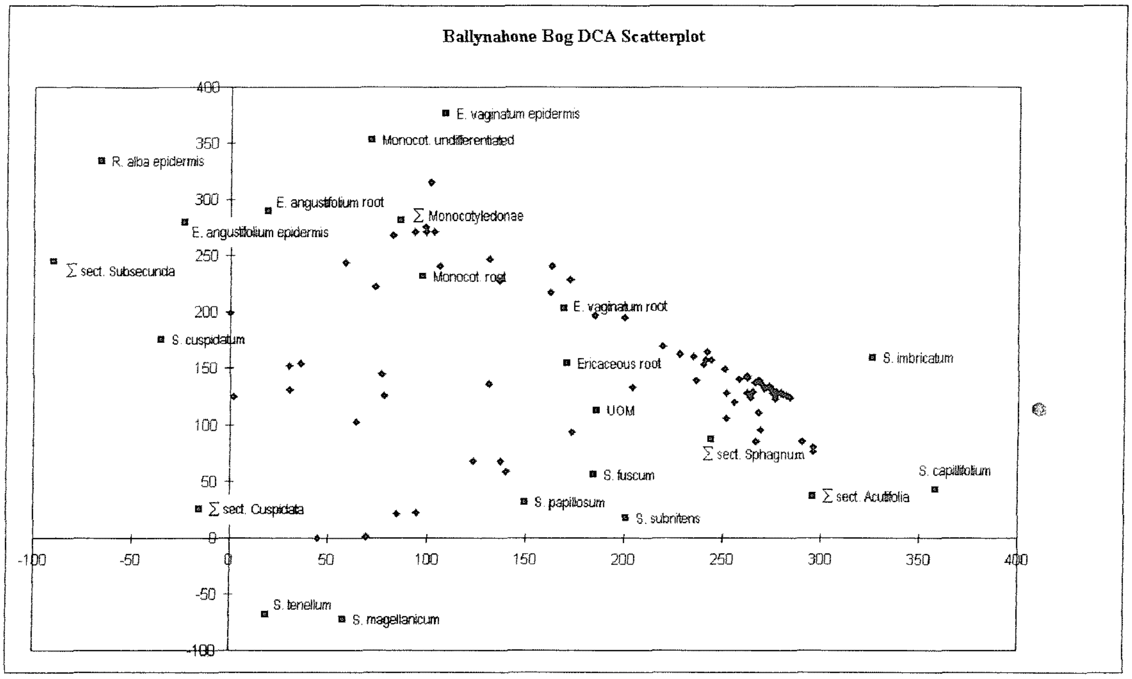

Figure 4.2.5 DCA scatterplot for the Ballynahone Bog macrofossils.

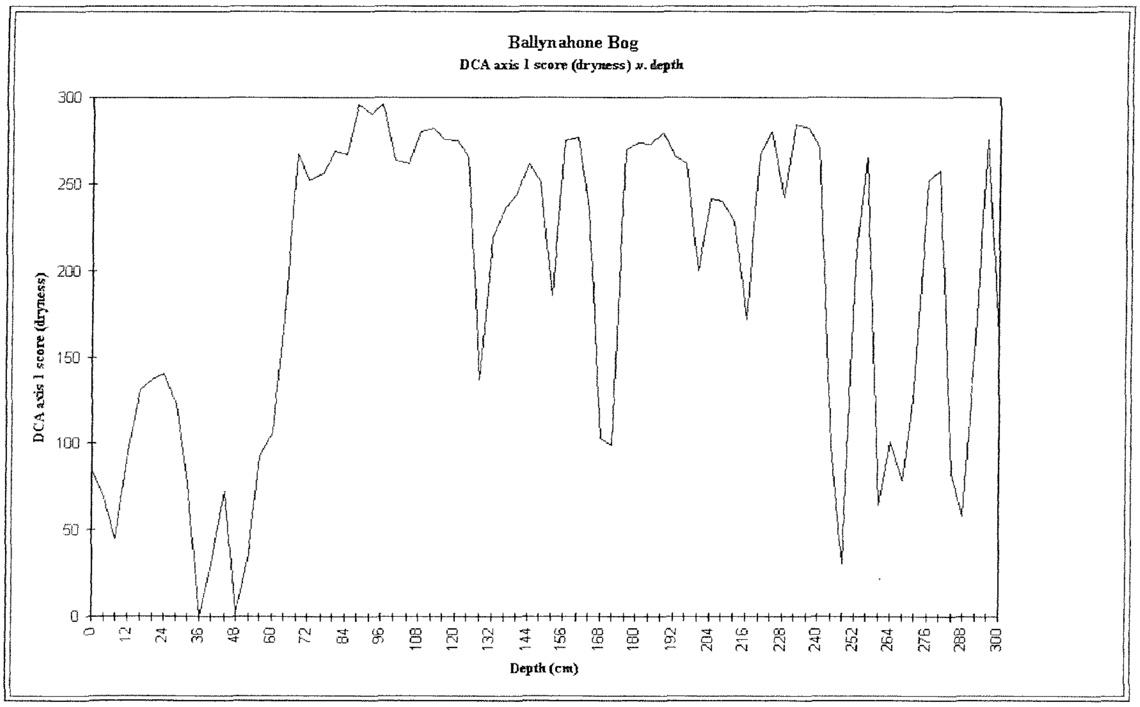

Figure 4.2.6 Surface dryness - depth model for Ballynahone Bog. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

the dryness of the mire surface since the most xeric species are presented to the right hand side of the diagram. This rather invariable plot suggests long term stability of the water table at Ballynahone Bog despite the presence of shorter term peaks and troughs in this model which are primarily due to the expansion and contraction of *S. cuspidatum* pools. These fluctuations may be due to small scale, pool margin movements next to the borehole or represent larger scale fluctuations. Latterly, species of *S.* section *Cuspidata* predominate in the stratigraphy and at this point the DCA Axis 1 .v. depth plot remains at low (wet) values due to the abundance of *S. tenellum* and this is indicates the relatively minor effect of the now reversed drainage on Ballynahone Bog. DCA Axis 2 appears to have no clear ecological significance.

4.2.4 Coalburn Moss

The scatterplot for Coalburn Moss (Figure 4.2.7) is strongly indicative of a water table gradient along DCA axis 1 and the high eigenvalue of 0.687 indicates the large amount of variability accounted for within this axis. The statistically rare species, *S. auriculatum* and *S. balticum* perhaps appear too dry and this is probably a consequence of their rarity and association with *E. vaginatum* at 242 cm to 254 cm. However, *S. auriculatum* may be regarded as a dry species in certain contexts since it is dependant only upon seasonal inundation, such as around pool margins or along montane track-sides. Whatever the role of this species, the relative dryness of the moss is modelled in the DCA Axis 1 .v. depth plot (Figure 4.2.8) since the obligate, xeroindicative species scores are the highest. A marked low in surface dryness between 46 cm and 58 cm is referable to the development of a *S. cuspidatum* dominated phase.

The DCA Axis 2 plot (not illustrated) with an eigenvalue of 0.353 bears no readily apparent ecological significance.

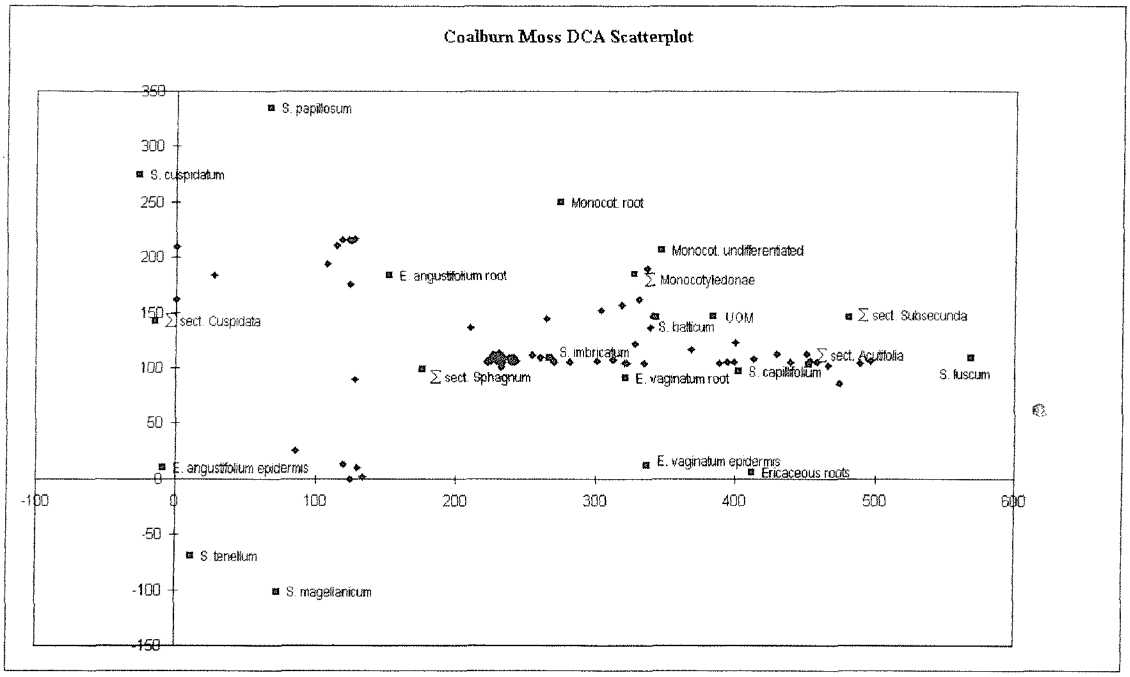

Figure 4.2.7 DCA scatterplot for the Coalburn Moss macrofossils.

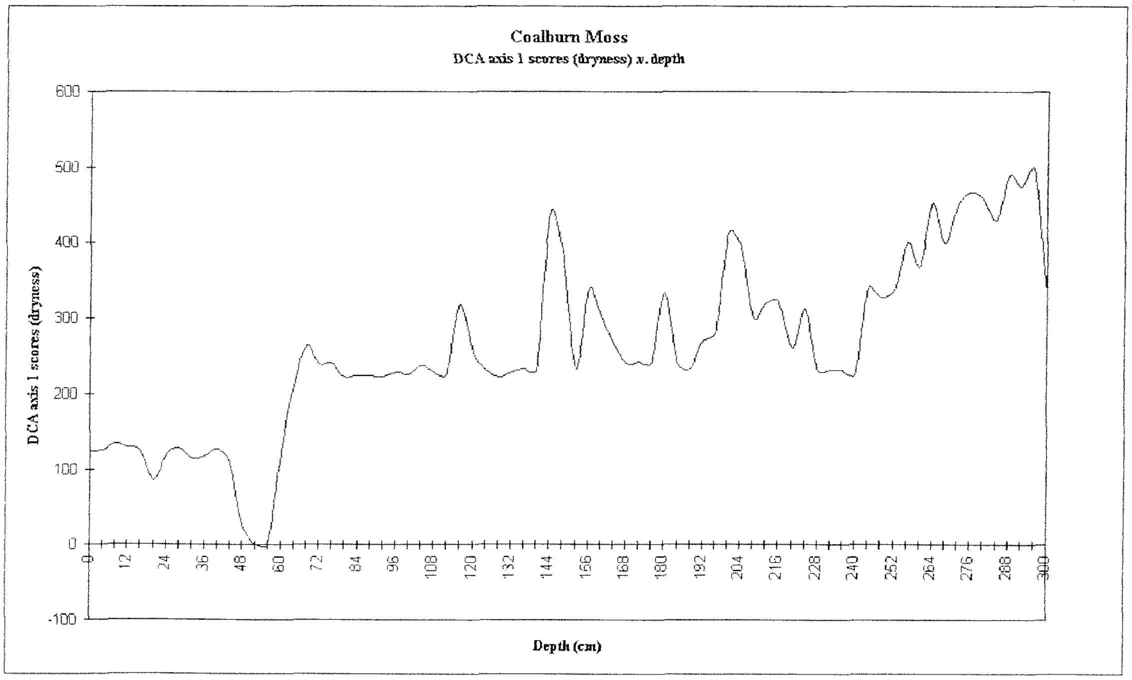

Figure 4.2.8 Surface dryness - depth model for Coalburn Moss. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

4.2.5 Cranley Moss

In this case the direct, hydrological signal is relegated to axis 2 of the scatterplot (Figure 4.2.9; eigenvalue 0.431). On this secondary axis the species are almost perfectly arranged according to their classical positions along the hummock-hollow gradient (*cf.* Rydin, 1985 & 1993, for example). It was initially considered that relegation of the hydrological axis was related to the analysis of data where *Sphagnum* was identified wholly to species level rather than the aggregates of sections *Acutifolia* and *Cuspidata* normally utilised in such studies (Barber, *et al.* 1994, Stoneman, 1993). However, running the data again, to the exclusion of species level data for the *Sphagnum* sections, resulted in a similar arrangement of taxa.

The arrangement of species along DCA Axis 1 (eigenvalue, 0.732) appears to be related to the topographical diversity of the site. This is suggested by the occurrence of *S. imbricatum* and *S. magellanicum* dominated samples to the left hand side of the diagram because both of these species are, in this instance, responsible for the formation of smooth lawns in which other species are largely absent or only of sporadic occurrence. Those species and samples to the right hand side of the diagram occur in diverse phases where the high degree of biodiversity is indicative of an equally diverse hummock - hollow topography. This axis is accordingly plotted against depth in Figure 4.2.10 to derive a depth-topography model.

Stratigraphically, the greatest biodiversity is seen during the initial phase of *S. capillifolium* dominance where the presence of wet hollows and dry hummocks are seen in the respective remains of *S. auriculatum* and *C. vulgaris*. This community subsequently suffers an apparently high degree of modification following a fire event at 264 cm and this permits entry of *S. tenellum* into the vegetation. How this effects the topography is unclear from the data but fire events may have no effect, increase or decrease the topographic variation of a vegetation surface (Barkman, 1992). However, the continuing presence of a hydrologically diverse flora indicates that some degree of microform diversity is maintained.

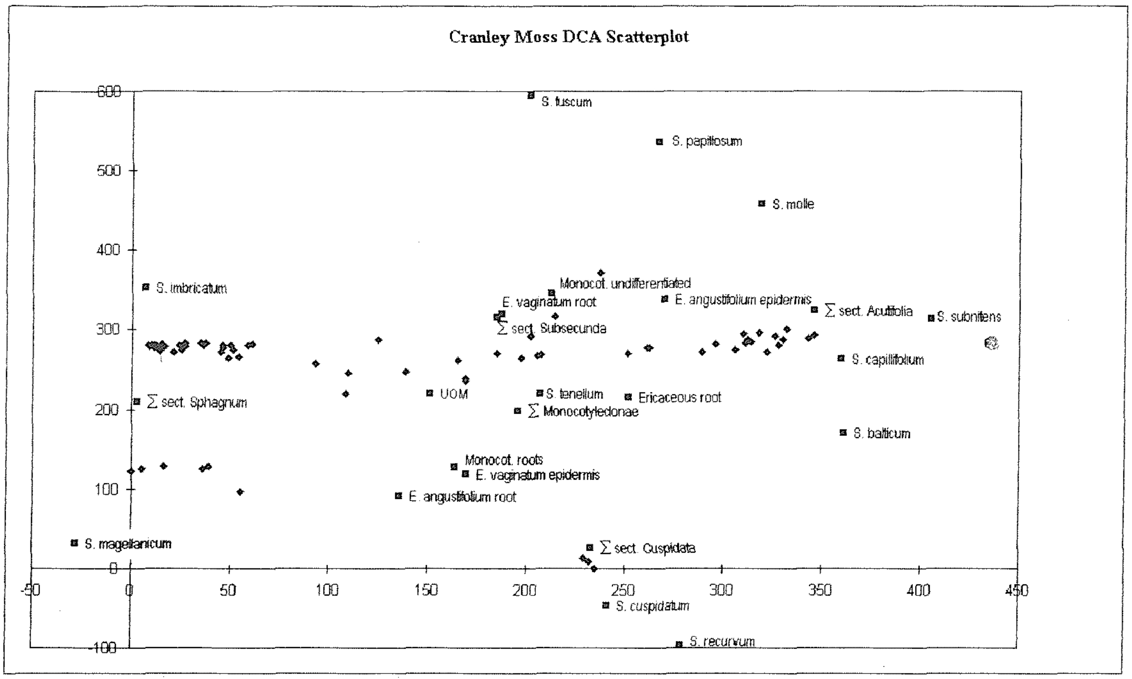

Figure 4.2.9 DCA scatterplot for the Cranley Moss macrofossils.

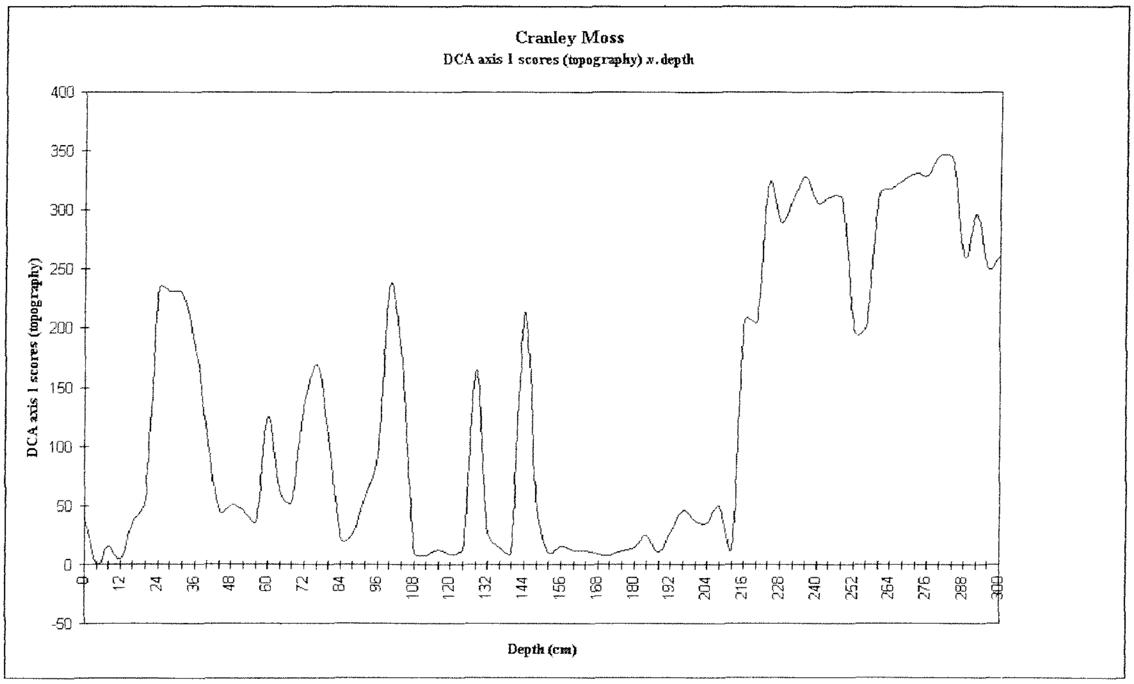

Figure 4.2.10 Topography - depth model for Cranley Moss. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

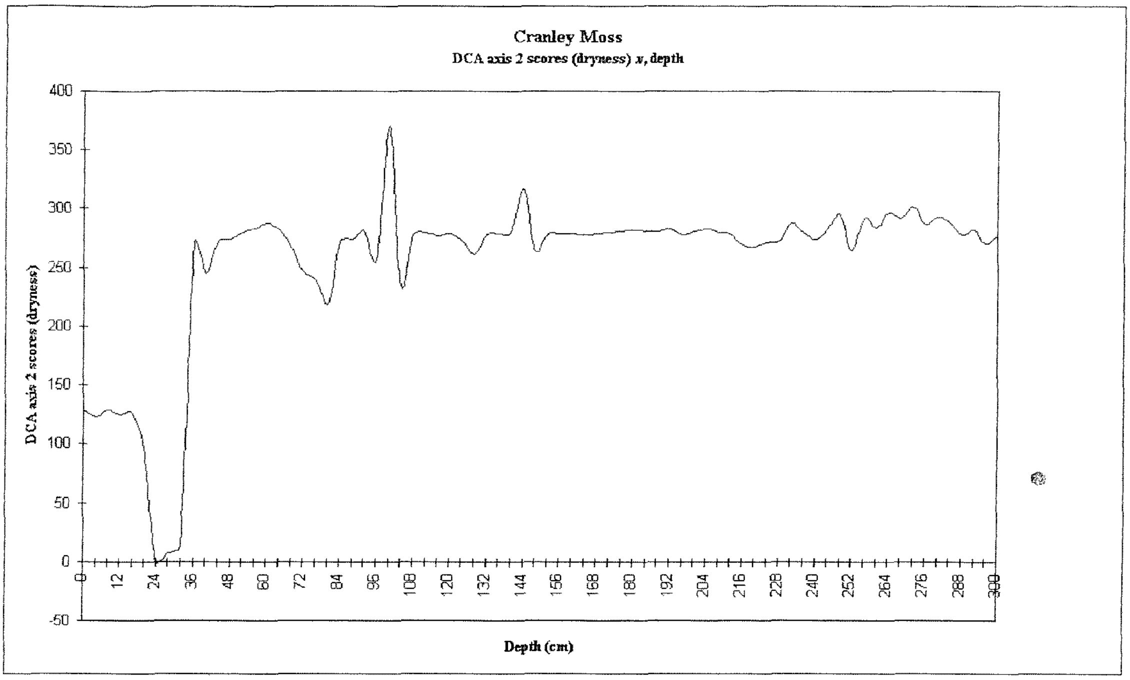

Figure 4.2.11 Surface dryness - depth model for Cranley Moss. Derived from axis 2 of a Detrended Correspondence Analysis of the plant macrofossils.

The vegetation appears to form relatively smooth lawns after the initial phase of dominance by *S. capillifolium* and until recent times this undulating surface was punctuated only by the sporadic occurrence of *E. vaginatum* tussocks, indicated by peaks in the DCA Axis 1 .v. depth plot (Figure 4.2.10). In the last 12 cm of stratigraphy, *C. vulgaris* and *E. vaginatum* are seen to have become prevalent and it is assumed that a hummocky surface has come to predominate although its low diversity results in the absence of its signal from Figure 4.2.10. This increase in topography is probably due to disturbance of the site but in the absence of a good historical account and/or dates this cannot be confirmed.

The DCA Axis 2 plot (Figure 4.2.11; eigenvalue 0.420) reflects the degree of dryness at the vegetation surface since the most xeroindicative species, clustered to the right hand side of the scatterplot, have the largest values. Relegation of the hydrological axis to this position does not entail rejection of the hypothesis that hydrology is the single most important determinant upon the vegetation, since this factor is obviously still an important environmental component explaining a relatively large degree of variation in the vegetation. However, it is suggestive of the importance of topography upon the biodiversity of a raised bog and also, that the presence of hummocks and hollows overrides, to some extent, control exerted upon the vegetation by the water table.

4.2.6 Deer Dyke Moss

In the scatterplot constructed for Deer Dyke Moss (Figure 4.2.12) an apparently hydrological gradient that accounts for a moderate amount of variation is reiterated in the DCA axis 1 .v. depth plot to obtain a surface dryness - depth model (Figure 4.2.13; eigenvalue 0.734). The hydrological gradient is determined from the presence of a chain of samples stretching between the usually xeroindicative UOM to a cluster around the more hydrophilous *S. imbricatum*. The majority of the remaining taxa cluster around the mid-point of this axis to which they show no marked correlation because, by reference to the macrofossil diagram (Figure 4.1.6), they occur sporadically throughout the stratigraphy in association with either of the two marked groups. The penultimate position of *S. magellanicum* and *S. papillosum* at the dry end of the scale is a consequence of their statistical rarity in a UOM dominated phase between 26 cm and the current surface.

Comparison of the DCA axis 1 .v. depth plot with the abundance curve for Unidentified Organic Matter (Figure 4.1.6) shows that they are mirror images of one another. The negative value and outlying position of Unidentified Organic Matter indicates that it is largely responsible for the low DCA axis 1 scores in the plot with depth. Accordingly, it is proposed that this axis is indicative of preservation within the stratigraphy. This may be a feature of the vegetation in samples below 30 cm but above this point secondary mineralisation will certainly have resulted from the recent, extensive drainage, fire and afforestation suffered by this site. Unfortunately, due to the use of a more moderate water flow to wash the samples from Deer Dyke Moss, large amounts of Unidentified Organic Matter were retained within the sample and it is uncertain how this has amplified the DCA results.

DCA axis 2 (Figure 4.2.14) is more directly indicative of a hydrological gradient within the vegetation, as opposed to the state of decomposition, but with a much lower eigenvalue of 0.146. This second axis is derived from the pool species clustered at the top of the scatterplot as distinguished from those present during the hummock building *S.* sect *Acutifolia* phase with negative scores on this axis.

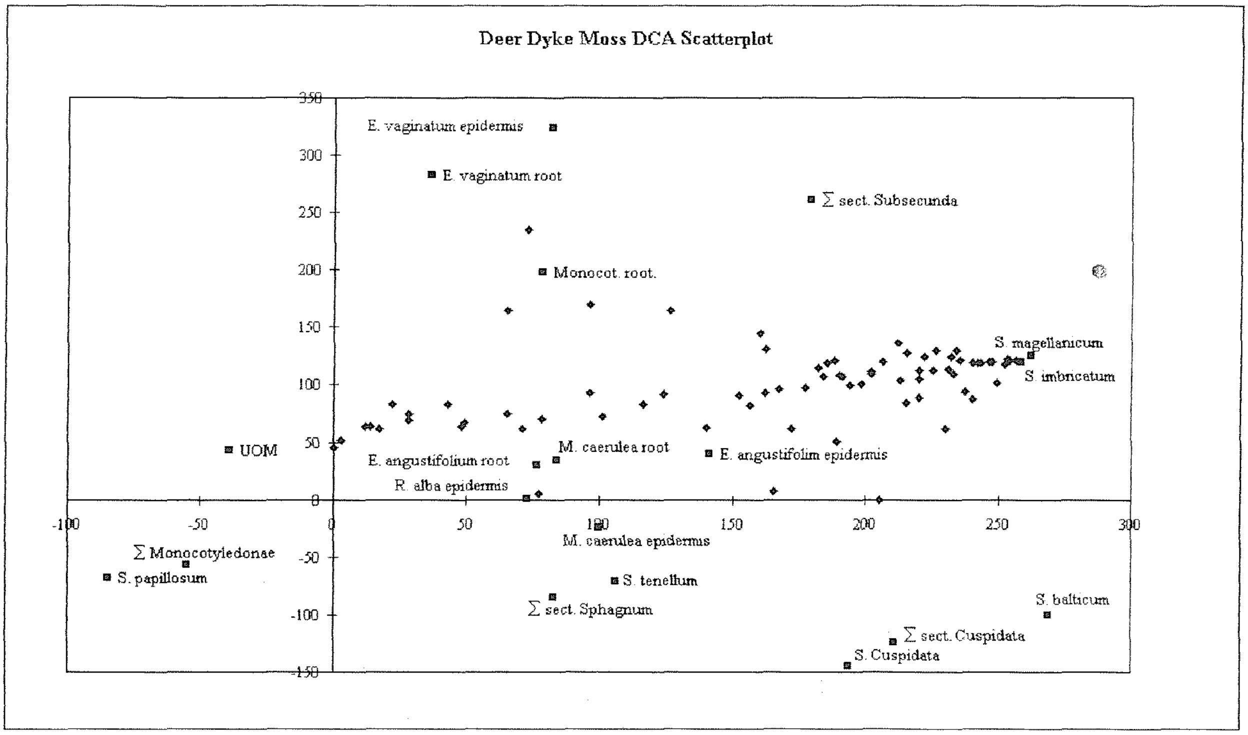

Figure 4.2.12 DCA scatterplot for the Deer Dyke Moss macrofossils.

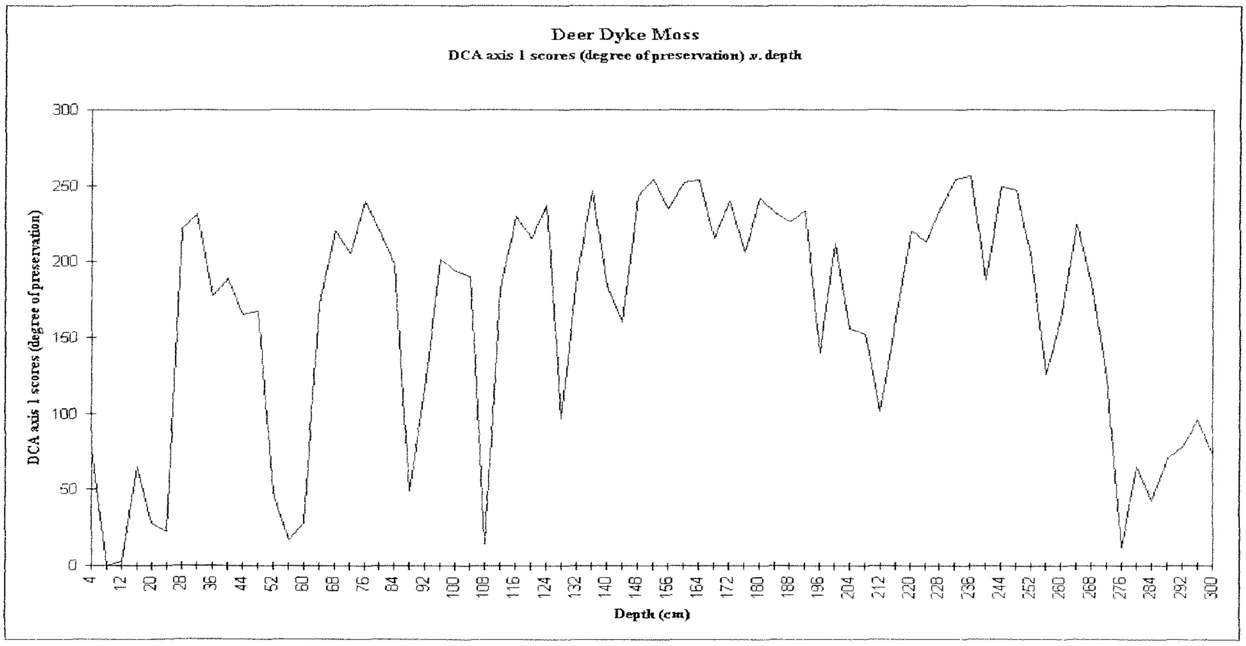

Figure 4.2.13 Degree of preservation - depth model for Deer Dyke Moss. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

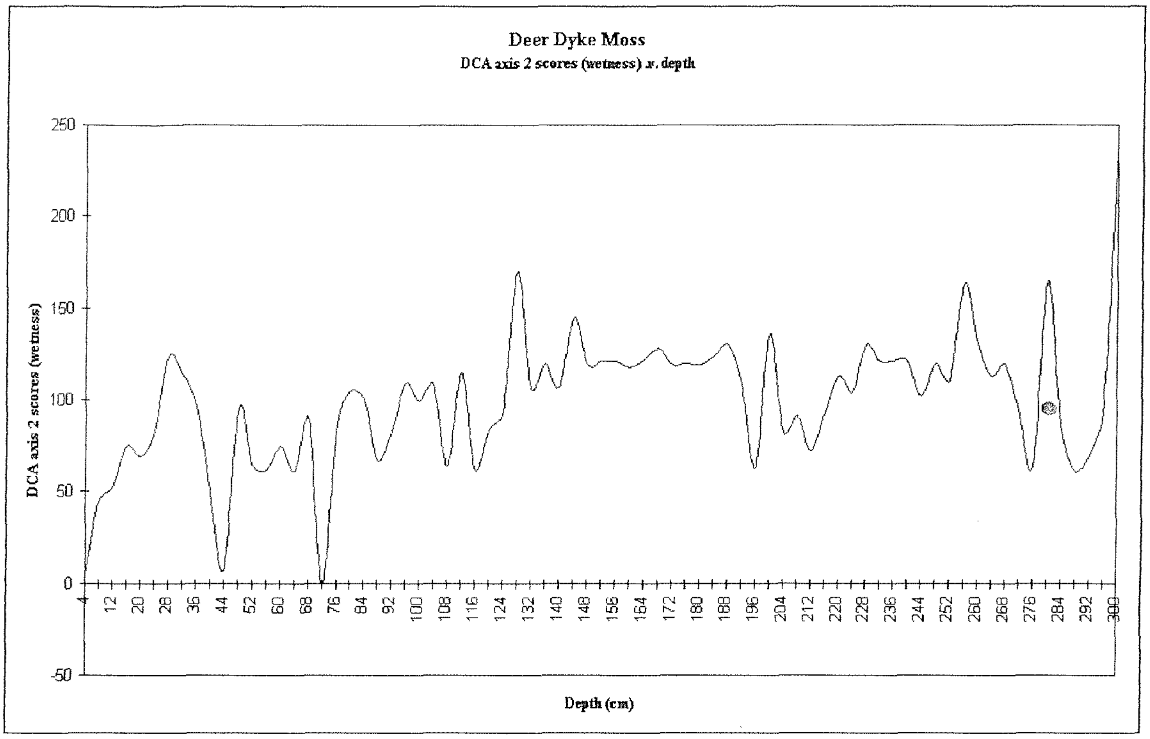

Figure 4.2.14 Surface wetness - depth model for Deer Dyke Moss. Derived from axis 2 of a Detrended Correspondence Analysis of the plant macrofossils.

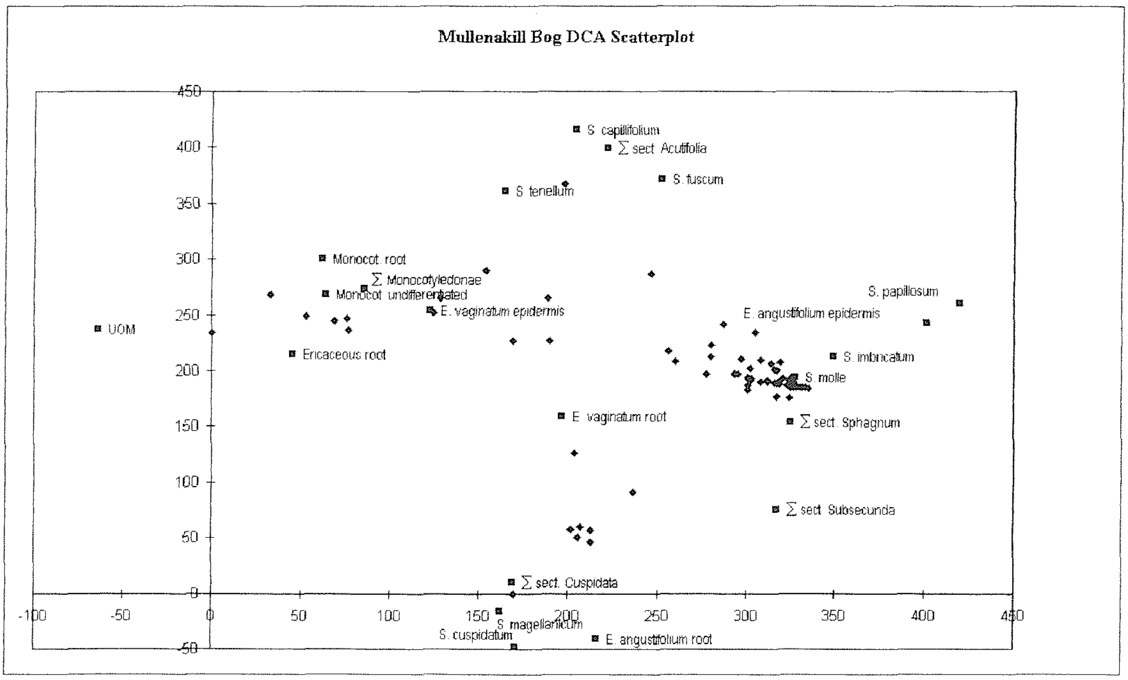

Figure 4.2.15 DCA scatterplot for the Mullenakill Bog macrofossils.

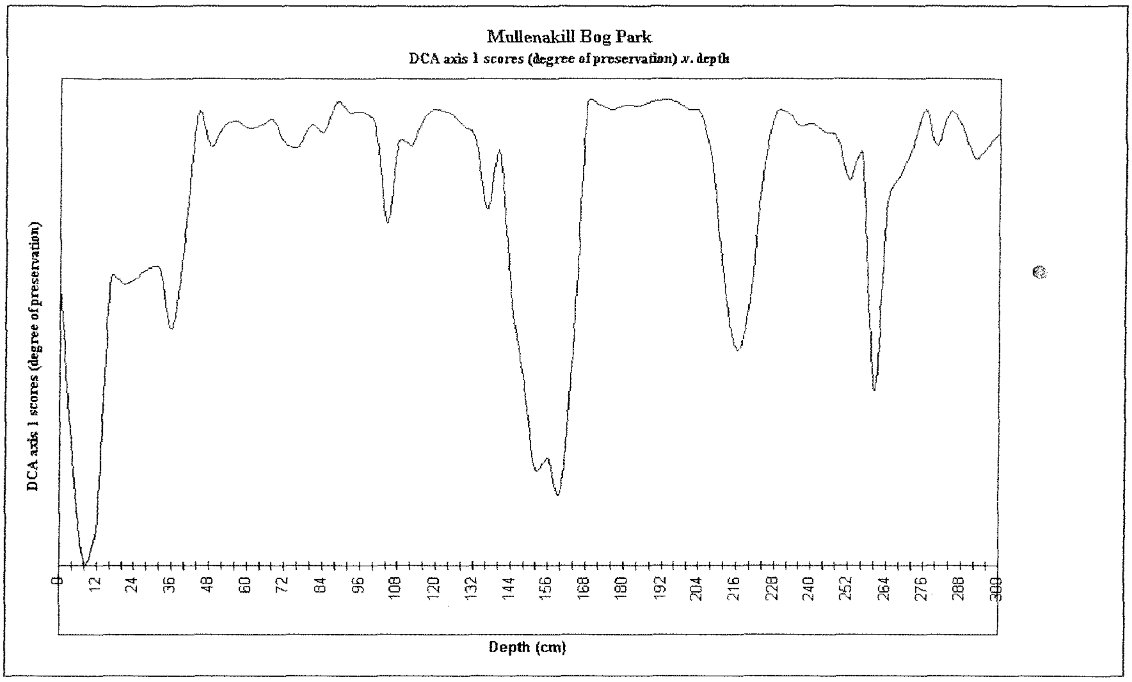

Figure 4.2.16 Degree of preservation - depth model for Mullenakill Bog. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

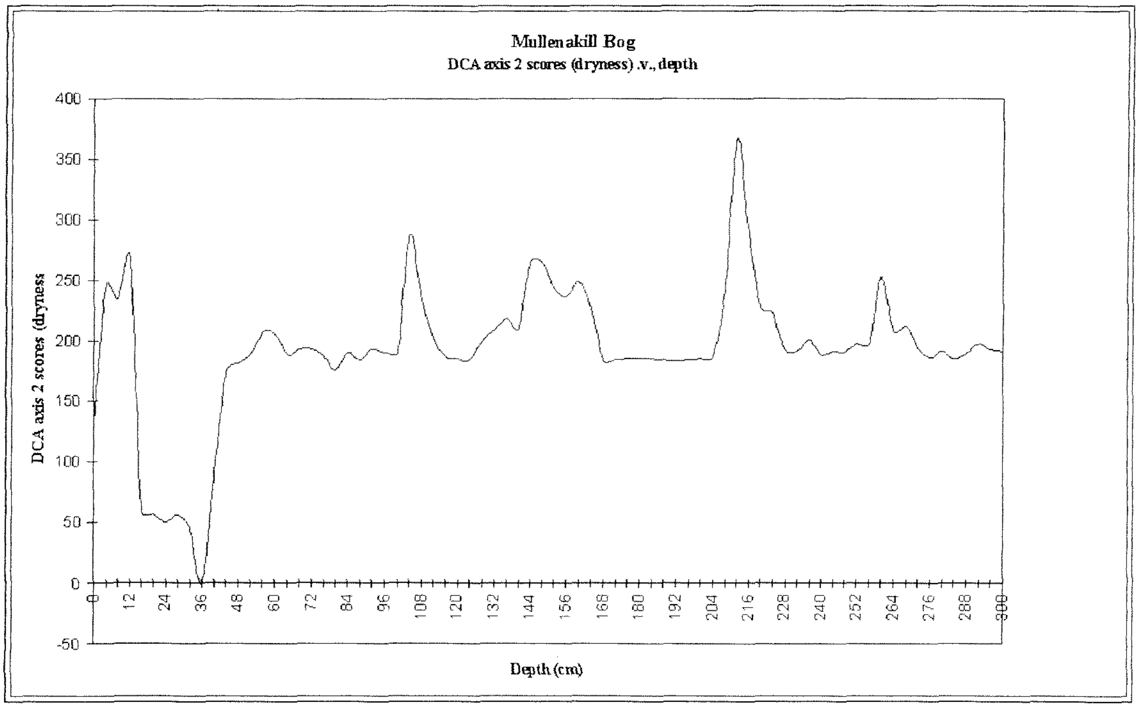

Figure 4.2.17 Surface dryness - depth model for Mullenakill Bog. Derived from axis 2 of a Detrended Correspondence Analysis of the plant macrofossils.

4.2.7 Mullenakill Bog

On the scatterplot for Mullenakill Bog (Figure 4.2.15), the hydrological gradient is again relegated to DCA Axis 2 (Figure 4.2.17; eigenvalue 0.346). *S. tenellum* and *S. magellanicum* appear out of place on this gradient due to their statistical rarity and respectively sporadic associations with *S. capillifolium* and *S. cuspidatum* in what must have been topographically diverse situations, such as at the margins of neighbouring microforms.

DCA Axis 1 is perpendicularly split with a cluster of samples presented to the right hand side, dominated by *Sphagnum* sect. *Sphagnum*. The relatively high scores generated by this cluster dominate the DCA Axis 1 scores which consequently, largely reflect the abundance of this taxon. On the left hand side of this scatterplot are xeric peat components which are present to the variable exclusion of *Sphagnum* sect. *Sphagnum*, namely; undetermined monocotyledonous components, *E. vaginatum* epidermis and Unidentified Organic Matter. This second axis therefore appears to be related to hydrology in the replacement of *Sphagnum* by the recurrent phases of peat mineralisation seen in the macrofossil diagram. As was the case at Deer Dyke Moss, with its methodically elevated levels of Unidentified Organic Matter, we see here the degree of preservation indicated on DCA axis 1 and modelled in the plot of this axis with depth (Figure 4.2.16). In the stratigraphy of Mullenakill Bog, Unidentified Organic Matter is present in two distinct phases; 2 cm to 14 cm and 150 cm to 166 cm. The derivation of the former of these at least is through the secondary mineralisation of peat layers underlying the contemporary surface during a period of water table draw down. In this instance, secondary mineralisation arose as a consequence of drainage.

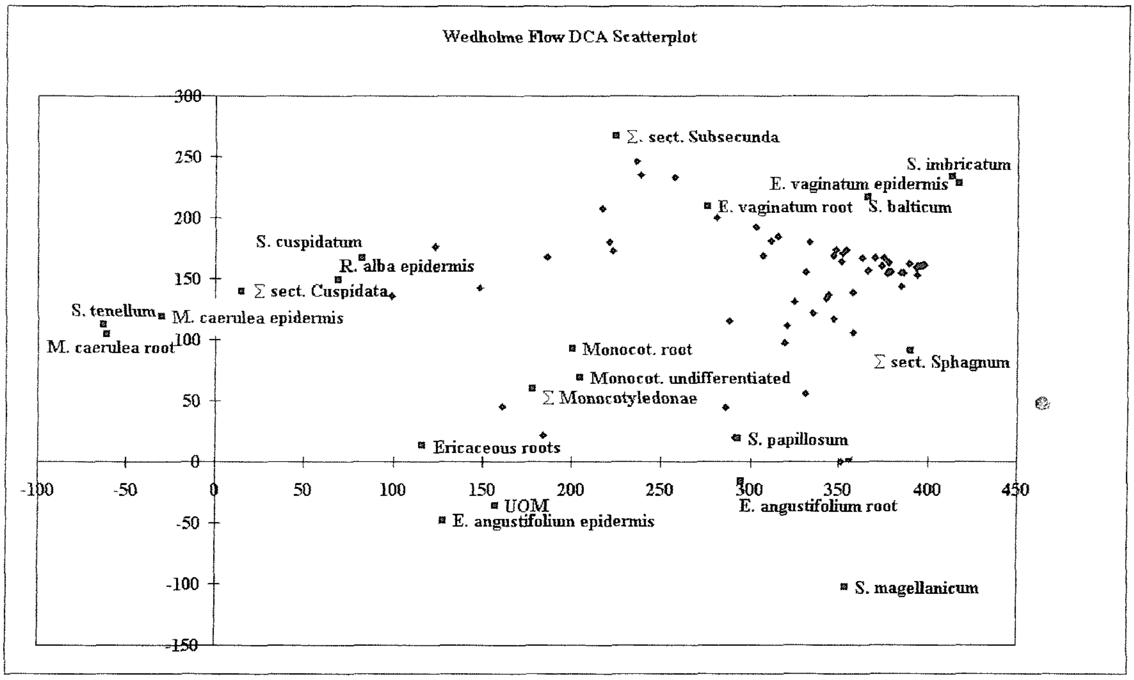

Figure 4.2.18 DCA scatterplot for the Wedholme Flow macrofossils.

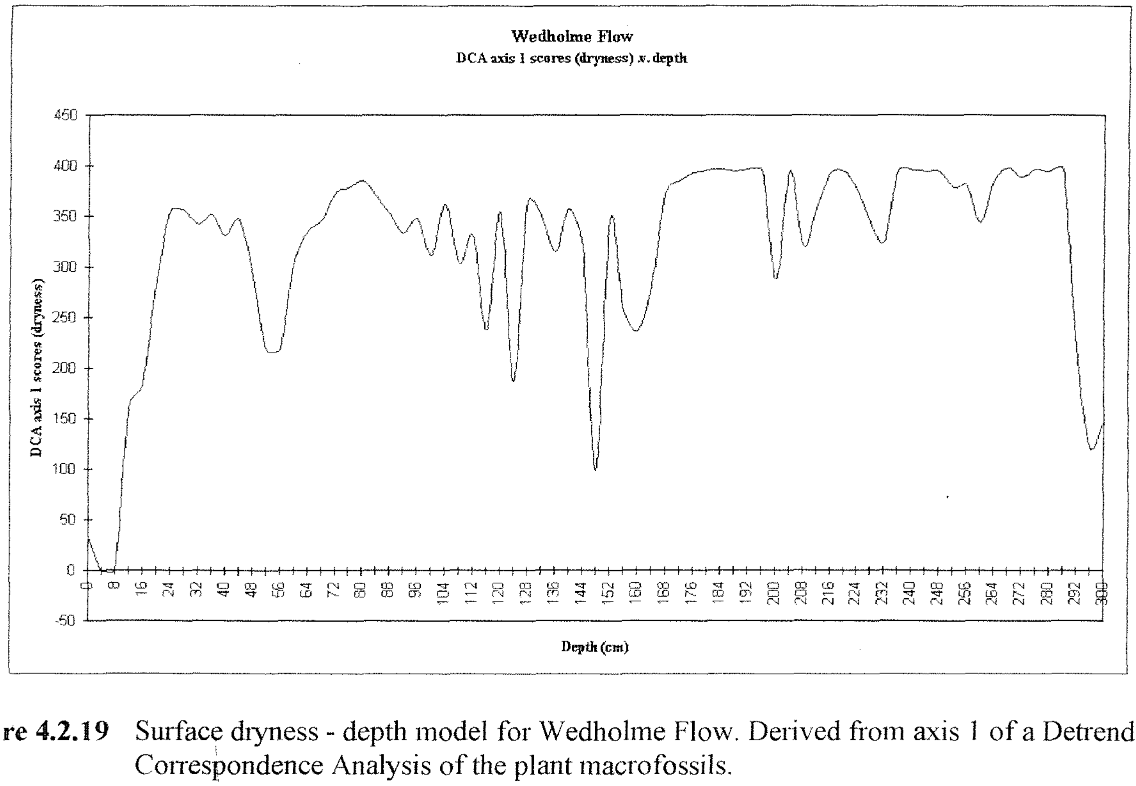

Figure 4.2.19 Surface dryness - depth model for Wedholme Flow. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

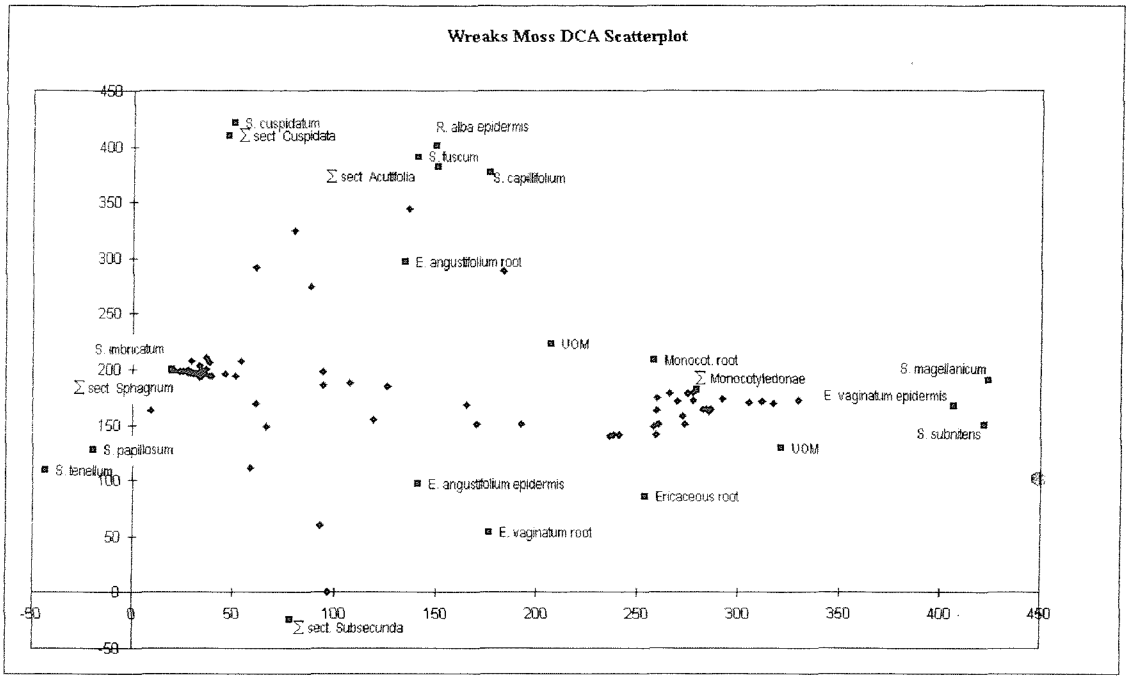

Figure 4.2.20 DCA scatterplot for the Wreaks Moss macrofossils.

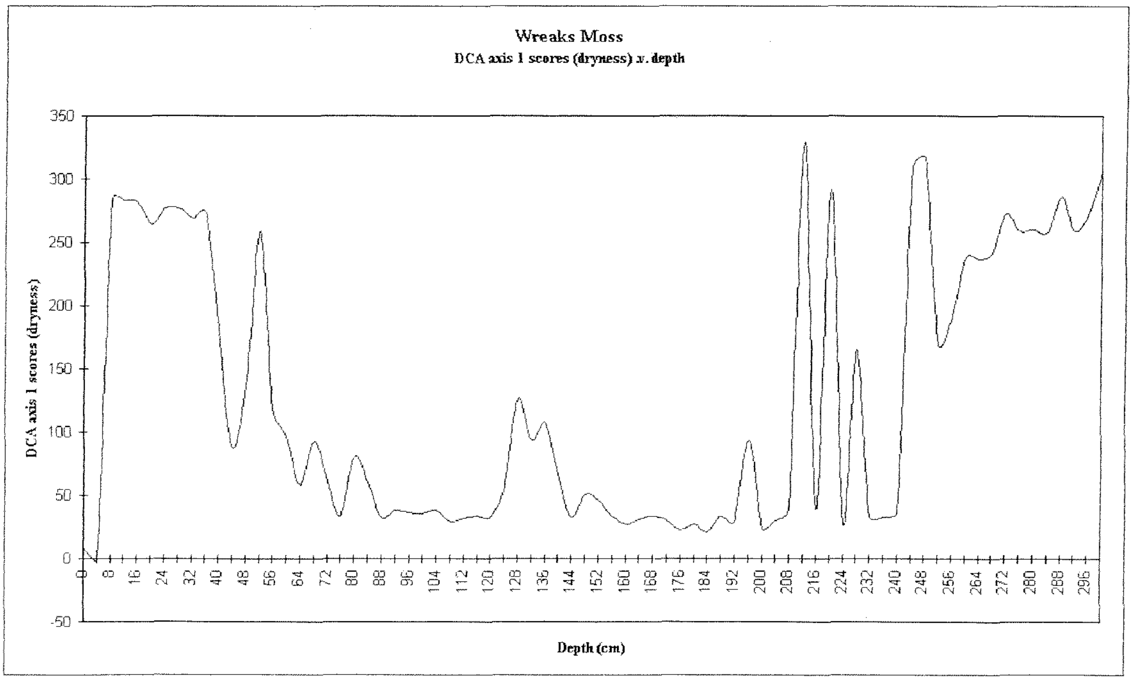

Figure 4.2.21 Surface dryness - depth model for Wreaks Moss. Derived from axis 1 of a Detrended Correspondence Analysis of the plant macrofossils.

4.2.8 Wedholme Flow

A hydrological gradient is indicated by the first axis of the DCA scatterplot for Wedholme Flow (Figure 4.2.18). The wettest species, including the statistically rare, modern recolonists *S. tenellum* and *Molinia caerulea* are presented with low scores to the left hand side of the diagram so that the corresponding DCA axis 1 .v. depth plot (Figure 4.2.19) models the relative dryness at the mire surface. ∑ sect. *Subsecunda* is probably intermediate in relation to the gradient since it occurs in association with *S. imbricatum* and not to its exclusion as is the case for *S. cuspidatum*. By comparison, the similarly placed, monocotyledonous components are probably insensitive to the axis since they are consistently present throughout the stratigraphy. DCA axis 2 (eigenvalue 0.360) does not have an obvious ecological relationship and is discussed no further.

4.2.9 Wreaks Moss

An obvious hydrological gradient is indicated by the arrangement of species and samples along DCA axis 1 in the scatterplot (Figure 4.2.20; eigenvalue 0.696). Two distinct clusters are apparent. To the left hand side are those samples and species present within the Sphagnetum, whereas to the right are those of the relatively dry Callunetum. Thus the DCA axis 1 .v. depth plot (Figure 4.2.21) models site dryness. The dry scores are derived primarily from the abundance of Monocotyledonous components and Unidentified Organic Matter and to a lesser extent, the rare associations of *S. magellanicum* and *S. subnitens* with these former taxa. The second DCA axis does not appear to have any ecological meaning and is discussed no further.

4.3 THE PALAEOECOLOGICAL PLANT COMMUNITIES

4.3.1 Introduction and key to the palaeoecological plant communities

In this study it is assumed that the plant communities of raised bogs appear stratigraphically in distinct phases which persist until its hydrological threshold (or tolerance is surpassed). This model draws upon the work of Barber (1981) who proposed the Phasic Theory of bog growth in replacement of the falsified, cyclic regeneration theory that initially held favour for much of this century. The concept of a hydrological, threshold value for a particular raised bog community was initially proposed by Von Post whose work in Dutch has been translated and reiterated by Conway (1948). The stratigraphic profiles obtained for this study which reveal these simultaneous, hydrological and vegetational changes support the ideas of these workers.

From the macrofossil diagrams (Figures 4.1.1 to 4.1.9), it is apparent that particular assemblages persist for a phase of many centuries although the proportions of any individual taxon may be very variable. These smaller scale variations are considered to represent the ecological noise created by patch dynamics and more widespread, sub-threshold changes in hydrology that may alter the composition but not the assemblage of species. This temporal persistence of a particular community allows for replicate samples to be taken within its stratigraphic limits in much the same way as a contemporary ecologist would take a number of replicate quadrats from within the geographical boundaries of an extant vegetation community. This replication allows the specific composition of a community to be subjectively determined from the residual ecological noise which accompanies it. The normal limits of an individual species' abundance within a community are therefore indicated below with the absolute limits as they appear in stratigraphy indicated in brackets. Species which are constant throughout the phase of a given community are indicated in bold type and those which are faithful to and/or indicative of it are indicated in the key, title and description.

When the hydrological threshold of a particular community is surpassed the transition to another is an apparently rapid event which may at times, proceed via a phase where *E. vaginatum* attains a short period of abundance possibly in response to a fluctuating water table that reduces the competitive ability of other species. During these transitions, concurrent changes in the hydrology, as indicated by the testate amoebae, are usually present. In some isolated instances the changes in testate amoebae assemblage are due to modifications in their physical environment, according to the habit of the plant species present. Marked instances of this are only seen in the association of *Centropyxis* spp. with *E. vaginatum* tussocks which results in the appearance of dry peaks within the testate amoebae derived water table models (section 4.4.1). This suggests that the water table data from heathy phases may not be so reliable as a consequence of this error which arises as a serious problem only in this habitat for which the model was not tested. Otherwise the figures obtained for this study remain relatively consistent within communities and across bogs which attests to their efficacy in *Sphagnum* based vegetation.

The hydrological limits of a community are crudely indicated by the maximum and minimum figures indicated in the tables below. The mean and median figures are also given together with the standard deviation in order to indicate the more usual water table range for a particular community, since the hydrological limits are subject to the ecological noise noted above. Where the communities are indicated to be topographically diverse the water table range is considered to be somewhat indeterminable because of the subtle changes in topography and corresponding shifts in the testate amoebae assemblages that are sampled throughout a given phase. In this instance the depth to water table indicated is perhaps best viewed as an average across all of the microtopes present.

The water table data for each community was extracted from the full dataset, summed and the mean, median, standard deviation, maximum and minimum values where determined. In addition, the number of testate amoebae samples for each plant community is also given. Further statistics given in the tabulated description of each community include the position of individual occurrences of each community within the stratigraphies.

The data presented below expresses the abundance limits of the individual taxa on a scale of 1 to 5 (see section 2.2.2), according to their presence within the palaeoquadrats. This measure is considered to be most equable to the cover of a plant on its contemporary surface although the differential preservation of individual components should be borne in mind and this is the reason why certain, currently common raised bog plants are not indicated. Frequency might also have been used as a measure, recording the percentage presence of individual taxa within the palaeoquadrats of a given phase of samples. The use of both is adopted within the National Vegetation Classification of mires and heaths but within this study, bearing in mind the provisos outlined above, it was considered that the additional use of frequency data would offer only a spurious veneer of rigour and add unnecessary complication. Additionally, the relationship between a palaeoquadrat of dimensions 1 cm x 4 cm x 10 annum^{-1} and a contemporary quadrat of 1 m^{-2}gives rise to some philosophical question but the former's use as a palaeoecological technique has been substantiated by the meaningful and consistent data so obtained in many studies (Barber *et al.*, 1997).

Key to the Palaeoecological Plant Communities

1.	*Sphagnum* patchily present (<< 20 %) or absent from the vegetation	**2**
	Sphagnum consistently present within the vegetation (>20%)	**3**
2.	Well developed bryophyte layer present, dominated by hypnaceous species	**4.3.11**
	Poorly developed or absent bryophyte layer	**4.3.12**
3.	*S. tenellum* a conspicuous component of the bryophyte layer (> 10 %) often in association with *S. magellanicum* and *S. papillosum*; bare peat may be common	**4.3.3**
	S. tenellum an inconspicuous component of the vegetation (10 %)	4

4. Semi-/aquatic *Sphagnum* of sections *Cuspidata* and *Subsecunda* abundant within the vegetation (> 25 %); *C. vulgaris* restricted to isolated hummocks within a pool and hollow dominated topography that may comprise of extensive lawns **5**

Lawn and hummock *Sphagnum* species of sections *Acutifolia* and/or *Sphagnum* abundant within the vegetation; *C. vulgaris* present on lawn and possibly hollow microforms with pools either absent or limited in extent (< 15 %) **9**

5. Hummocks of *S.* sect. *Sphagnum* (> 15 %) present upon a lawn or raft of semi-/aquatic *Sphagnum* **6**

Semi-/aquatic *Sphagnum* almost exclusively dominant with little or no cover attributable to *S.* sect. *Sphagnum* or *S.* sect *Acutifolia* species (≤ 10 %) **8**

6. Secondary vegetation arising after peat harvesting under the variable influence of a eutrophic groundwater table; minerotrophic vegetation dominated by *S. palustre* and *S. recurvum* **4.3.13**

Not as above but may be present on cut-over peat surfaces although in such instances the groundwater table is low enough for ombrogenous species to dominate 7

7. *S. auriculatum* and *S. cuspidatum* in association with low hummocks of *S.* sect. *Sphagnum* **4.3.4**

As above but in response to a release of nutrients through oxidation of the peat, *S. cuspidatum* consequently absent; *P. commune* common **4.3.5**

S. cuspidatum almsot exclusively dominant in a pool or wet lawn microform **4.3.6**

8. *S. recurvum* varieties dominant, forming a lawn within pools and drains or over extensive areas of cut-over peat where some eutrophic influence is present **4.3.2**

S. cuspidatum dominant in similar habitats to the above but in the absence of a dominating eutrophic water supply; *S. recurvum* may be present at low values (< 10 %) and *S.* sect. *Sphagnum* species become increasingly prevalent as the raft stabilises **4.3.3**

9. *S. sect Acutifolia* species dominant or co-dominant with those of *S.* sect. *Sphagnum*; pool microform largely absent; hummocks and lawns prevalent and semi-/aquatic species very limited in extent **10**

S. sect. *Sphagnum* species dominant as a homogenous lawn or accompanied by species of *S.* sect *Acutifolia* and *S.* sect *Cuspidata* as the topographic diversity increases and comes to include equable cover values for the pool and hummock microtopes **11**

10. *S.* sect. *Sphagnum* species co-dominant with those of *S.* sect *Acutifolia* **4.3.9**

S. sect *Acutifolia* species dominant **4.3.10**

11. *Sphagnum* layer homogenous and of low topographic and biological diversity; *S.* sect. *Sphagnum* dominant **4.3.7**

Sphagnum layer heterogenous and of high topographic and biological diversity; *S.* sect. *Sphagnum* species may predominate but *S.* sect *Acutifolia* and *S.* sect *Cuspidata* are now prevalent within the hummock and pool microforms which form an extensive cover component **4.3.8**

4.3.2 *Sphagnum recurvum* Lawn

This community has only one constant and diagnostic species, the titular *S. recurvum*, which occurs consistently throughout these sections of stratigraphy as the dominant component of a lawn microform. A number of other, less common, species are probably constant here too but the relatively local origin of sub-fossil material within the respective cores creates the appearance that these species are sporadic in their occurrence; but this relates to and is indicative of their surficial distribution. These potentially constant species include; *A. palustre*, *C. vulgaris*, *E. tetralix*, *Eriophorum* spp., *P. commune* and *V. oxycoccus*. The shrub *M. gale* is included within this community but it is probably not a common component of this type of regenerating vegetation unless already on the site within refugia.

Taxa	**Abundance (5-point scale)**
Sphagnum	
S. auriculatum	0 - 2
S. cuspidatum	0 - 1
S. palustre	0 - 1
S. papillosum	0 - 2
S. recurvum	**4 - 5**
Other Bryophytes	
Odontoschisma sphagnicola	0 - 1
Aulacomnium palustre	0 - 2
Calliergon stramineum	0 - 4
Drepanocladus fluitans	0 - 2
Hypnum cupressiforme	0 - 2
Polytrichum commune	0 - 2
Monocotyledonae	
Eriophorum angustifolium	0 - 3
E. vaginatum	(0-) 1 -4
Dicotyledonae	
Calluna vulgaris	0 - 2
Erica tetralix	0 - 3
Myrica gale	0 - 2
Vaccinium oxycoccus	0 - 1

Predicted Water Table Data	
Mean	-2.16
Median	-1.90
Standard Deviation	1.80
Minimum	-6.26
Maximum	0.15
n	12

Occurrences	
Arnaby Moss Regeneration Peat	0 cm - 72 cm
Arnaby Moss	0 cm - 10 cm
	$n = 2$

Table 4.3.1 Summary data for the *Sphagnum recurvum* Lawn community.

A number of other Sphagna may occur within the *S. recurvum* lawn but none of them ever attain the abundance of this species. *S. cuspidatum* was an apparently constant component of the vegetation at Arnaby Moss Regeneration Peat but once the water table fell below *c.* 2 cm, this species became extinct and could not be located during contemporary field work. Another hydrophile, *S. auriculatum*, was sporadically present at Arnaby Moss and this species may enter the vegetation as a consequence of hydrological instability, such as at pool margins where recurrent flooding and drying may occur although the phenotypic plasticity of *S. recurvum* would also accommodate this.

Initial development of the *S. recurvum* lawn within a matrix of *S. palustre* hummocks at Arnaby Moss Regeneration Peat has led to inclusion of this latter species within the community. However, hummocks of *S. palustre* may again become a component of this community as the mire surface comes to exceed that of the ground water table, resulting in a shift towards ombrogeny (Hughes, 1997).

Of the non-*Sphagnum* bryophytes, *A. palustre* and *P. commune* are regarded as faithful to this community by Rodwell (1991) and on the Arnaby Mosses, they are currently common components of the vegetation. Of the remaining species only *C. stramineum* and *D. fluitans* may be regarded as typical components of this community since both *H. cupressiforme* and *O. sphagnicola* are species derived from upstanding areas of cut-over peat, the latter particularly where *Sphagnum* section *Sphagnum* species are present.

The water table of this community is indicated by the testate amoebae data to lie close to the surface, typically above -2 cm for Arnaby Moss Regeneration Peat. For Arnaby Moss, this figure is somewhat lower but may be affected by the inclusion of dry, testate amoebae from the neighbouring, stagnant hummocks. The most crucial hydrological feature of this community though is the mineral status which, as indicated by the abundance of *S. recurvum*, is relatively high.

Mobilisation of nutrients is a common phenomenon following hydrological restoration on drained, raised bogs (Braekke, 1981) as well as those which have been cut-over (Wind-Mulder, 1996) and both of these scenarios are respectively represented here by Arnaby Moss and Arnaby Moss Regeneration Peat. Under more oligotrophic conditions it is expected that this community will be replaced by the *S. cuspidatum* lawn or pool community described below.

This community is directly comparable to the *Sphagnum cuspidatum/recurvum* bog pool community, or M2 of the National Vegetation Classification (NVC) and more specifically, to the *S. recurvum* sub-community of this classification (Rodwell, 1991). Spatially it may be present as isolated pools, as at Arnaby Moss or, as the wider expanse of secondary mire seen at Arnaby Moss Regeneration Peat.

4.3.3 *Sphagnum tenellum - S. magellanicum* Lawn

This community is usually indicated by the presence of *S. magellanicum* and *S. tenellum* in variable proportions but the former species is replaced by *S. papillosum* at Wreaks Moss where carpets of *S. magellanicum* are currently limited in extent. In the longest section of this community at Ballynahone Bog, *S. papillosum* comes in latterly, instigating the development of a hummock within a lawn of *S. magellanicum* and dominance of these taxa as the abundance of *S. tenellum* declines. Other Sphagna are apparently scarce, possibly limited by their dispersal ability and only *S. subnitens* is recorded as an additional species, from Ballynahone Bog. Occasionally, extensive carpets of *O. sphagnicola* may be found within the lawn of these species but the other bryophytes included here, *C. introflexus* and *H. cupressiforme* are present here on areas of bare peat derived from a preceding, degenerative phase. Both of these species may be expected to persist on raised areas of bare peat prior to their encroachment by *Sphagnum* species.

Among the vascular components of this community, the ubiquitous *C. vulgaris* and *E. tetralix* are most consistent and abundant. *Eriophorum* spp. are not well represented and appear largely absent while *M. caerulea* is found as a component of the vegetation only at Wedholme Flow.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-5.52
S. magellanicum	**(1-) 3 - 4 (-5)**	Median	-5.06
S. subnitens	0 - 1	Standard Deviation	1.81
S. papillosum	0 - 5	Minimum	-8.61
S. tenellum	**(1-) 3 - 4 (-5)**	Maximum	-3.81
		n	5
Other Bryophytes			
Odontoschisma sphagnicola	0 - 3		
Campylopus introflexus	0 - 1	**Occurrences**	
Hypnum cupressiforme	0 - 1		
		Ballynahone Bog	0 cm - 14 cm
Monocotyledonae		Coalburn Moss	18 cm - 30 cm
Eriophorum angustifolium	0 - 1	Deer Dyke Moss	0 cm - 6 cm
E. vaginatum	0 - 2	Mullenakill Bog	0 cm - 2 cm
Molinia caerulea	0 - 2	Wedholme Flow	2 cm - 10 cm
		Wreaks Moss	2 cm - 6 cm
Dicotyledonae			
Calluna vulgaris	(0-) 3 (-5)		$n = 6$
Erica tetralix	(0-) 1 - 2 (-5)		

Table 4.3.2 Summary data for the *S. tenellum* - *S. magellanicum* Lawn community.

This community is, in almost all cases, developed upon the compacted peat resulting from raised bog drainage, except at Coalburn Moss where it is responsible for the infilling of a *S. cuspidatum* dominated wet lawn or pool. Accordingly, the hydrology of this community is always transitional, in one direction or the other and within the parameters outlined above.

In terms of the NVC, no direct analogues exist for this community but floristically it would appear to be the most hydrophilous component of Rodwell's (1991) *S. magellanicum* - *A. polifolia* sub-community (M18a). Spatially, it may occur widely over the surface of restored raised bogs or more locally, such as where it is responsible for the infilling of pools.

4.3.4 *Sphagnum cuspidatum/auriculatum* - *Sphagnum* sect. *Sphagnum* Wet Lawn or Pool

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-2.57
S. auriculatum	**(0-) 1 - 4 (-5)**	Median	-1.91
S. capillifolium	0 - 1	Standard Deviation	2.39
S. cuspidatum	**(0-) 1 - 5**	Minimum	-9.45
S. fuscum	0 - 1	Maximum	1.81
S. imbricatum	(0-) 2 - 5	*n*	52
S. magellanicum	(0-) 1 - 4		
S. molle	0 - 2		
S. papillosum	0 - 2 (-4)	**Occurrences**	
Σ sect. Sphagnum	**(0-) 2 - 5**		
S. tenellum	0 - 2 (-3)	Arnaby Moss	10 cm - 58 cm
		Ballynahone Bog	30 cm - 54 cm
Other Bryophytes			246 cm - 298 cm
Aulacomnium palustre	0 - 2	Cranley Moss	34 cm - 78 cm
			250 cm - 258 cm
Monocotyledonae		Mullenakill Bog	14 cm - 38 cm
Eriophorum angustifolium	**(0-) 1 - 2**	Wedholme Flow	50 cm - 166 cm
E. vaginatum	0 - 2 (-5)		286 cm - 300 cm
Rhynchospora alba	**(0-) 1 - 2**	Wreaks Moss	50 cm - 142 cm
Dicotyledonae			*n* = 9
Calluna vulgaris	0 - 1 (-3)		
Erica tetralix	**(0-) 1 - 2 (-5)**		
V. oxycoccus	0 - 2		

Table 4.3.3 Summary data for the *Sphagnum cuspidatum/auriculatum* - *Sphagnum* sect. *Sphagnum* Wet Lawn or Pool community.

This community is indicated by the presence of aquatic *Sphagnum* species in association with those of *S.* section *Sphagnum*. Currently, within this latter section, *S. magellanicum* is the most common taxon but it may occasionally be present with lesser amounts of the hummock former *S. papillosum* supporting the sporadic occurrences of *C. vulgaris* within this community, as at Ballynahone Bog (30 cm - 58 cm). The general absence of xerophytic *C. vulgaris* suggests that *S. imbricatum* adopted its lax growth form here (*cf.* Flatberg, 1986) which, in the current vegetation of raised bogs appears to be equivalent to the role now played by *S. magellanicum* (Stoneman, Barber & Maddy, 1993). Once the commonest member of *S.* section *Sphagnum* within this community, *S. imbricatum* is currently an unlikely component on account of its restricted occurrence (Daniels and Eddy, 1990) and possibly reduced gene pool (Barber, 1981; Wyatt, 1992).

The aquatic Sphagna represented here are *S. auriculatum* and *S. cuspidatum* with an occasional admixture of the less strictly hydrophilous *S. tenellum*. In the north and west of mainland Britain *S. auriculatum* is the commonest, aquatic *Sphagnum* amongst the sites studied. In the north of Ireland *S. auriculatum* is largely replaced by *S. cuspidatum* but to the complete exclusion of the former at Mullenakill Bog. In this instance it appears that this phase represents the succession from a *S. cuspidatum* dominated pool or lawn from which *S. auriculatum* was initially and subsequently excluded. A single record for the moss *A. palustre* exists from Cranley Moss where it appears within this community following a severe episode of burning.

Sub-shrubs appear to be largely excluded from this community, presumably on account of the waterlogging that supports its aquatic *Sphagnum* species. *C. vulgaris*, as already noted, is restricted to where hummocks of *S. papillosum* have developed but the locally preserved *E. tetralix* is probably a more consistent member of this community than its apparent occurrence within the stratigraphic sections would initially suggest. Its mode of appearance in the stratigraphic sections indicate that it is probably only recorded if growing adjacent to the bore hole. When one considers the size and number of leaves and flowers (and hence seeds) in *E. tetralix* it seems prudent to assume that these parts are not so widely or densely dispersed over the mire surface, as they are in *C. vulgaris*. Accordingly, despite its apparent absence from sections of stratigraphy it is suggested to be a constant plant within this community.

Of the monocotyledonous species tabulated above, only *E. vaginatum* occurs within each occurrence of the community. That both *E. angustifolium* and *R. alba* should be wholly absent from Cranley Moss and the latter from Mullenakill Bog is improbable so it is suggested that it is a consequence of their distribution relative to that of the bore hole. Accordingly, both are assigned as a constant and diagnostic species of this community and this approach is supported by the work of Rodwell (1991) on the occurrence of Rhynchosporion communities.

Topographically, this community is regarded as a relatively smooth lawn becoming more undulate with the appearance of *Sphagnum* sect. *Sphagnum* taxa, to the extreme where hummocks of *S. papillosum* may develop. In terms of its hydrology the prevalence of *S. auriculatum* within the community would suggest that the depth to water table is variable and this is supported by the species of testate amoebae present. Hydrophilous taxa, as one would expect, are common, but there are also to be found here the strongly xeric species; *Bullinaria indica*, *Difflugia pulex* and *Trigonopyxis arcula* as well as frequent and abundant representation of the desiccation tolerant *Centropyxis* spp. (Woodland, 1996). It is worthy of note too, in support of this, that *S. cuspidatum* is prevalent within the vegetation only when the water table is indicated to be stable and at no more than 2 cm below the mire surface. The unstable water table here is the distinction between this community and the *S. cuspidatum* wet lawn and pool community described below for which a constant water table is indicated. In addition, the *S. cuspidatum* wet lawn and pool community is instigated by an increase in the water table to superficial levels. By comparison, the *Sphagnum cuspidatum/auriculatum - Sphagnum* sect. *Sphagnum* lawn or pool is often preceded by a sharp dip in the water table before its recovery to surficial levels which suggests a minerotrophic response.

The description given by Rodwell (1991) for his *S. auriculatum* bog pool community, M1 adequately describes what is found here. However, I consider this palaeoecological community to primarily represent an extensive wet lawn community as well as that of a pool on account of the high cover frequently attributable to *Sphagnum* sect. *Sphagnum* species. This may be, in part, a reflection of the data gathering method since contemporary phytosociologists have the benefit of selecting a discrete microform whereas in palaeoecological work this is not possible and one cannot be definite of whether there is sampling of one, two or more biotopes; in this instance, the postulated pool and its neighbouring lawn. The data collected here would suggest that the community fluctuates between pool and wet lawn concomitantly with the prevailing, sub-threshold, hydrological conditions, which are in turn influenced by the pattern and amount of rainfall. It would appear from its constancy throughout long sections of stratigraphy, that this community was expansive in the past but currently, by reference to Rodwell (1991), it would appear to be restricted to pools.

4.3.5 *S. auriculatum* - *Sphagnum* sect. *Sphagnum* - *Polytrichum* Lawn

This community bears some resemblance to the *Sphagnum cuspidatum/auriculatum* - sect. *Sphagnum* lawn described above but here, *Polytrichum* spp. are co-dominant with the *Sphagnum* species. The Sphagna appear to be present as isolated patches amongst tussocks of *C. vulgaris* and *E. vaginatum*, the former at least, in association with hypnaceous mosses. Non-*Sphagnum* bryophytes include; *A. palustre*, in lawns of *Sphagnum* and the hypnaceous mosses *H. splendens*, *H. jutlandicum* and *Thuidium tamariscinum* on hummocks. A distinctive component of this vegetation is *M. gale* but this species appears to be sporadic in its contemporary occurrence on raised bogs and is an accordingly poor, faithful species.

Burning of the preceding, *E. vaginatum* dominated community appears to have allowed expansion of the current species, some of which were previously present at low values. Such an event suggests that controlled burning of Monocotyledonous dominated peatlands might permit the re-establishment of *Sphagnum*, particularly if accompanied by water table management. However, the effect of a further fire within this community results in the local extinction, at least, of *C. vulgaris*, *E. vaginatum* and *M. gale*. The presence of fragrant *M. gale* increases the intensity and duration of any fire on account of the high oil content found in this plant and this may be the origin of this apparent sensitivity.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-10.03
S. auriculatum	**(0-) 2 - 4**	Median	-10.63
S. imbricatum	**1 - 2 (-4)**	Standard Deviation	5.20
Σ sect. Sphagnum	**1 - 2 (-4)**	Minimum	-14.65
		Maximum	-4.231
Other Bryophytes		n	4
Aulacomnium palustre	0 - 2		
Hylocomium splendens	0 - 1		
Hypnum jutlandicum	0 - 1	**Occurrences**	
Polytrichum commune	**(0-) 2 - 5**		
P. juniperinum	**(0-) 2 - 5**	Arnaby Moss	198 cm - 226 cm
Thuidium tamariscinum	0 - 1		
			$n = 1$
Monocotyledonae			
Eriophorum vaginatum	0 - 2		
Dicotyledonae			
Calluna vulgaris	1 - 3		
Myrica gale	0 - 2		

Table 4.3.4 Summary data for the *S. auriculatum - Sphagnum* sect. *Sphagnum - Polytrichum* Lawn community.

Two water table depths are recorded during the duration of this community, one at *c.* -5 cm and the other at *c.* -15 cm. The former, shallow depth is indicated when a hummock of *S. papillosum* is dominant within the vicinity of the borehole and there is here a testate amoebae fauna of hydrophiles (*Amphitrema flavum*, *A. wrightianum* and *Hyalosphenia papilio*) and xerophiles (*Difflugia pulex Hyalosphenia subflava* and *Trigonopyxis arcula*). After the second fire event, when *S. auriculatum* comes to dominate, the hydrophilous testate amoebae become extinct and indicate a water table drop to -15cm. which is sustained throughout the following community. This water table depth is considered closer to the true figure than that under the hummock of *S. papillosum* which would have provided a favourable microenvironment for the hydrophilous species whose presence may also be determined by the moisture content of their environment (Wanner & Meisterfield, 1994 and Woodland, 1996). The effects of this deep water table are apparently mitigated by precipitation gathering upon the mire surface because drainage is impeded by ash (Tolonen, 1995) and comminuted peat particles blocking pores in the surficial peat layers. This ponding of water is apparently sufficient in its quantity and temporal distribution for the maintenance of *S. auriculatum* but not for hydrophilous testate amoebae away from the protective microclimate of *Sphagnum* sect. *Sphagnum* hummocks. Fire can accordingly be seen as a complicating factor in the determination of a raised bog water table since it can, in effect, instigate and maintain a surficial, pseudo-water table by impeding drainage under appropriately wet, climatological conditions.

This fire modified community has no direct analogues within the NVC but it may be considered as a variant of M1, the *S. auriculatum* pool community, juxtaposed with hummocks formed by the taxa; *C. vulgaris*, *E. vaginatum*, *Sphagnum* sect. *Sphagnum* and the hypnaceous mosses. The hummocks of *Sphagnum* sect. *Sphagnum* might be considered as mini-raised bogs because they are developed upon peat rendered relatively impervious by fire, perched above the true water table and accordingly, responsible for capture and storage of their own water.

Some degree of mineralisation must have accompanied the burning and the effect of this upon the vegetation may be reduced by the lack of a sustained, high water table as is prevalent under the *S. recurvum* lawn described above. The only components of this *S. recurvum* community prevalent here are the mosses *A. palustre* and *P. commune* whose presence may be related to mineral enrichment of their rooting zone. In addition, the creation of gaps in the canopy is thought to be an important ecological factor in the expansion of *P. commune* (section 4.5.2) and it is probably the most notable macroscale feature of this community.

4.3.6 *S. cuspidatum* Wet Lawn or Pool Community

This community is indicated primarily on the dominance of *S. cuspidatum* either within a pool or wet lawn microform. Other species present here are presumably restricted to the periphery of the community and become present within its limits only when the *S. cuspidatum* lawn is of sufficient stability to support them. These species include, in a suggested, successional series; *S. recurvum, S. auriculatum, S. tenellum, S. magellanicum, S. papillosum, E. tetralix* and finally, *C. vulgaris* which may not appear until the hummocks of *S. papillosum* have reached *c.* 2 cm above the water table (*cf.* Gimingham, 1960). Only *E. angustifolium*, excluded from the preceding list, may be consistently present throughout the duration of the community since it can root in the mud bottom of a pool or wet carpet microform. It is present, albeit sparingly, in both occurrences of this community and it is defined as a constant species on account of this, its ecology and diffuse, spatial structure reducing the probability of its inclusion and subsequent representation within a palaeoquadrat.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-2.69
S. auriculatum	0 - 2	Median	-2.72
S. cuspidatum	**5**	Standard Deviation	2.06
S. magellanicum	0 - 2 (-3)	Minimum	-4.77
S. papillosum	0 - 2 (-3)	Maximum	-0.57
Sphagnum sect. Sphagnum	0 - 2 (-3)	*n*	4
S. recurvum	0 - 2		
S. tenellum	0 - 2		
Monocotyledonae		**Occurrences**	
Eriophorum angustifolium	**0 - 1**		
		Coalburn Moss	46 cm - 58 cm
Dicotyledonae		Cranley Moss	18 cm - 34 cm
Calluna vulgaris	0 - 3		
Erica tetralix	(0-) 1 - 3 (-5)		*n* = 2
Vaccinium oxycoccus	0 - 1		

Table 4.3.5 Summary data for the *S. cuspidatum* Wet Lawn or Pool community.

S. cuspidatum generally does not occur in this study within any community where the testate amoebae derived water table model is consistently below -2 cm from the surface but at Cranley Moss it is seen to be as low as -4.8 cm. This figure is reduced due to the inclusion of xeroindicative testate amoebae species but whether these are derived from the surrounding lawn and hummock communities or, summer drying of the pool is not apparent.

Common to both occurrences of the community is a preceding, sharp rise of the water table, in the order of 5 cm to 10 cm and similar, but short lived expansions of *S. cuspidatum,* are seen to accompany this phenomenon throughout stratigraphic sections of the closely related *Sphagnum cuspidatum/auriculatum - Sphagnum* sect. *Sphagnum* lawn or pool community. *S. cuspidatum* is commonly seen to colonise rewetted peat cuttings (such as at Peatlands Park) and its apparently similar response to increased water table levels in the natural state appears to be little studied in the current regime of downwardly mobile water tables. Whether the water table is continuous (Cranley Moss) or rising (Coalburn Moss), *S. cuspidatum* is rapidly replaced by either *S. magellanicum* or *S. papillosum*. This is commonly seen in the Bargerveen (Joosten, 1992) and other restored peatlands such as at Peatlands Park (Shaw, 1993) when the loose raft or lawn of *S. cuspidatum* becomes coherent.

In absence of all the faithful, vascular species indicated by Rodwell (1991) it is not possible to allocate either sub-community of the wider *S. cuspidatum/recurvum* bog pool community (M2) which is represented here. The presence of *S. recurvum* at Cranley Moss does however suggest the local existence of the *S. recurvum* sub-community (M2b) at least there. Spatially, the community is clearly seen to exist as a discrete pool or wet hollow at Coalburn Moss with *C. vulgaris* present on surrounding hummocks of indeterminate extent. At Cranley Moss the distribution of the community is not readily discernible but in the continued absence of *C. vulgaris* and the antecedence of an extensive *S. imbricatum* lawn it may be supposed to account for a greater extent of the vegetation.

4.3.7 Homogeneous *Sphagnum* Lawn

This community is dominated by *Sphagnum* sect. *Sphagnum* species and is defined on this feature alone in the absence of any other consistent or abundant species. Any of the raised bog taxa may be present here, as is indicated in the table below but always and diagnostically, at low values. Separation from the Heterogeneous *Sphagnum* Lawn, of which this community may be a component, is on account of the greater species diversity and topography found there. No real hydrological difference is apparent although the limits of the Heterogeneous *Sphagnum* Lawn appear larger but this is considered to be a statistical consequence of this community's predominance and accordingly greater sample size.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-4.25
S. auriculatum	0 - 1	Median	-4.45
S. capillifolium	0 - 1	Standard Deviation	2.64
S. cuspidatum	0 - 1	Minimum	-10.59
S. fuscum	0 - 1	Maximum	1
S. magellanicum	0 - 5	*n*	46
S. papillosum	0 - 5		
Sphagnum* sect. *Sphagnum	**5**		
S. tenellum	0 - 1	**Occurrences**	
Monocotyledonae		Arnaby Moss	58 cm - 126 cm
Eriophorum angustifolium	0 - 1	Ballynahone Bog	14 cm - 30 cm
E. vaginatum	0 - 2	Coalburn Moss	0 cm - 18 cm
Rhyncospora alba	0 - 1		30 cm - 46 cm
		Cranley Moss	6 cm - 18 cm
Dicotyledonae			146 cm - 214 cm
Calluna vulgaris	0 - 1 (- 3)	Mullenakill Bog	166 cm - 206 cm
Erica tetralix	0 - 1 (- 3)	Wedholme Flow	22 cm - 50 cm
			166 cm - 198 cm
		Wreaks Moss	142 cm - 194 cm
			n = 10

Table 4.3.6 Summary data for the Homogeneous *Sphagnum* Lawn community.

In terms of topography, the extent of lawn to low hummock is largely obscured by the dominance of heteromorphic *S. imbricatum* throughout most of the relevant stratigraphy. In more recent sections where *S. magellanicum* and *S. papillosum* are present it would appear that either species may become established but the former is more common and usually antecedent to the appearance of *S. papillosum*. This suggests that the topography is low, at least initially but that a more heterogenous surface may subsequently develop.

The NVC has no comparable community to the Homogenous Sphagnum Lawn but, as suggested for the *S. tenellum* - *S. magellanicum* Lawn, it can be considered as a component of the M18a, *A. polifolia* - *S. magellanicum* sub-community (Rodwell, 1991). Separation from the *S. tenellum* - *S. magellanicum* Lawn depends primarily upon the abundant presence of the former, titular species and the frequent development of this community upon degraded peat surfaces. The Homogeneous *Sphagnum* sect. *Sphagnum* Lawn typically develops upon an extant *Sphagnum* surface and succeeds or precedes any of the *Sphagnum* communities present here. At Wreaks Moss (142 cm - 194 cm) the community has its origins in the expansion of *Sphagnum* within a Callunetum, a similar ecological role to that noted for the *S. tenellum* - *S. magellanicum* Lawn. In this case, a single, low occurrence of *S. tenellum* may be seen at the onset of the Homogeneous *Sphagnum* sect. *Sphagnum* Lawn and the phase is placed here on the subsequent absence of this species.

The Homogenous *Sphagnum* Lawn community maintained itself for *c*. 370 years at Mullenakill Bog and for comparable timespans elsewhere. On account of this it may be suggested to be a stable, widespread community since the plagiotropic growth of *C. vulgaris* and *E. vaginatum* would be expected to cross the path of the borehole more often than is seen here within such a long timespan. However, this community may also exist on the scale of lawn microform within wider expanses of vegetation, such as that described below for the Heterogeneous *Sphagnum* Lawn.

4.3.8 Heterogeneous *Sphagnum* Lawn

In the absence of clear floristic or hydrological discontinuities and the difficulty in determining the spatial distribution of species, the community recognised here is a composite of six recognised within this study and four sub-communities of the NVC. However, the recurrence of these diverse floristic elements as a matrix of pools, carpets, lawns and/or hollows lends itself to the currently held notion of a desirable, management objective and therefore to their consideration as a single unit wherein some general trends are apparent. The sub-/communities present within the Heterogeneous *Sphagnum* Lawn are listed below in Table 4.6.7.

NVC	Current Study
S. cuspidatum/recurvum bog pool - *R. alba* sub-community	*S. cuspidatum* Wet Lawn or Pool Community
S. auriculatum bog pool	*Sphagnum cuspidatum/auriculatum* - *Sphagnum* sect. *Sphagnum* Lawn or Pool
E. tetralix - *S. papillosum* mire;	*Sphagnum tenellum* - *S. magellanicum* Lawn
(i) S. magellanicum - *A. polifolia* sub- community	Homogeneous *Sphagnum* Lawn
(ii) E. nigrum - Cladonia spp. sub-community	*Sphagnum* sect. *Sphagnum* - *Sphagnum* - sect. *Acutifolia* Lawn and Hummock
	Section *Acutifolia* Lawn and Hummock

Table 4.3.7 Table of the palaeo- and NVC plant communities recognised as forming a component of the Heterogeneous *Sphagnum* Lawn.

In the past, the dominant species in the bryophyte layer has been *S. imbricatum* in either its lax form of lawns and lower hummocks or the more turgid, compact form of hummocks (*cf.* Flatberg, 1986). In the absence of biometric data for this study it is not always apparent which growth form or forms that *S. imbricatum* was adopting but in the presence of *C. vulgaris* it may be assumed that hummocks were present and that the turgid, compact form, seemingly analogous with contemporary *S. papillosum* was present. In wetter communities, where *S. cuspidatum* and *S. tenellum* may be present, the lax growth form is adopted and it is suggested that this morph is currently replaced by *S. magellanicum*. The other diagnostic species; *S. capillifolium*, *S. cuspidatum* and *S. tenellum* are assumed to be consistently present although their palaeoecological presence is not always apparent. Additionally, the relative prevalence of biotopes is expected to be altered, according to the prevailing, hydrological conditions and one may therefore see phases where either pools or hummocks are more prevalent leading to the ultimate development of the *S. sect Acutifolia and S. sect Cuspidata* dominated communities. In the former instance, there is often an increase in the quantity of *S. fuscum* and *S. auriculatum* may also be encountered in wet lawns or pools, replacing *S. cuspidatum* as flooding becomes more sporadic. *S. molle* is present only at Cranley Moss where it forms part of an interesting association with *S. auriculatum* and *S. tenellum* in possibly recolonising dry, bare peat, indicated by resting spores of the fungus *Coenococcum* sp., as the water table rises.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-4.66
S. auriculatum	0-1	Median	-4.03
S. capillifolium	**(0-) 1 - 3**	Standard Deviation	3.55
S. cuspidatum	**(0-) 1 - 3**	Minimum	-15.57
S. fuscum	0 - 1	Maximum	1.78
S. imbricatum	(0-) 2 - 5	*n*	91
S. magellanicum	(0-) 1 - 4		
S. molle	0 - 2		
S. papillosum	0 - 2 (-4)	**Occurrences**	
Σ sect. Sphagnum	**(0-) 2 - 5**		
S. tenellum	(0-) 1 - 2 (-3)	Ballynahone Bog	98 cm - 246 cm
		Coalburn Moss	58 cm - 134 cm
Other Bryophytes		Cranley Moss	0 cm - 6 cm
Kurzia sp.	0 - 2		78 cm - 146 cm
Aulacomnium palustre	0 - 1	Deer Dyke Moss	26 cm - 274 cm
Campylopus sp.	0 - 1	Mullenakill Bog	38 cm - 150 cm
Polytrichum juniperinum type	0 - 3 (-5)		206 cm - 300 cm
Racomitrium canesecens	0 - 3 (-5)	Wedholme Flow	0 - 2 cm
			198 cm - 286 cm
Monocotyledonae		Wreaks Moss	194 cm - 242 cm
Eriophorum angustifolium	0 - 2		
E. vaginatum	0 - 2 (-5)		*n* = 10
Rhynchospora alba	0 - 2		
Dicotyledonae			
Calluna vulgaris	0 - 3 (-5)		
Erica tetralix	0 - 3 (-5)		
V. oxycoccus	0 - 2		

Table 4.3.8 Summary data for the Heterogeneous *Sphagnum* Lawn community.

Of the other bryophytes present within this community three of the five are indicative of bare peat, namely; the liverwort *Kurzia* spp., and mosses, *Campylopus* sp. and *Racomitrium canescens*, the former facultatively so. The records for *R. canescens* from this community are interesting on account its current ecological range which is predominantly on well drained sands, gravels and soils (*cf.* Smith, 1978) and never on peat (pers. comm., Professor J.H. Dickson). The Pleistocene record of this easily identified moss was a single record at the time of Dickson's (1973) account but recent work by Hughes (1997) and that presented here suggests that it was not an uncommon component of raised mire vegetation during the Late Holocene. The remaining moss species, *A. palustre* and *P. juniperinum* type are prevalent in lawns of *S. capillifolium*.

The vascular vegetation of this community may, at its most impoverished, include only *E. vaginatum* with a sparse occurrence of *C. vulgaris* and *E. tetralix* under an apparently unstable water table regime. This is considered to be an erroneous signal because dips in the water table are associated with peaks of *E. vaginatum* epidermis and accordingly thought to be a consequence of changes in the micofauna, determined by the microenvironment generated within tussocks of this species. This is supported by the concomitant appearance of drier, hummock testate amoebae particularly *Assulina* spp..

At times, the relative scarcity of *C. vulgaris* within this community is unusual since a marked, hummocky topography can be indicated by the Sphagna and a water table depth within the apparent ecological tolerances of this species by the testate amoebae. Otherwise, *C. vulgaris* and *E. tetralix* are common components of the vegetation with *V. oxycoccus* occasional and poorly represented in palaeoecological contexts on account of its growth form and rapid breakdown. In wet areas of *S. cuspidatum* and *S. tenellum* the cyperaceaeous, *E. angustifolium* and *R. alba* are present but never comprise a significant component of the community or its peat.

The hydrology of such a floristically and topographically diverse community must be variable spatially and this seen in the substitution of time with extremes between +2 cm and -15 cm although the modal range is in the region of -2 cm to -6 cm. The development of this community under a water table indicated to be as deep as -15 cm during its onset at Wreaks Moss (194 cm - 246 cm) follows a phase of peat development under a Callunetum. In this instance, the water table is rising to a figure of -3 cm throughout the existence of this community and the initially impeded drainage created by the underlying Callunetum peat may have helped to initiate and sustain expansion of the *Sphagnum* species by impeding drainage or acting as the narrow end of a V-shaped weir. Otherwise, the dips in the water table to -15 cm are considered to be erroneous features due more to the microenvironment of an *E. vaginatum* tussock than the prevailing hydrological conditions in a *Sphagnum* lawn.

4.3.9 *Sphagnum* section *Acutifolia* Lawn and Hummock

This community is distinguished by the dominance of *Sphagnum* sect. *Acutifolia* species, primarily *S. capillifolium* but *S. fuscum* can be an important component here too. The presence of *S. balticum*, *S. molle* and *S. tenellum* at Cranley Moss indicates the existence of open areas of vegetation and possibly, areas of wet, bare peat in which these uncompetitive species (Daniels and Eddy, 1990) can subsist. These areas are presumably maintained by the fire events indicated in the macrofossil diagrams for both occurrences of this community. At Cranley Moss, one of these fire events is particularly severe and leads to establishment of the *Sphagnum cuspidatum/auriculatum - Sphagnum* sect. *Sphagnum* Lawn or Pool community. This phase is short lived and the Section *Acutifolia* Lawn and Hummock soon restores itself although *S. tenellum* remains abundantly present within the vegetation. The growth form of *S. imbricatum* within this community is not apparent and it may be present, in low quantities, as either a lawn component or with *S. fuscum* at the top of hummocks. *S. cuspidatum* is still present within this community but only towards the end of each phase when a decrease in the depth to water table leads to the expansion of *S. imbricatum* .

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-5.19
S. balticum	0 - 1	Median	-5.30
S. capillifolium	**1 - 4**	Standard Deviation	1.66
S. cuspidatum	0 - 1	Minimum	-8.03
S. fuscum	(0-) 1 - 2 (-5)	Maximum	-2.15
S. imbricatum	0 - 1 (-2)	*n*	12
S. molle	0 - 2		
S. tenellum	0 - 2		
		Occurrences	
Other Bryophytes			
Aulacomnium palustre	0 - 1	Coalburn Moss	250 cm - 300 cm
Pohlia sp.	0 - 1	Cranley Moss	214 cm - 250 cm
			258 cm - 286 cm
Monocotyledonae			
Eriophorum angustifolium	0 - 1		*n* = 3
E. vaginatum	0 - 2		
Dicotyledonae			
Calluna vulgaris	(0-) 1 - 3 (-5)		
Erica tetralix	0 - 1 (-3)		

Table 4.3.9 Summary data for the *Sphagnum* section *Acutifolia* Lawn and Hummock.

This community is further distinguished from the *Sphagnum* sect. *Sphagnum* - *Sphagnum* sect. *Acutifolia* Lawn and Hummock community by the persistence of *C. vulgaris* and *E. tetralix*. *V. oxycoccus* is also present here and the preservation of this species, in both instances, is on account of a fire event leading to carbonisation of the leaves. This species is apparently absent otherwise and accordingly, its sociology in the past cannot be faithfully determined. Both species of *Eriophorum* are present but only *E. vaginatum* appears to be a consistent component of the vegetation. The mosses, *A. palustre* and *Pohlia* spp. are sporadic and singular in their appearance.

The modal range of the water table is in the range of -4 cm to -8 cm which suggests it to be a drier community than the *Sphagnum* sect. *Sphagnum* - *Sphagnum* sect. *Acutifolia* Lawn and

Hummock. This is indicated also by the floristics with particular regard to the presence and abundance of *S. fuscum* and *C. vulgaris*.

The appearance and maintenance of the *S.* section *Acutifolia* Lawn and Hummock in two distinct sections of stratigraphy, from two bogs in the upper Clyde Valley suggests that it was an extensive community covering much of the mire surface. This community must have formed a visually striking component of the landscape and on this scale it seems without parallel in contemporary times (*cf.* Rodwell, 1991). Within the British Isles this community is to be found forming the hummock component of raised bogs which fall into the category of *E. tetralix* - *S. papillosum* raised and blanket mire and more specifically, its *E. nigrum* - *Cladonia* spp. sub-community although dry elements of the *S. magellanicum* - *A. polifolia* sub-community are also indicated (Rodwell, 1991). In terms of this study, it likewise forms a component of the Heterogeneous *Sphagnum* Lawn community.

4.3.10 *Sphagnum* sect. Sphagnum - *Sphagnum* sect. *Acutifolia* Lawn and Hummock

This community is present within the Heterogeneous *Sphagnum* Lawn where it represents the drier end of the vegetation continuum and constitutes a dry lawn and hummock component. It is an apparently drier community than the *S.* sect *Acutifolia* Lawn & Hummock community described below (section 4.3.11) with *Sphagnum* sect. *Sphagnum* species now present, it is assumed at the tops of the hummocks. Accordingly it is recognised as representing the drier component of the *E. tetralix* - *S. papillosum* mire (M18) (Rodwell, 1991) and analogous to the *E. nigrum* - Cladonia spp sub-community. Separation from the Heterogeneous *Sphagnum* Lawn is based on the almost complete absence of pool indicators, particularly *S. cuspidatum* and the prevalence of *Sphagnum* sect. *Acutifolia* species, especially *S. capillifolium* in association with *Sphagnum* sect. *Sphagnum*. *S. imbricatum* was the main *Sphagnum* sect. *Sphagnum* species in the past but it is now replaced by *S.*

magellanicum and *S. papillosum* except in the west of the British Isles where it is an uncommon hummock species (J. H. Dickson, pers. comm.; *cf.* Daniels & Eddy, 1990).

Despite the consistently low level of the water table here, *C. vulgaris* is surprisingly sparse, particularly at Coalburn Moss even though the water table values are within its ecological limits elsewhere in this study. Upward growth of the *S. capillifolium* lawn or hummock is not considered to exclude *C. vulgaris* because the radiocarbon dates obtained for this community at Cranley Moss do not indicate rates of peat accumulation that are more rapid than those elsewhere. Accordingly, no explanation can be found for the absence of this otherwise common species. However, shedding of its remains from the smooth mounds of *S. capillifolium* and the relatively xeric conditions within this community may have reduced its potential for preservation. The predominance of anthocyanin, in *S.* sect *Acutifolia* functions, as in other plants, to reduce wave lengths of light disruptive to the photosynthetic mechanism, converting this light energy to heat. It is possible that the temperatures generated are inhibitory for *C. vulgaris* but this appears to have not been investigated.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-7.85
S. capillifolium	**1 - 4**	Median	-7.75
S. cuspidatum	0 (-1)	Standard Deviation	4.65
S. fuscum	0 - 3	Minimum	-15.21
S. imbricatum	2 - 5	Maximum	-1.99
S. papillosum	0 - 2	n	20
Σ sect. Sphagnum	**2 - 5**		
S. subnitens	0 (- 3)		
		Occurrences	
Monocotyledonae			
Rhyncospora alba	0 - 2	Ballynahone Bog	54 cm - 98 cm
Eriophorum vaginatum	0 - 1 (-3)	Coalburn Moss	142 cm - 242 cm
		Wreaks Moss	38 cm - 50 cm
Dicotyledonae			
Calluna vulgaris	0 - 1 (-3)		$n = 3$

Table 4.3.10 Summary data for the *Sphagnum* sect. Sphagnum - *Sphagnum* sect. *Acutifolia* Lawn and Hummock community.

Other vascular species are poorly represented with only *E. vaginatum* and *R. alba* recorded and *E. tetralix* is apparently absent throughout each phase. *R. alba* is only present within this community at the stratigraphic margins where it indicates expansion or contraction of pool or wet lawn biotopes.

The water table of this community is indicated to lie between -2 cm and -4.5 cm at Ballynahone Bog and Wreaks Moss, just below the stable range required for the presence of *S. cuspidatum*. At Coalburn Moss, the predicted water table differs markedly from these figures and lies instead within the range of -8 cm to - 15 cm. This is due to an abundance of xerophilous *H. subflava* replacing the otherwise prevalent *Amphitrema* spp. and *Assulina* spp. in the testate amoebae fauna. No obvious reason exists for this anomaly but it may be related to elevation of the hummock above average water table depth at Coalburn Moss.

4.3.11 Hypnaceous Callunetum

This community is distinct from the other Callunetum described below in the dominance here of hypnaceous mosses in the bryophyte layer. The initiation of this community is dated to 3 700 BP when Yong (1998) records a fall of 50 cm in the height of Mean High Water Spring Tide at Roudsea Wood in the neighbouring estuary. Tooley (1978) considers a more major transgression at this time but whatever the scale of change it seems plausible that a drop in regional water table increased groundwater recharge from Arnaby Moss and lead to the replacement of Sphagna by hypnaceous mosses. In addition, the infrequent recurrence of fires within this flammable community may have favoured the maintenance of the hypnaceous community (0.04 fires.dm^{-1}). By comparison, the greater consistency of fire during the phase of Callunetum at Wreaks Moss (0.77 fires.dm^{-1}) may have been deleterious to any hypnaceous community forming there and pushed the vegetation towards that of the highly disturbed, species poor, *E. vaginatum* mire community described for the NVC (Rodwell, 1991).

Amongst the Sphagna only *S. imbricatum* is a consistent but sparse component which is presumably kept in check by the low water table (*c.* -10 cm to -15 cm). A small amount of increase in its abundance is to be seen as the water table rises to within *c.* 10 cm below the vegetation surface and at this depth, the water table appears to exert a corresponding, deleterious effect upon the hypnaceous species which then start to decline. *S. capillifolium* is also present but this species occurs very sporadically and patchily throughout the phase.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-10.05
S. capillifolium	0 - 1 (-2)	Median	-10.17
S. imbricatum	1 - 2	Standard Deviation	3.87
Σ sect. *Sphagnum*	1 - 2	Minimum	-14.84
		Maximum	-4.93
Other Bryophytes		n	9
Kurzia spp.	0 - 4		
Aulacomnium palustre	0 - 1		
Campylopus sp.	0 - 1	**Occurrences**	
Dicranum scoparium	0 - 5		
D. undulatum	0 - 1	Arnaby Moss	126 cm - 198 cm
Hypnum sp.	0 - 1		
H. cupressiforme	0 - 2		n = 2
H. jutlandicum	0 - 3		
Pohlia sp.	0 - 3		
Polytrichum commune	0 - 2		
P. juniperinum	0 - 5		
Rhytidiadelphus squarrosus	0 - 2		
Thuidium tamariscinum	0 - 1		
Σ Other Bryophytes	**2 - 3 (-5)**		
Monocotyledonae			
Eriophorum angustifolium	0 - 1		
E. vaginatum	**(0-) 2 - 4**		
Dicotyledonae			
Calluna vulgaris	**4 - 5**		
Erica tetralix	0 - 2		

Table 4.3.11 Summary data for the Hypnaceous Callunetum.

The vascular components are not an apparently striking feature of the vegetation with only *C. vulgaris* and *E. vaginatum* consistently and abundantly present as the vascular co-dominants. In addition, *E. tetralix* and *E. angustifolium* are sporadically present.

The co-dominance of *C. vulgaris* and *E. vaginatum* and scarcity of *Sphagnum* here indicates the *C. vulgaris-E. vaginatum* community (M19) of the NVC (Rodwell, 1991). In addition, the apparent juxtaposition of hypnaceous mosses and *E. tetralix* with *Sphagnum* indicates the further presence of two sub-communities recognised within M18; respectively, the *E. nigrum*-subsp. *nigrum* and *E. tetralix* sub-communities.

4.3.12 Callunetum

This community bears much similarity to the Hypnaceous Callunetum described above from Arnaby Moss. However here, the hypnaceous moss species are absent and the prevalence of fire as an environmental factor is apparent in the frequency of charcoal layers. The further effects of fire within this community are seen in the absence of aerial *E. vaginatum* remains and the carbonisation of *C. vulgaris* components. It is therefore difficult to determine the relative proportions of these species since carbonisation of ericaceous remains appears to enhance their preservation whereas only the root components of *E. vaginatum* remain. However, the overall impression is that both of these species are common and abundant, probably as co-dominants. Other ericaceous species are apparently scarce; *E. tetralix* and *V. oxycoccus* are recorded only once within the 12 samples spanning this phase and preservation of the latter is apparently due to its carbonisation during a fire event. *E. angustifolium* is uncommon but appears where there is some indication of wetter conditions, often accompanied by a small amount of *Sphagnum*.

A diverse, hummock forming *Sphagnum* flora of low cover can be present within this community (*S. capillifolium*, *S. fuscum* and *Sphagnum* sect. *Sphagnum*). *S. cuspidatum* may also be present and this species is probably indicative of desiccation driven, peat compaction leading to the retention of meteoric water in hollows or pools via an increase in hydraulic resistance. The other bryophyte species present in this community are so around a cluster of charcoal layers and it is assumed that fire induced openings in the *C. vulgaris-E. vaginatum* canopy enabled these species to colonise (i.e. *A. palustre*, *Campylopus* sp., *Pohlia* sp. and *R. canescens*).

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-12.56
S. capillifolium	0 - 1	Median	-12.15
S. cuspidatum	0 - 1	Standard Deviation	3.18
S. fuscum	0 - 1	Minimum	-16.50
S. imbricatum	0 - 1 (-2)	Maximum	-8.69
Σ sect. *Sphagnum*	0 - 1 (-2)	*n*	7
Other Bryophytes			
Kurzia spp.	0 - 4	**Occurrences**	
Aulacomnium palustre	0 - 1		
Campylopus sp.	0 - 1	Wreaks Moss	246 cm - 300 cm
Pohlia sp.	0 - 3		
Racomitrium canescens	0 - 2		*n* = 2
Σ Other Bryophytes	**0 - 3**		
Monocotyledonae			
Eriophorum angustifolium	0 - 1		
E. vaginatum	**(0-) 1 - 4**		
Dicotyledonae			
Calluna vulgaris	**4 - 5**		
Erica tetralix	0 - 3		

Table 4.3.12 Summary data for the Callunetum

In relation to the NVC this community appears to be intermediate between the *E. vaginatum* (M20) and *C. vulgaris-E. vaginatum* (M19) mires by account of the floristics and frequency of fire events. In the absence of fire events during the phase of this community the vegetation might be more readily referable to the latter, *C. vulgaris-E. vaginatum* community (M19).

4.3.13 *S. palustre - S. recurvum* Mosaic

This community has developed upon an expanse of fen peat exposed by the cutting of ombrogenous peat at Arnaby Moss. Consequently, the water supply is minerotrophic but the development of *S. palustre* indicates the presence of a local ombrogenous component which is developing above the groundwater table. However, in this instance, it is overcome by an increase in the groundwater table and the phase of this community is terminated by expansion of *S. recurvum*, into the lawn that persists until contemporary times.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-8.59
S. cuspidatum	1 - 2	Median	-9.36
S. palustre	**1 - 2**	Standard Deviation	3.84
S. recurvum	1	Minimum	-11.98
		Maximum	-4.42
Other Bryophytes		*n*	3
Drepanocladus fluitans	1 - 2		
Hylocomium splendens	0 - 2		
Pleurozium schreberi	1 - 2	**Occurrences**	
Pohlia sp.	0 - 1		
Polytrichum commune	0 - 1	Arnaby Moss	
P. juniperinum type	0 - 1	Regeneration Peat	73 cm - 78 cm
Rhytidiadelphus squarrosus	0 - 1		
Monocotyledonae			*n* = 1
Phragmites communis	**0 - 1**		
Dicotyledonae			
Calluna vulgaris	**1 - 4**		

Table 4.3.13 Summary data for the *S. palustre - S. recurvum* Mosaic.

The topography of this community is assumed to be in part, a consequence of that left by peat cutting with *S. palustre* on the upstanding parts and *S. recurvum* or to a lesser extent, *S. cuspidatum* in the hollows. However, the appearance of *S. palustre* hummocks may also take place on a lawn of *S. recurvum* that is approaching ombrotrophy as the height of the peat accumulation equals or exceeds that of the groundwater table (Hughes, 1997; pers. obs.).

The water table of this phase is indicated to be low, in the region of -4 cm to - 12 cm which places it in a similar hydrological range to the Callunetum communities described above. However, this figure is considered relevant only to the hummocks of *S. palustre* through which the core may have passed, since the *S. cuspidatum* and *S. recurvum* communities are presumed to exist only under surficial water conditions only. In addition, some error may be prevalent in the model since the modern data set used for calibration was derived from oligotrophic communities.

4.3.14 Degradation Phases

This collection of phases encompasses periods when little active growth of the mire may be in evidence, as illustrated by the chronological leap in Mullenakill Bog between 150 cm and 166 cm (Figure 4.5.3). In more contemporary layers this community is suggested to be indicative of the oxidation taking place above the receding water table in drained mires. Accordingly, it is difficult to consider as a community since the vegetation components of preceding phases may also be included as the process of oxidation reaches deeper into the peat massif during prolonged periods of water table draw down. However, the community prevailing during these phases is presumably derived from cyperaceous and/or ericaceous species as, indicated by the abundant presence of their roots.

Regard to the depth of oxidation revealed in the upper peak of Unidentified Organic Matter serves as a crude proxy in determining how deep into the peat massif the water table has receded.

Indeed, reference to some sites, Ballynahone Bog, Coalburn Moss and Cranley Moss indicates that the hydrological perturbation to these systems has not induced much mineralisation of the peat whereas recent degeneration phases are well developed at Deer Dyke Moss, Mullenakill Bog, Wedholme Flow and Wreaks Moss and this accords well with the known history of exploitation for these sites.

Taxa	**Abundance (5-point scale)**	**Predicted Water Table Data**	
Sphagnum		Mean	-6.47
S. auriculatum	0 - 2	Median	-6.03
S. cuspidatum	0 (- 1)	Standard Deviation	2.55
S. fuscum	0 - 1	Minimum	-11.24
S. imbricatum	0 - 1	Maximum	-4.03
S. magellanicum	1	*n*	6
S. papillosum	0 - 1		
Σ sect. *Sphagnum*	(0-) 1 (-2)		
		Occurrences	
Other Bryophytes			
O. sphagnicola	0 - 2	Deer Dyke Moss	6 cm - 26 cm
Campylopus introflexus	0 - 1	Mullenakill Bog	2 cm - 14 cm 150 cm - 166 cm
Monocotyledonae		Wedholme Flow	10 cm - 22 cm
Eriophorum angustifolium	0 - 1	Wreaks Moss	6 cm - 38 cm
E. vaginatum	0- 1		
			$n = 5$
Dicotyledonae			
Calluna vulgaris	0 - 1		
Erica tetralix	0 (- 1)		

Table 4.3.14 Summary data for Degraded surfaces.

Floristically there is little point in describing a community type on the basis of the species included here since the amount of Unidentifiable Organic Matter attributable to these phases in the macrofossil diagrams would indicate that most of the vegetable matter is broken down and the overall picture is therefore somewhat sketchy. However, in all cases there is a continuous presence of *S. magellanicum* occasionally with *S. imbricatum* and *S. papillosum* and it may be considered that Sphagna are able to linger on, probably in wetter depressions. This is supported by the rapid expansion of these species once suitable hydrological conditions return. Other bryophytes include *C.*

introflexus, a common colonist of bare peat surfaces and *O. sphagnicola* which may be able to persist in the lawns of *S. magellanicum*. *E. tetralix* may persist in a similar manner and the only other constant, vascular associates are considered to be *C. vulgaris* and *E. vaginatum*. Under such conditions as those presented here it is probable that the *C. vulgaris* growth was rank and possibly capable of passing right through the degenerative cycle.

The hydrological conditions under these periods of degradation are not likely to lie within the range indicated because this would suggest the development of a *Sphagnum* section *Acutifolia* community. It is therefore suggested to lie below -15 cm since, above this depth, active peat accruement can ensue under the Callunetum recognised above. The reason for this erroneous figure probably lies in the incorporation of wet phases where active peat growth took place and the breakdown of this peat to produce such peaks of UOM is an unrelated, secondary event. Additionally, compaction of the peat surface may have created a secondary, pseudo- water table above the true one lying deeper within the peat and the former may have supported populations of hydrophilous testate amoebae. Recourse to the microfossil diagrams indicates that there possibly was temporal variation in this pseudo- water table since xeric and hydrophilous species are found together in an otherwise unlikely association.

4.4 TESTATE AMOEBAE AND OTHER MICROFOSSILS

4.4.1 Introduction

The microfossil stratigraphies are described in this section and in particular, the testate amoebae communities whose counts produced the water table - depth models also presented here. These models were derived from the testate amoebae counts by Dr. D. Charman who used WACALIB to perform weighted averaging regression and calibration of the data against a modern data set (Birks, 1995). In addition, bootstrapped confidence limits of 68 % and 95 % were derived and the latter is indicated on the diagrams. Comparison is also made between the testate amoebae derived water table models and those constructed from the vegetation based, DCA results. The words surficial and superficial are used throughout the section to respectively refer to a water table at or above the vegetation surface.

4.4.2 Arnaby Moss Regeneration Peat

The reconstructed water table model for this mire (Figure 4.4.2) clearly illustrates the relatively dry conditions prevailing throughout the colonising *S. palustre* - *S. recurvum* Mosaic community. During this phase the dominant protists, *Assulina muscorum*, *Hyalosphenia subflava* and *Trigonopyxis arcula* are gradually replaced by the hydrophilous *Arcella discoides* and *H. papilio* (Figure 4.4.1). The reconstructed water table model is accordingly indicative of surficial levels by 64 cm and these are maintained throughout the remainder of the stratigraphy. However, a shallow dip of some 2 cm is apparent above 24 cm stratigraphic depth and this could indicate that the mire surface has now surpassed its previous equilibrium with the water able and may imminently undergo a shift towards ombrogeny.

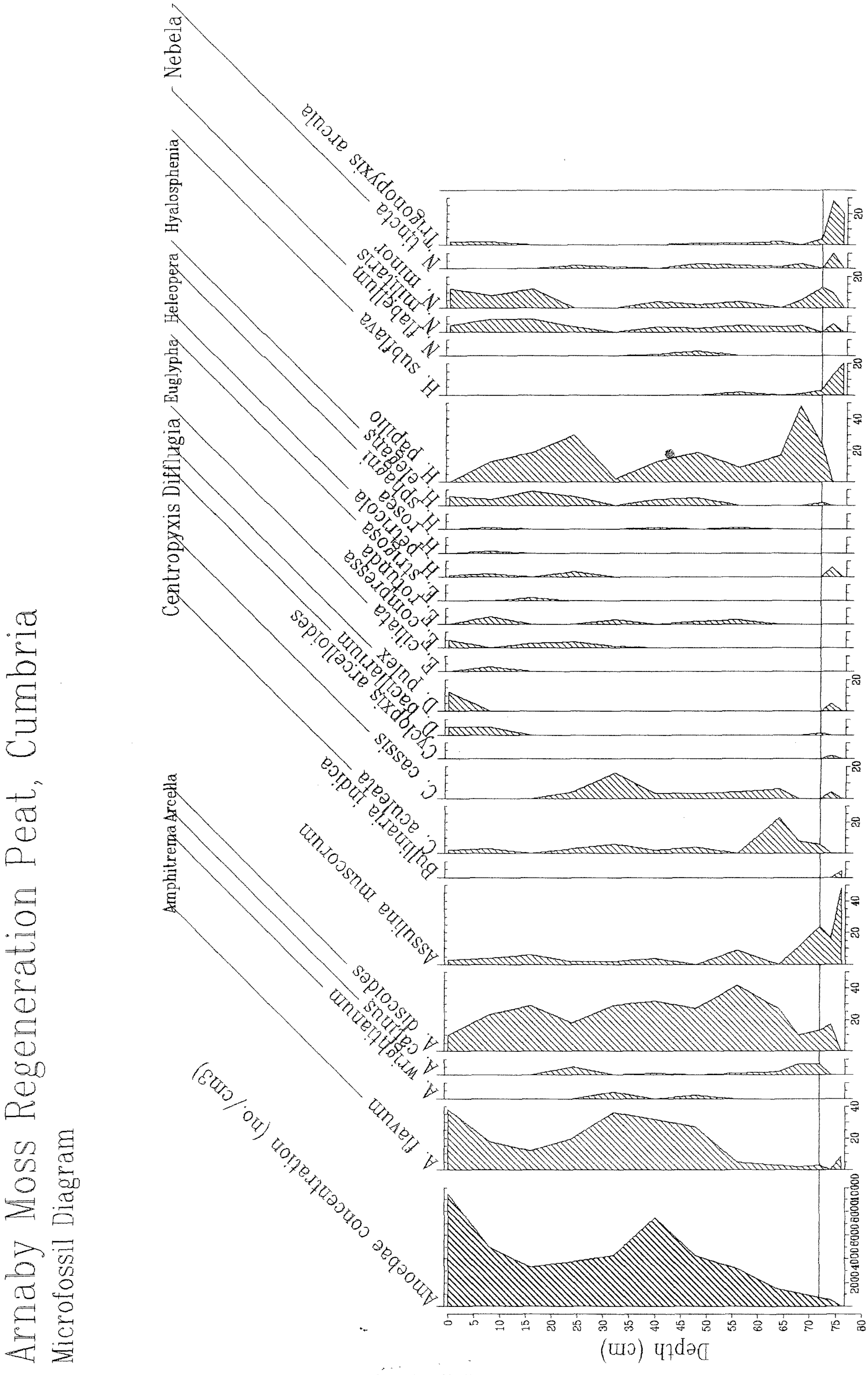

Figure 4.4.1 Arnaby Moss Regeneration Peat microfossil diagram.

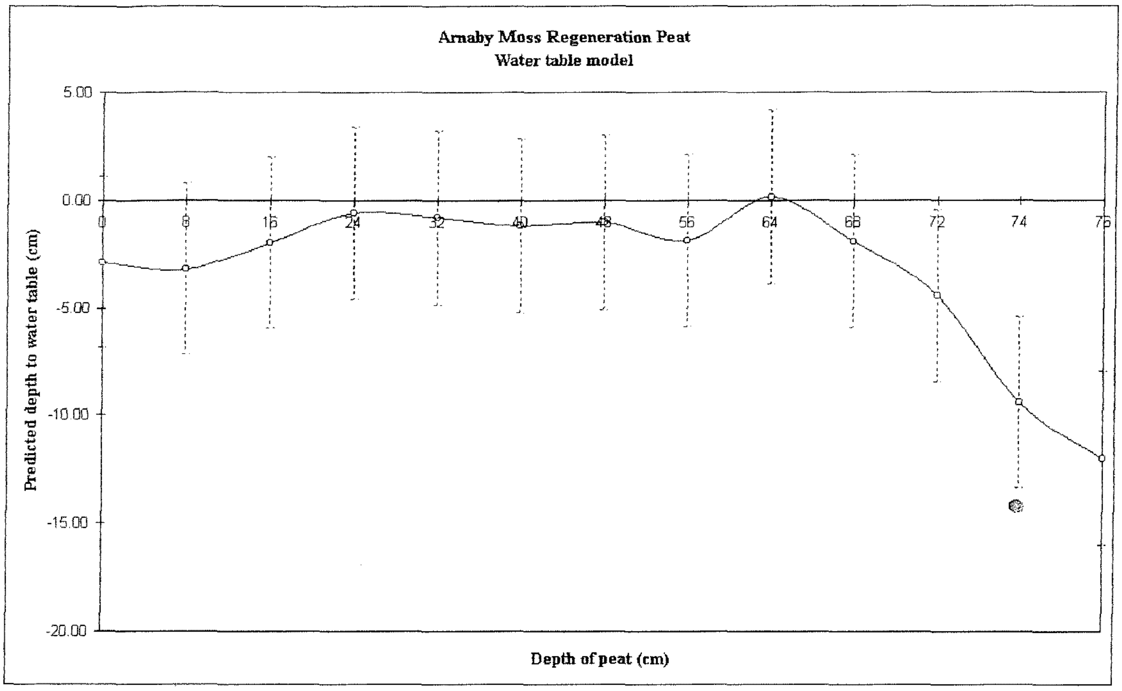

Figure 4.4.2 Water table - depth model for Arnaby Moss Regeneration Peat.

Although the dominant, hydrophilous species noted above maintain their dominance throughout the stratigraphy a diverse range of species occur at consistently low values (e.g. *A. muscorum*, *Centropyxis aculeata*, *Nebela militaris* and *N. minor*) and others (e.g. *Amphitrema wrightianum*, *Arc. catinus*, *Difflugia* spp., *Euglypha* spp.) more sporadically. These latter species are probably responding to ephemeral events such as precipitation quantity and quality since it has been shown that the response of testate amoebae communities to hydrological change can be very rapid (Warner and Chmielewski, 1992). Additionally, changes in the vegetation's physiography may also be responsible; *Centropyxis cassis*, for example, appears to be associated with the presence of *E. vaginatum* epidermis. Other associations are not so readily apparent but one may also remain mindful of the relative plasticity of *S. recurvum* and the ephemeral nature of low amplitude hummocks and hollows thus formed.

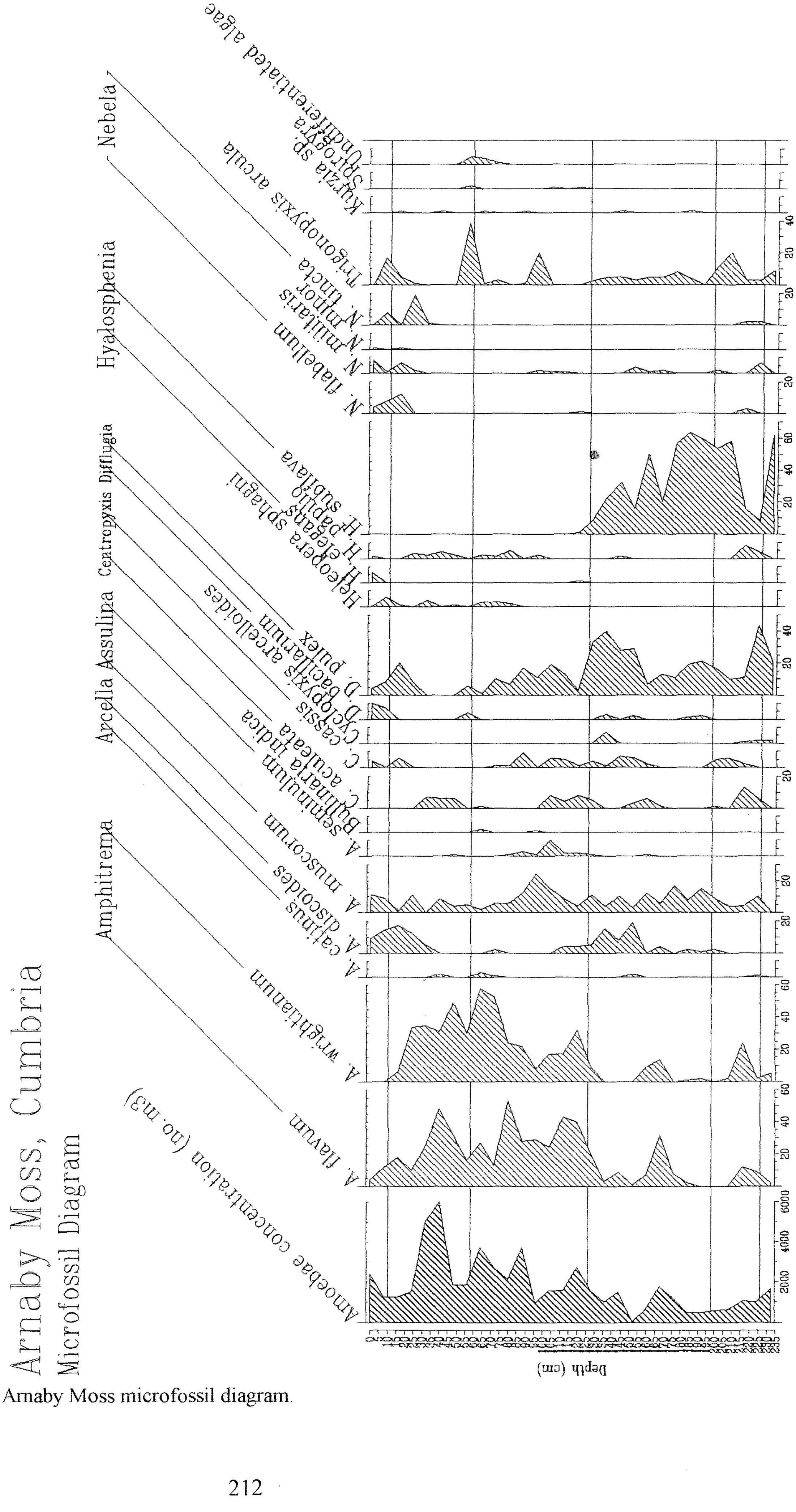

Figure 4.4.3 Arnaby Moss microfossil diagram.

4.4.3 Arnaby Moss

Between 152 cm and 232 cm the stratigraphy is dominated by xeroindicative *Difflugia pulex*, *H. subflava* and *T. arcula* (see Figure 4.4.3). The corresponding water table reconstruction is therefore calculated throughout this period to lie within the range of -10 cm to -15.0 cm. However, the peak of *S. imbricatum* centred on 220 cm, associated with the testate amoebae, *Amphitrema flavum*, A. *wrightianum*, C. *aculeata*, *Hyalosphenia papilio* and *Nebela* spp. corresponds to a brief period when the water table model attains values of up to *c*. -5.0 cm. The peak of *S. auriculatum* following this, at 204 cm, is not accompanied by a similar shift in the calculated water table and it is therefore assumed that this plant was responding to a local increase in the water table that was apparently, too sporadic to maintain hydrophilous testate amoebae species.

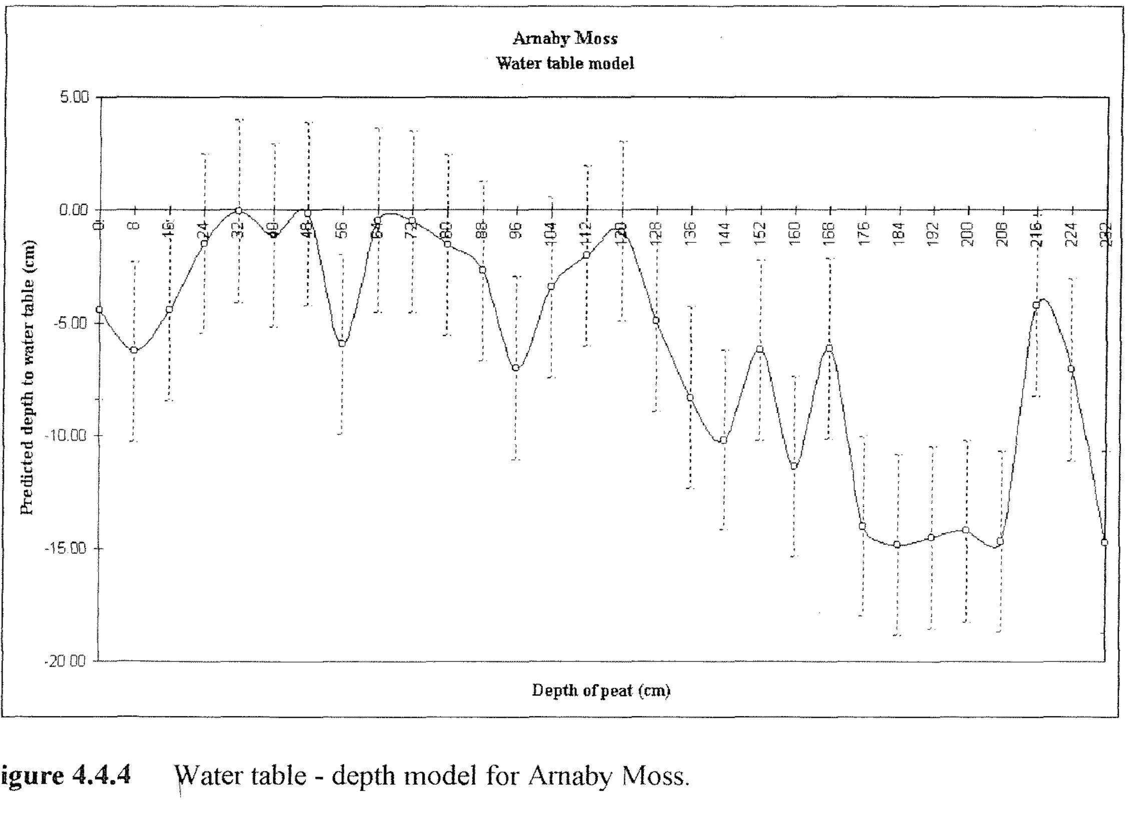

Figure 4.4.4 Water table - depth model for Arnaby Moss.

The emergence of *S. imbricatum* at 152 cm is accompanied by a decline in the presence of xeroindicative *D. pulex*, *T. arcula* and *H. subflava*, the latter becoming extinct as the predicted water table rises to surficial levels by 120 cm. Accompanying this transition is a low but consistent presence of *Arcella discoides* suggesting that the impervious nature of the ericaceous acrotelm must have retained a high moisture content and this is supported latterly by the presence of the algal genus, *Spirogyra* probably indicating the presence of shallow pools and open areas in the vegetation. *A. discoides* is widely noted as a very hydrophilous species and it is suggested by Woodland (1996) that the small size of this species allows it to exist within a wide range of water table values because of its ability to inhabit the shallow water films such as those present here. The presence of bare peat is further indicated by the microscopic remains of *Kurzia* spp.

Concomitant with the appearance of *S. imbricatum* at 126 cm, the reconstructed water table attains high, but subsurficial levels with small dips attributable to the presence of *T. arcula* which is in turn, associated with *E. vaginatum* remains. This suggests that *T. arcula* either inhabited the tussocks of *E. vaginatum* or that *S. imbricatum* gained physical or nutritional support from these structures and accordingly developed hummocks.

From 32 cm, upwards, the water table is seen to gradually recede, probably as a response to drainage and/or marginal peat cutting peat cutting. In this phase the xerophilous species; *D. pulex* , *Nebela militaris*, *N. minor* and *T. arcula* come to associate with the preceding hydrophiles. All of these xerophile species are probably derived from surrounding hummocks in what is more generally described by some vegetation components and the hydrophilous testate amoebae, *A. discoides*, *D. bacillarium*, *Heleopera* spp., *Nebela flabellum and N. tincta* as a wet period. In part, this calculated down turn in the testate amoebae derived water table is also attributable to the extinction of *A. wrightianum* and the accompanying decline *of A. flavum.*

Correspondence between the testate amoebae derived water table model and that derived from the vegetation based DCA axis 1 scores (Figure 4.2.4) is almost exact with only sporadic differences in the relative amplitude of changes. However, the two short dry periods, at 56 cm and 96 cm, in the testate amoebae derived water table model are not indicated in the vegetation based DCA axis 1 scores. It is suspected that the dimorphic nature of the then dominating *S. imbricatum* masked these changes, if they are indeed real. Additionally, the inclusion of tests from a cyperaceous hummock is indicated at 56 cm when the accompanying emergence of *S. cuspidatum* would indicate a shift to wetter conditions.

Conversely, no response in the testate amoebae derived water table model is seen when *S. imbricatum* forms a short-lived hummock during the initial phase of this stratigraphy (at 224 cm). In this instance it is suggested that the *Sphagnum* was not responding to a large scale change in water table but rather to small scale patch dynamics, possibly expanding in response to short term environmental cues, or subject to lateral movement through the borehole as it developed.

4.4.4 Ballynahone Bog

As indicated by the preponderance of *S. cuspidatum* in the macrofossil diagram (Figure 4.1.3), the stratigraphy from Ballynahone Bog initially indicates a high water table. The testate amoebae derived water table model (Figure 4.4.5), dominated at these levels by *Amphitrema* spp. and *Arcella* spp., (Figure 4.4.6) indicates that the water table was at least locally superficial at around 272 cm to 280 cm depth. Following this, the water table recedes to the range of -2 cm to -4 cm by 264 cm. *Amphitrema* spp. remain present at reduced percentages with *Assulina* spp. and *D. pulex* emerging to become codominant with these former species.

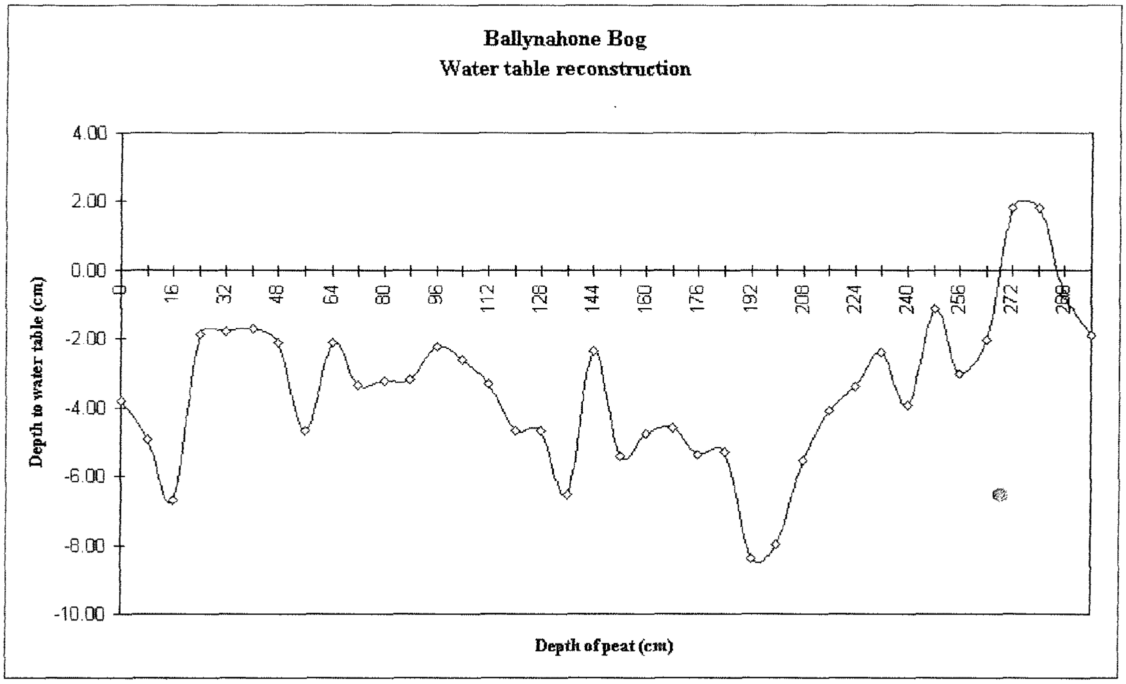

Figure 4.4.5 Water table - depth model for Ballynahone Bog.

Throughout the remainder of the stratigraphy the water table continues to remain at around -6 cm depth except for a recession between 184 cm and 216 cm which is attributable to a sharp rise in the abundance of *A. muscorum*. This may indicate a low hummock forming within the lawn of *S. imbricatum* stimulated by the antecedent presence of an *E. vaginatum* tussock. It is notable too that the abundance of *C. vulgaris* within the stratigraphy falls at this point (Figure 4.1.3). This may be attributable to the shedding nature of a hummock preventing the accumulation of macrofossils or the local extinction of this plant by rapid, upward growth of *Sphagnum*.

As the water table returns to above -2 cm depth at 96 cm, *S. cuspidatum* returns at low values and *A. wrightianum* regains its former dominance amongst the testate amoebae in association with lesser amounts of *A. flavum*, *A. muscorum* and *D. pulex*. As *S. auriculatum* and *S. cuspidatum* come to dominate the vegetation a sustained value of -2 cm water table depth is indicated and *D. pulex* disappears from the stratigraphy. This xeroindicative species previously marked the

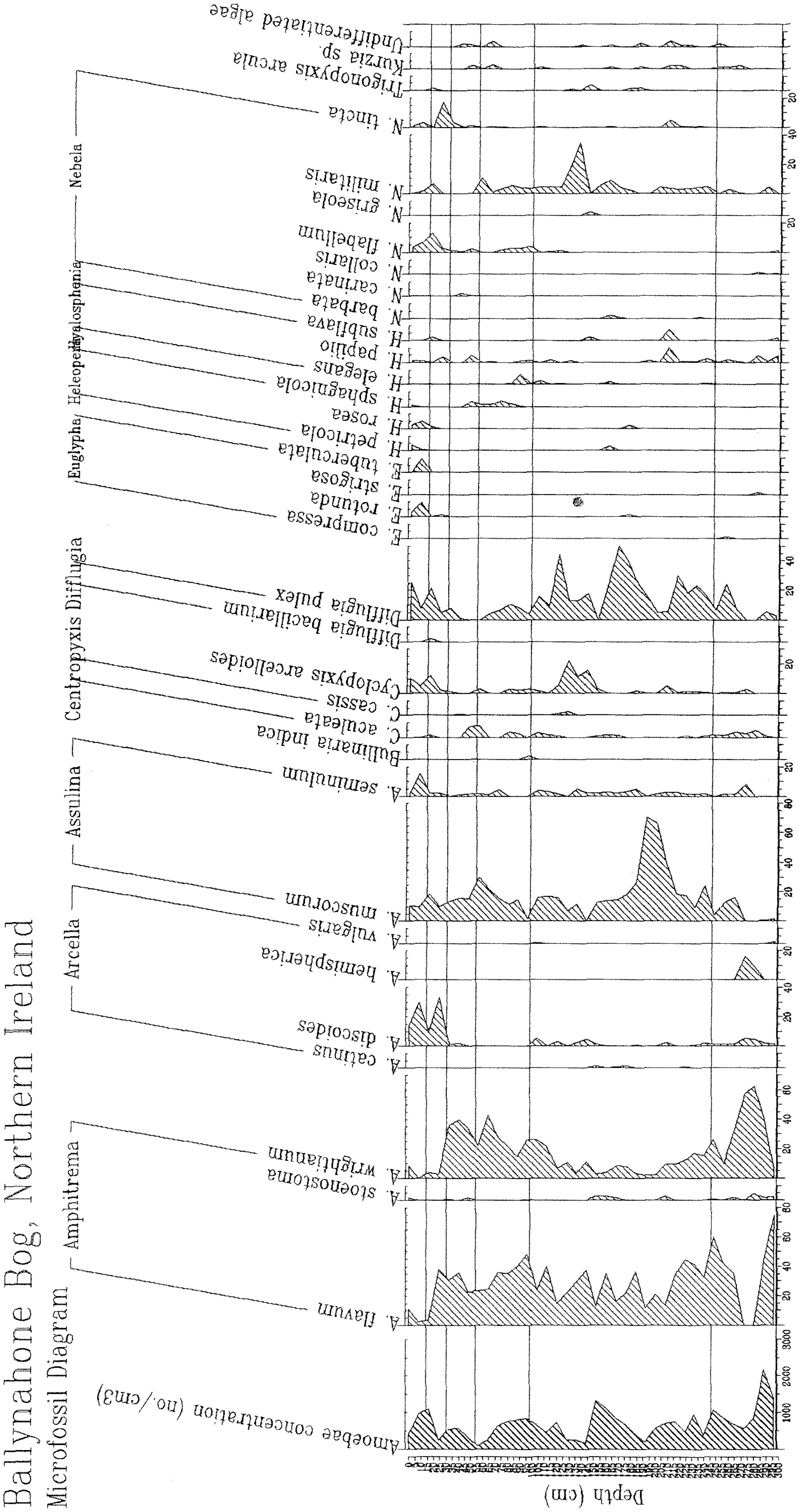

Figure 4.4.6 Ballynahone Bog microfossil diagram.

widespread occurrence of hummocks which become localised during the expansion of *S. cuspidatum* to be indicated now only by readily dispersed *C. vulgaris* seeds.

Within the last 24 cm of stratigraphy the *Amphitrema* spp. fall to low values. This is indicated on the water table model by an initial fall to - 6 cm from which it recovers as a diverse assemblage of testate amoebae becomes present by 8 cm stratigraphic depth indicative of the full complement of contemporary microhabitats upon Ballynahone Bog.

The DCA axis 1 (Figure 4.2.6) results are apparently much more variable than those of the testate amoebae derived water table model but this is simply a consequence of the scaling on the y axis. This variability in the DCA axis 1 scores is related to the relative prominence of *Sphagnum* and Monocotyledonae or Unidentified Organic Matter in the stratigraphy, the former generally maintaining dominance over short lived peaks of the latter pair.

Dominance by *Sphagnum*, especially the dimorphic *S. imbricatum*, results in a more complacent water table signal in the vegetation derived DCA axis 1 plot against that predicted by the testate amoebae. This is most prominent at 272 cm to 280 cm when *S. cuspidatum* appears within the stratigraphy. At this time, the testate amoebae indicate a superficial water table not indicated in the vegetation derived DCA axis 1 plot which, according to the prevalence of monocotyledonous remains, suggests a period of dryness interspersed by short lived returns of the water table to its original level. The Monocotyledonae involved are the hydrophilous *R. alba* and *E. vaginatum*, a plant capable of maintenance within pool habitat but more usually attributed to dry or disturbed raised bog states. Similarly, towards the top (< 62 cm) of the stratigraphy, we see apparently drier conditions in the DCA axis 1 plot according to the prevalence of Monocotyledonae, whereas the testate amoebae indicate wet conditions and this is supported by the appearance of aquatic Sphagna.

Accordingly, the vegetation derived water table model for this site reveals the possibility of inherent error, derived through the wide ecological amplitude of Monocotyledonae and *S. imbricatum*. In addition, the DCA analysis appears not to have given sufficient weight to the more hydrophilous *Sphagnum*; *S. auriculatum* and *S. cuspidatum*, resulting in a complacent water table signal from this genus.

4.4.5 Coalburn Moss

After the short phase of dominance by *S. capillifolium* (288 cm to 300 cm; Figure 4.1.4), associated with a modelled water table depth of *c.* -5 cm, the water table gradually recedes to lie in the range of -10 cm to -15 cm (Figure 4.4.7) by mid-phase of the *S.* sect *Acutifolia* - *S.* sect. *Sphagnum* community, present between 242 cm and 134 cm. During this period of water table recession, *H. subflava* comes to dominate the microfauna (see Figure 4.4.8), a species that has been regarded by as indicative of drained sites in Finland (Tolonen *et al.*, 1994) and widely, as preferential to high moisture levels (see Woodland. 1996, for example). Such moisture levels are maintained most efficiently in the hummock species prevalent during these two phases in times of summer drought which results in a hydrological inversion with wet hummocks and dry pools (Barkman, 1992).

The peak of *A. flavum* at 184 cm during the *S.* sect *Acutifolia* - *S.* sect. *Sphagnum* phase indicates the driest point in the history of Coalburn Moss with a calculated water table of -15 cm. From this point onwards the water table rises, as revealed most cogently by the decrease of *H. subflava* and increase in *A. discoides*. When this latter species reaches its greatest abundance at 32 cm, the water levels are indicated to range between superficiality and a depth of *c.* -1 cm. Xeroindicative *B. indica*, *Euglypha rotunda* and *N. militaris* are also present with *A. discoides* during this phase and these former species may derive from hummocks indicated by *C. vulgaris* remains or indicate periods of summer drought.

The microfauna antecedent to the contemporary condition, from 32 cm onwards, indicates a fall in the water table from superficial levels to those in the range of -5 cm to -9 cm. This period sees the replacement of *A. flavum* and *A. discoides* by *E. ciliata* and *Nebela* spp. These latter species are generally indicative of hummocks and reflect the drier conditions prevailing upon Coalburn Moss as a consequence of drainage and/or post-Little Ice Age climate change.

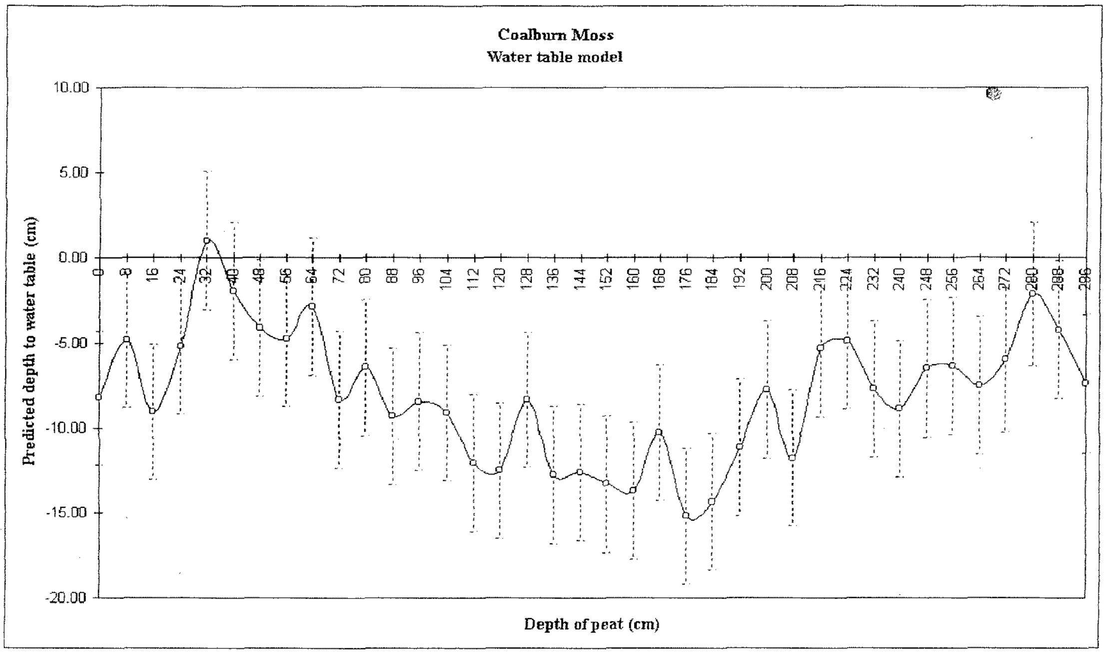

Figure 4.4.7 Water table - depth model for Coalburn Moss.

Discrepancy is found between the hydrological reconstructions of the testate amoebae (Figure 4.4.7) and the macrofossil derived DCA axis 1 (Figure 4.2.8). The testate amoebae derived model suggests the following sequence; wet, dry, wet, whereas that of DCA axis 1 is; dry, wet, wetter. The latter's derivation is largely based on the abundance of 'dry' indicator, *S. capillifolium* and 'wet' indicator, *S. cuspidatum*. In addition, it is suggested that in this case at least, when *S.* sect. *Acutifolia* is in association with *S.* sect. *Sphagnum*, the latter is more prevalent upon hummock tops. However, due to its later association with *S. cuspidatum*, in its lawn form (Flatberg, 1986) it is scored within the DCA analysis as a 'wetter' taxon. The presence of hummocks during the phase of *S.* sect *Acutifolia* - *S.* sect. *Sphagnum* codominance is attested to by the abundance of hummock

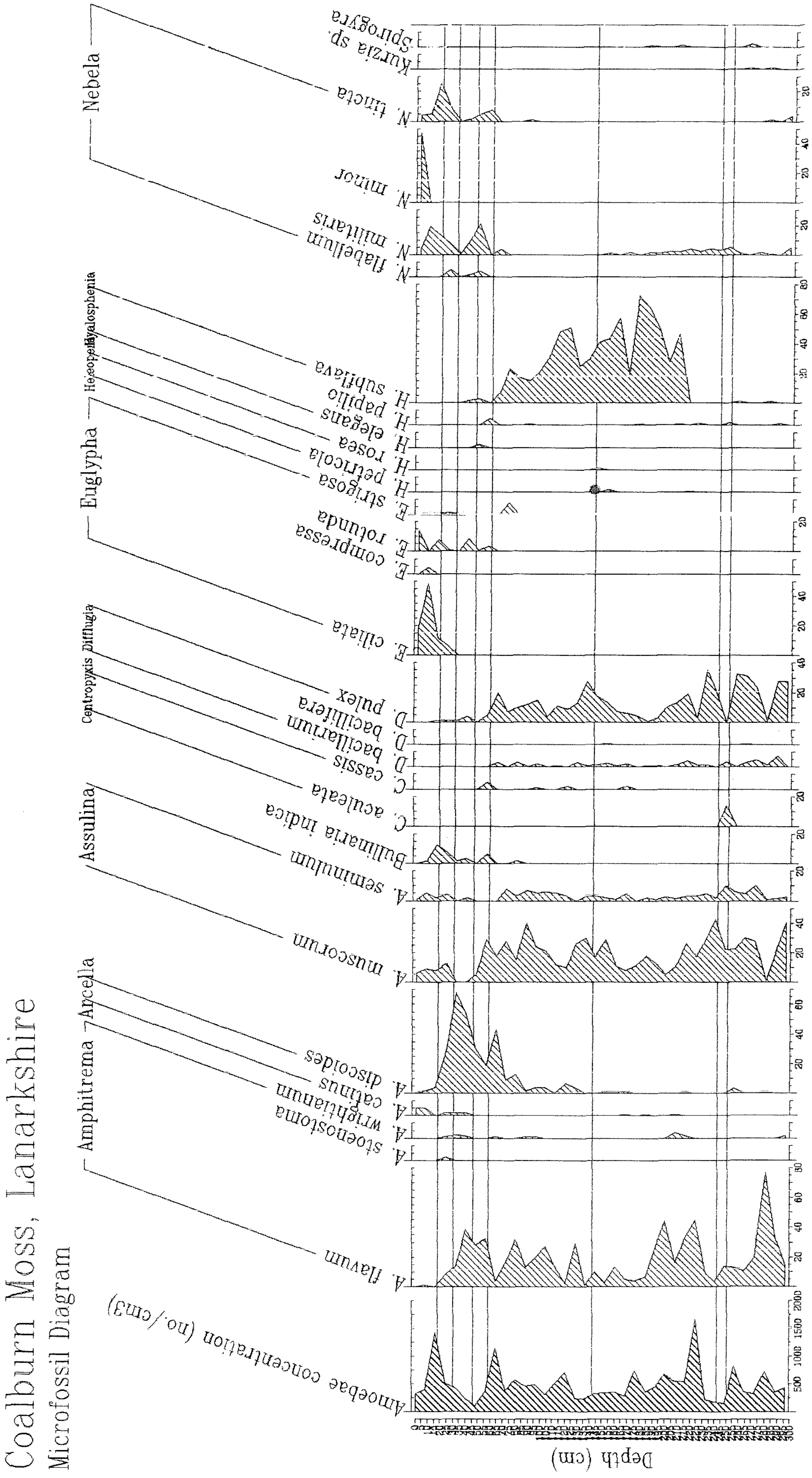

Figure 4.4.8 Coalburn Moss microfossil diagram.

indicators; *A. flavum*, *A. muscorum* and *D. pulex* (Figure 4.4.8). The absence of the more xeroindicative *Bullinaria indica* and *T. arcula* until *S.* sect. *Sphagnum* becomes codominant suggest that the *S.* sect *Acutifolia* hummocks were of low relief. In this instance it would appear prudent to disregard the vegetation derived water table model due to the dimorphism of *S. imbricatum* and accept instead that of the testate amoebae. This emphasises the importance of multi-proxy studies and how their discrepancies can reveal ecological intricacies.

4.4.6 Cranley Moss

The water table reconstruction for Cranley Moss initially shows a relatively stable hydrology fluctuating between -4 cm to -6 cm, until 128 cm stratigraphic depth (Figure 4.4.10). Throughout this period *A. flavum* maintains dominance in association with *Assulina* spp. (Figure 4.4.9) and these species collectively reflect the presence of wet *S. capillifolium* hummocks (Figure 4.1.5). Other, commonly present but sporadic species, *B. indica*, *D. pulex* and *T. arcula* indicate the hydrological variability tending towards dry but with wetter areas and/or times indicated by *A. discoides*.

The decreasing water table between 96 cm and 128 cm, coincident with a peak of *H. subflava*, appears to have been instigated by the appearance of *E. vaginatum*. This may indicate the localised development of a *S. imbricatum* hummock in association with the *E. vaginatum* tussock. Alternatively the *E. vaginatum* tussock may be the habitat from which the tests composing the peak of *H. subflava* were derived but no research on the residence of testate amoebae within such structures appears to be available. However, the regular coincidence of *E. vaginatum* with dry spikes in the testate amoebae derived water table models throughout this study suggests that this species offers an alternative, relatively xeric environment to the testate amoebae when compared with that of the *Sphagnum* carpet.

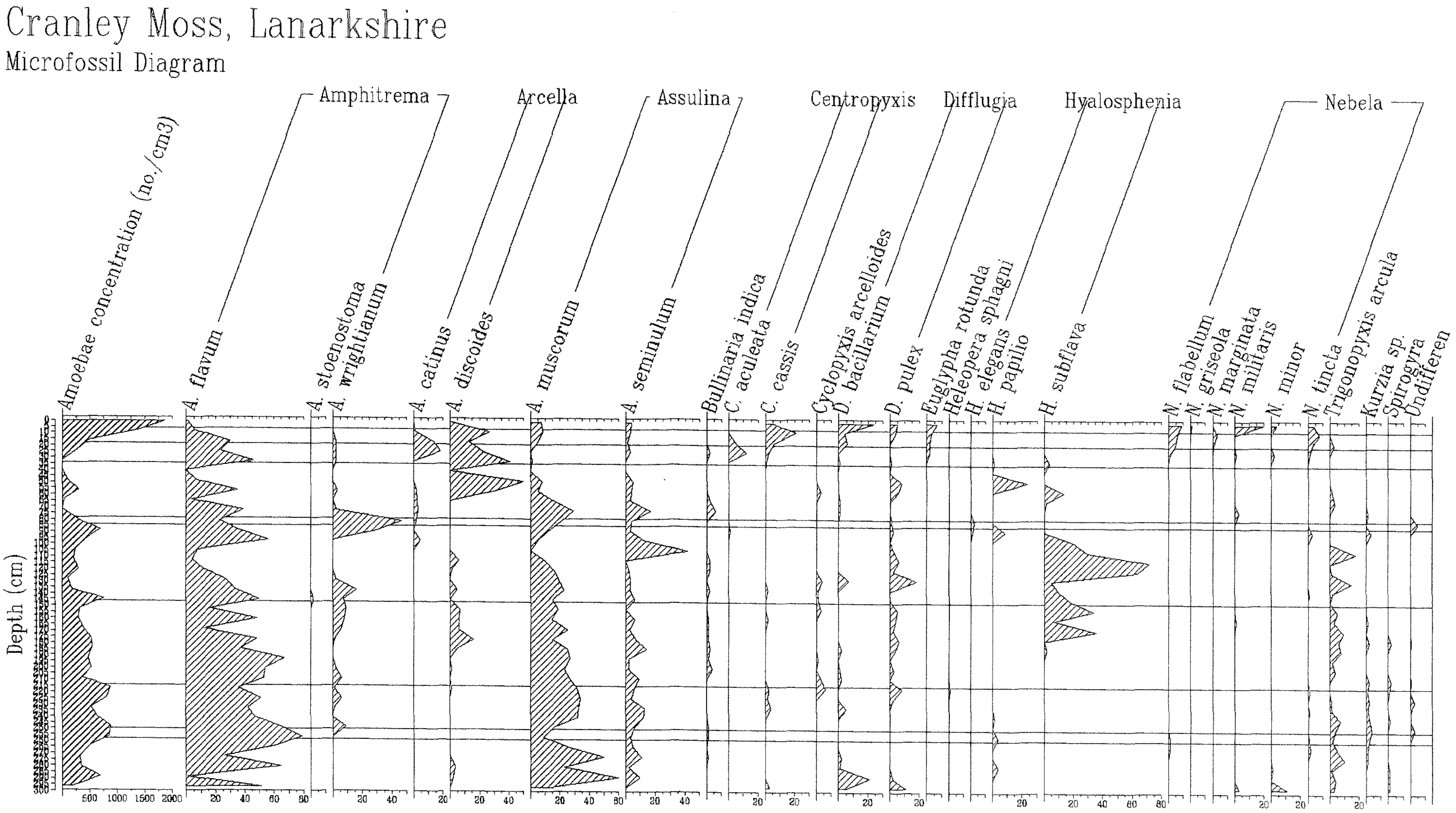

Figure 4.4.9 Cranley Moss microfossil diagram.

Throughout the period of dominance by *S. auriculatum*, between 32 cm and 80 cm depth, no hydroindicative testate amoebae species are present. This suggests that such species are intolerant of the temporary ponding of water that *S. auriculatum* may endure. It can also be suggested that the testate amoebae derived water table model at such points may be more indicative of the temporal balance between wet and dry conditions than the actual position of the water table position.

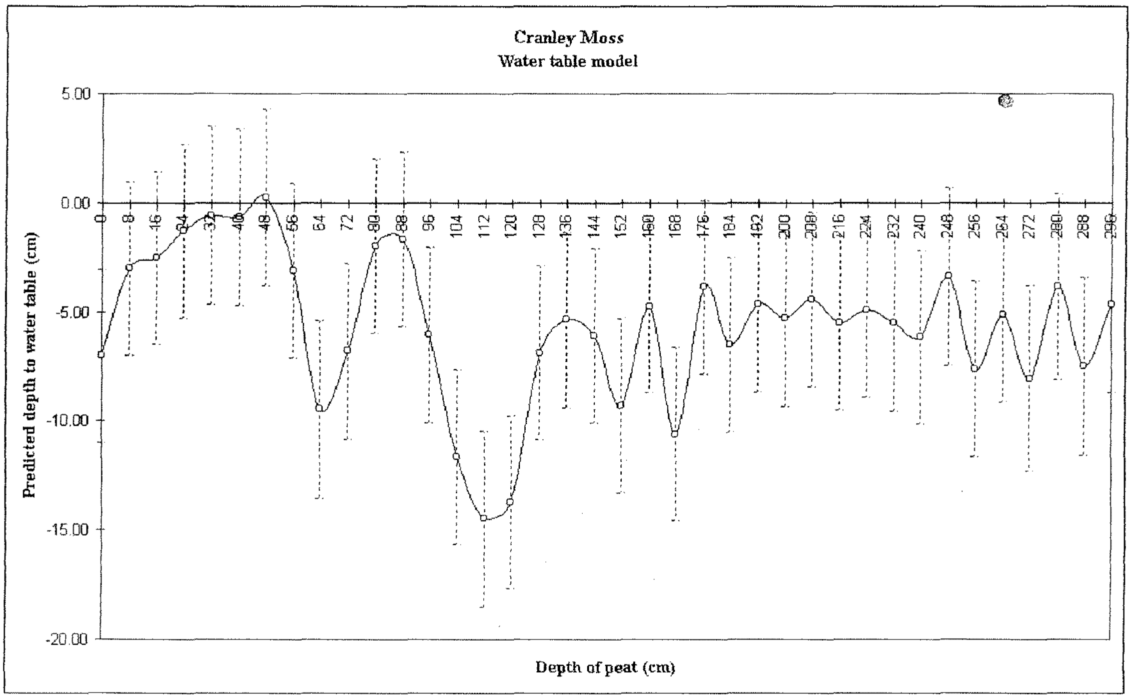

Figure 4.4.10 Water table - depth model for Cranley Moss.

At 48 cm stratigraphic depth the water table is shown to briefly reach superficial levels and this is reflected in the rise to dominance of *S. auriculatum* which is subsequently replaced by *S. cuspidatum* as water table levels remain consistently within -2 cm from the surface until 24 cm stratigraphic depth. As at Coalburn Moss, this upturn in the testate amoebae derived water table is largely attributable to the presence of *A. discoides*, but now in a more equable association with *A. flavum*. Following this peak we see a decline in the abundance of both these species as the predicted water table model falls to -7.0 cm. In their place we encounter the same assemblage of predominantly dry species as that currently found on neighbouring Coalburn Moss.

Good agreement is found between the DCA axis 2 plot (Figure 4.2.11) for dryness and the testate amoebae derived water table model (Figure 4.4.7). However, the dry phases recorded by the testate amoebae between 56 cm to 80 cm and 96 cm to 128 cm are not indicated in the vegetation derived model. The dimorphic *S. imbricatum* may be the primary cause of this but in addition it is prudent to consider a sub-threshold change of water table, in terms of the prevailing plant communities. A slight vegetation response may be seen in the disappearance of *S. capillifolium* between 96 cm and 128 cm but this is also seen at Coalburn Moss and may be related to another environmental variable.

Antecedence of the testate amoebae response to hydrological change is seen at 48 cm when these taxa record a superficial water table, but not until 36 cm is this indicated within the vegetation derived, DCA axis 2 plot, according to the score generated for *S. cuspidatum*. This lag in the vegetation response may be due to the water table rise initially being below the threshold requiresd for the vegetation to respond. In addition, this vegetation change may have been buffered by the phenotypic plasticity of *S. imbricatum*.

4.4.7 Deer Dyke Moss

The modelled water table (Figure 4.4.12) of this physically enclosed bog indicates relatively little long term change until more contemporary levels when anthropogenic influence becomes a dominant and important factor. However, short term fluctuations in the testate amoebae derived water table model are present, in the range of -1 cm to -6 cm. Dips to -6 cm are primarily attributable to peaks of *A. muscorum* and to a lesser extent; *D. pulex* and *T. arcula* (Figure 4.4.11). Some of these dips are also coincident with peaks of *E. vaginatum* and/or other monocotyledonous remains suggesting that the testate amoebae are responding to the presence of these taxa rather than

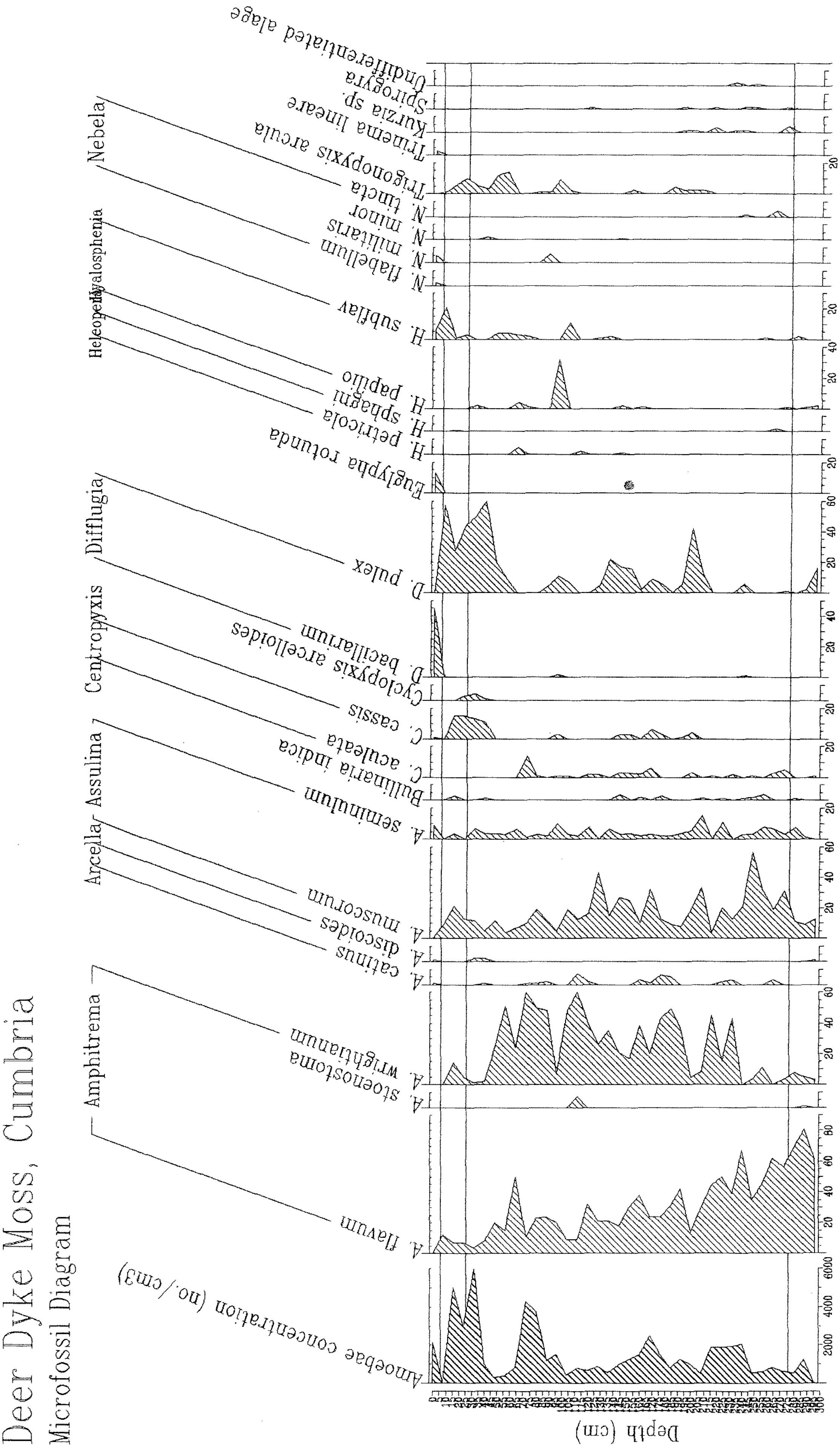

Figure 4.4.11 Deer Dyke Moss microfossil diagram.

the water table. If this is the case then the water table has naturally remained close to the vegetation surface of this bog throughout the late Holocene.

Marked hydrological change is restricted to the top 64 cm of stratigraphy at which point the predicted water table recedes from the surface to lie at -11.2 cm by 8 cm, stratigraphic depth. This perturbation is coincident with a layer of charcoal and Unidentified Organic Matter, the latter derived at least in part from the former, but also via drainage induced mineralisation. The burning event at 60 cm stratigraphic depth sees the emergence of *D. pulex* as a dominant species in association with the strongly xerophilous, *T. arcula*. The concomitant emergence of *C. cassis* may further indicate the presence of shallow, ephemeral pools on the compacted peat of the acrotelm the hydrology of which this genus can tolerate by encysting (Woodland, 1996).

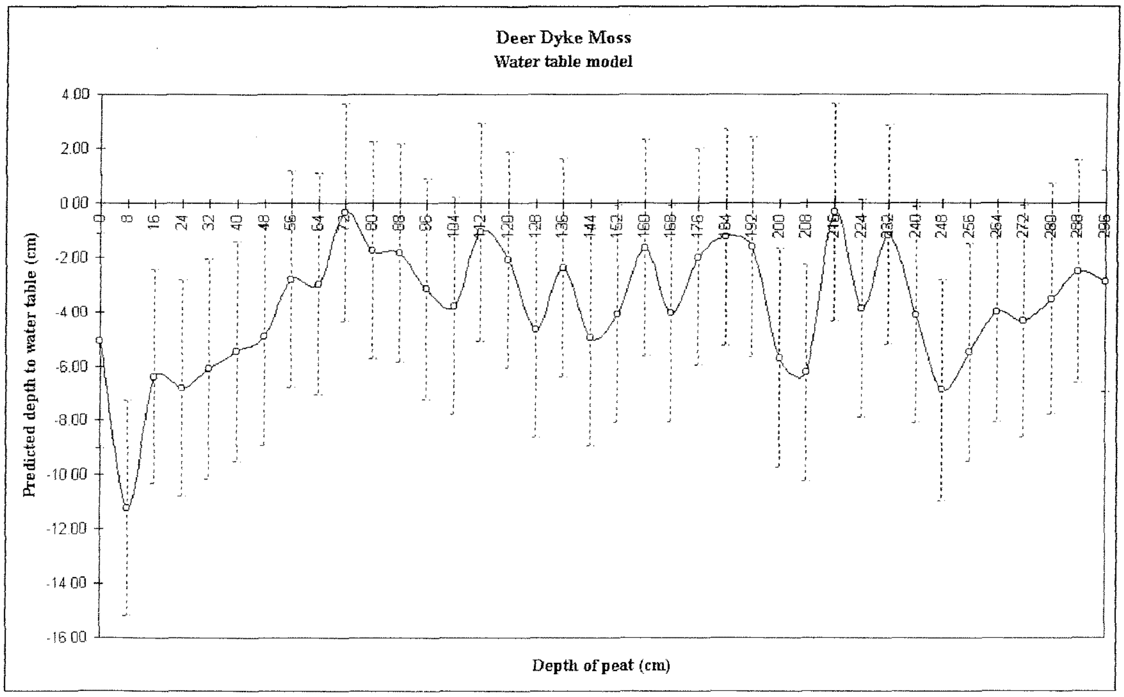

Figure 4.4.12 Water table - depth model for Deer Dyke Moss.

A final peak of UOM at -4 cm to -8 cm depth encompasses very poor preservation of the tests with values as low as 77.5 amoebae.cm^{-3} at the latter level. This surface is that upon which the contemporary biota has recently developed following restorative management of the moss and the model derived from this restored biota indicates an up turn in the water table to -5.1 cm. The presence of *D. bacillarium* as a dominant probably indicates consistently wet conditions (*cf.* Woodland, 1996) despite the low levels of *Sphagnum* cover currently extant.

Both the DCA axis 2 plot (Figure 4.2.14) and the testate amoebae derived water table model record a relatively complacent hydrological signal attesting further to the buffering effect of this site's physical enclosure on three sides. The vegetation derived, DCA axis 1 model appears, as before, more spikey due to the appearance of short-lived peaks of Monocotyledonae within plant communities otherwise dominated by *Sphagnum*.

Some discrepancy between the vegetation and testate amoebae derived water table models does exist in more contemporary levels. The testate amoebae show a consistent drop in the water table from 64 cm stratigraphic depth towards the surface whereas this feature is not seen in the DCA axis 2 plot until 32 cm. This suggests that the changes recorded by the testate amoebae were initially below the threshold of the then dominating plant community and/or buffered by the phenotypic plasticity of *S. imbricatum*.

The most contemporary testate amoebae sample indicates post-management recovery of the water table but this is not reflected in the DCA axis 2 plot with depth. The degree of secondary mineralisation in these layers has reduced the abundance of all constituent plant taxa and their replacement by Unidentified Organic Matter has resulted in dry scores in the DCA .v. depth plot.

4.4.8 Mullenakill Bog

Unusually, the superficial water table between 272 cm and the base of this stratigraphy, indicated by the testate amoebae derived water table model (Figure 4.4.14), is not accompanied by a corresponding peak of *S. cuspidatum*. The presence instead of *S. tenellum* (Figure 4.1.7) indicates that the plant community may have, at least locally, developed as a wet lawn in this instance. Following this superficial phase dominated by the testate amoebae *A. wrightianum* (Figure 4.4.13) the water table gradually recedes to its lowest value of -8.2 cm at 208 cm depth. This dip corresponds to a peak of *A. muscorum* undoubtedly resident in the coexistent, low hummock of *S. capillifolium*.

Following recession, the water table gradually rises back to within -2 cm off the surface and the fauna is again dominated by *Amphitrema* spp., *Assulina* spp., *D. pulex* and *N. militaris*. These species are present throughout most of the stratigraphy and are now accompanied by a diverse assemblage of taxa appearing sporadically at low values. The change in water table depth is described predominantly by the decrease of xerophilous *D. pulex* relative to the increase of hydrophile, *A. wrightianum*. This trend continues unabated until *c*. 24 cm stratigraphic depth. At this point *Amphitrema* spp. fall to very low values to the concomitant rise of *D. pulex* and *A. discoides*. The latter species rise synchronously and this is reflected in the water table model which is seen to dip sharply at 16 cm depth before recovering from this point to reach -3.1 cm at the surface of the stratigraphy. This latter sequence is probably attributable to restorative measures in and around Peatlands Park.

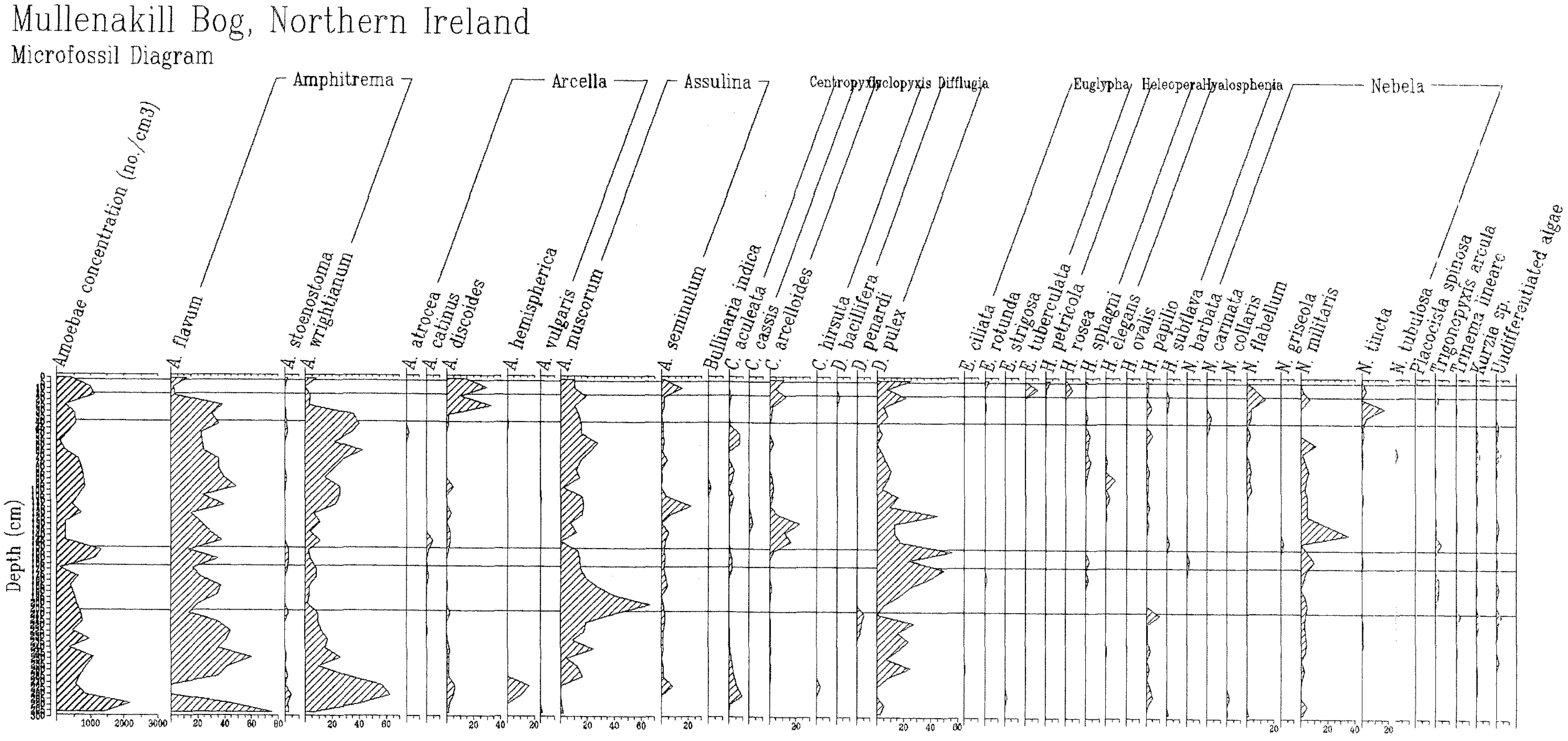

Figure 4.4.13 Mullenakill Bog microfossil diagram.

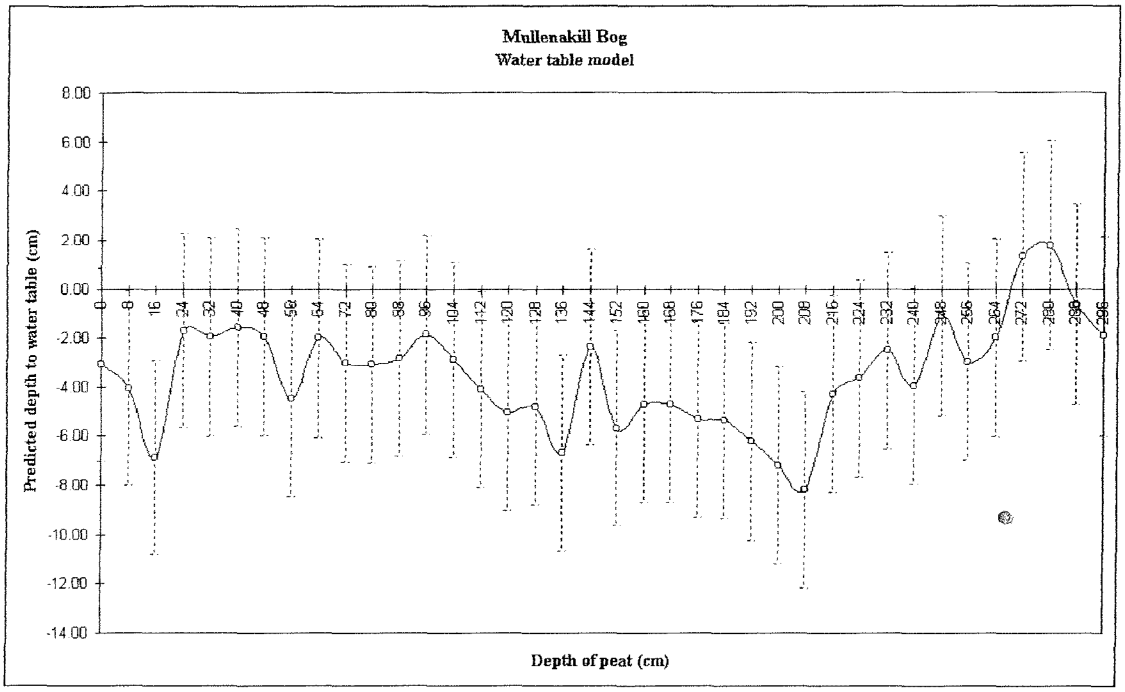

Figure 4.4.14 Water table - depth model for Mullenakill Bog.

Correspondence between the two water table models is good, although that derived from the vegetation derived DCA analysis (Figure 4.2.17) is rather constant, due to the consistent dominance of *S. imbricatum*, with only isolated dry peaks below 48 cm, stratigraphic depth. These peaks are to peaks of *E. vaginatum* which scores highly on the second DCA axis. Above 48 cm in the stratigraphy the testate amoebae derived water table model is much more complacent than that derived from the vegetation by DCA, when a phase of *S. cuspidatum* dominance is in evidence. It is normal for the testate amoebae to indicate that the water table is superficial prior to the expansion and rise to dominance of *S. cuspidatum* but in this instance such a feature is absent. The cause of this is not apparent in the absence of plant material indicating a bordering hummock so it may reflect the physiognomy of the *S. cuspidatum* raft or its temporal wet/dry balance.

Further peaks of *S. cuspidatum* at *c.* 80 cm and 204 cm are not picked up in either the testate amoebae derived water table model or the vegetation derived, DCA plot. It is not apparent why this should be although the presence of monocotyledonous remains may have added to the DCA scores, reducing the impact of those for *S. cuspidatum* and/or, been the source of hummock testate amoebae into the postulated pool or hollow. These hummocks would have been of low relief, according to the absence of *C. vulgaris*.

4.4.9 Wedholme Flow

The water table model (Figure 4.4.16) derived from the testate amoebae counts for Wedholme Flow is dominated by sharp peaks and troughs fluctuating throughout over the range of -1 cm to -10 cm. The statistical derivation of this feature is apparently attributable to the interplay between xeroindicative *T. arcula* and the hydrophilous, *Amphitrema* spp. (Figure 4.4.13). Initially, *T. arcula* is present at sporadically high percentages (<53%) and the water table is punctuated by several concomitant dips to *c*. -8 cm. The *Sphagnum* vegetation appears unresponsive to these changes but several peaks of Monocotyledonae are coincident with those of *T. arcula* suggesting that the testate amoebae may also be responding to vegetation forced changes in physiography.

The plateau of *A. wrightianum* and latterly, the peak of *A. discoides* lend their shape to the water table model between 108 cm and 164 cm. During this period the water table remains within *c*. -1 cm of the surface. This is interrupted by a fall in the water table at 104 cm associated with peaks of *D. pulex* and *T. arcula* and these two species combine again between 40 cm and 64 cm, with the same result.

After a brief rise to near surficial levels centred on 32 cm, attributable to an increase in *Amphitrema* spp. and *A. discoides*, the water table falls to -8.3 cm during the degeneration phase between 8 cm and 24 cm stratigraphic depth. This phase is dominated by xeroindicative species; *B. indica*, *A. seminulum*, *Difflugia* spp., *H. subflava* and *T. arcula* suggesting that peat accumulation as opposed to degeneration of an underlying, wetter phase may have been prevalent. The testate

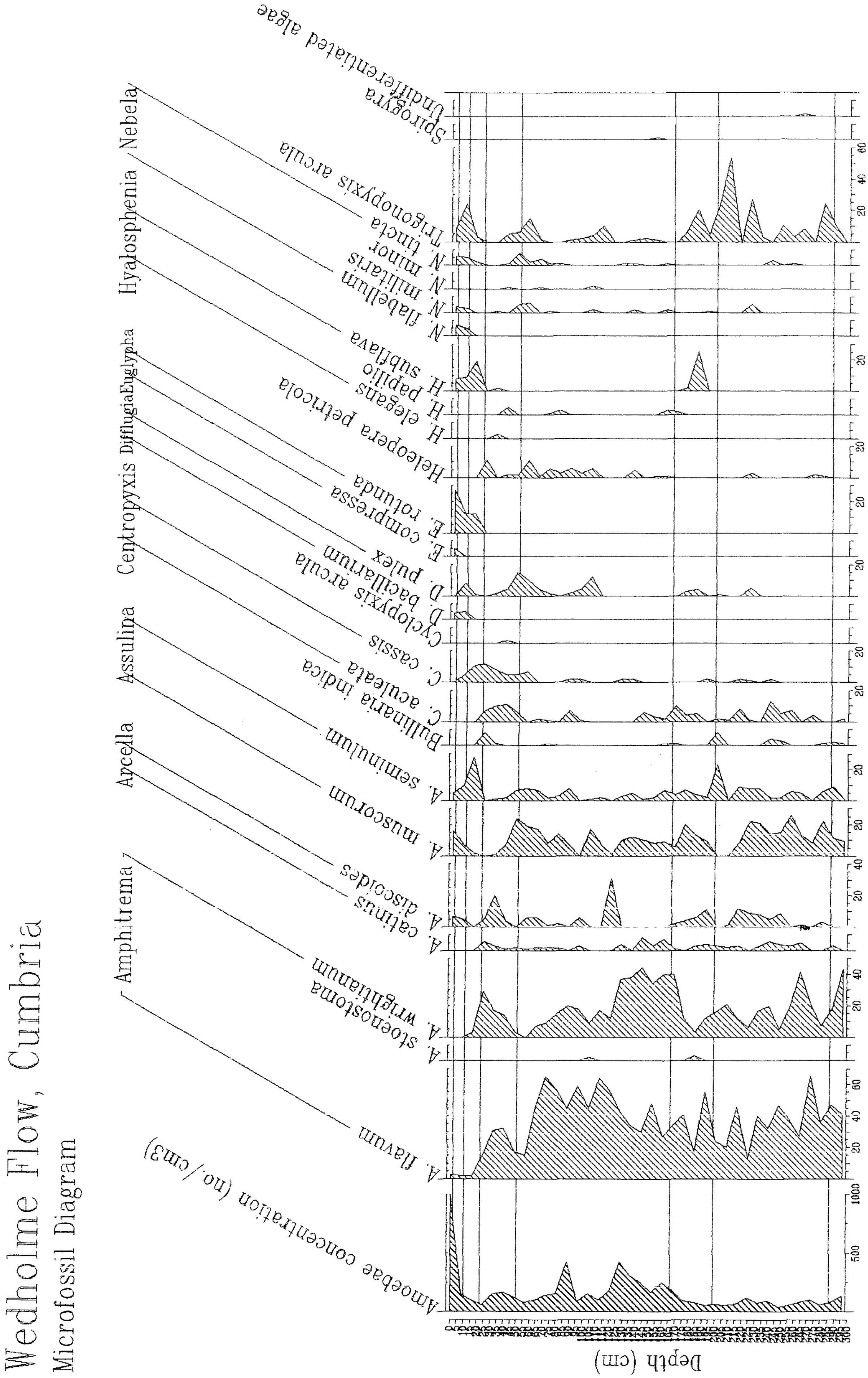

Figure 4.4.15 Wedholme Flow microfossil diagram.

amoebae derived water table is predicted to currently lie at -6.1 cm and this is determined by a diverse range of species most of which are typical of hummocks, i.e. *Assulina* spp., *D. bacillarium*, *Euglypha* spp., *Nebela* spp. and *T. arcula*. This is a crude average of the water table depths recently recorded on Wedholme Flow (*cf.* Bragg, 1992; Jackson, 1996). See section 5.2 for further details.

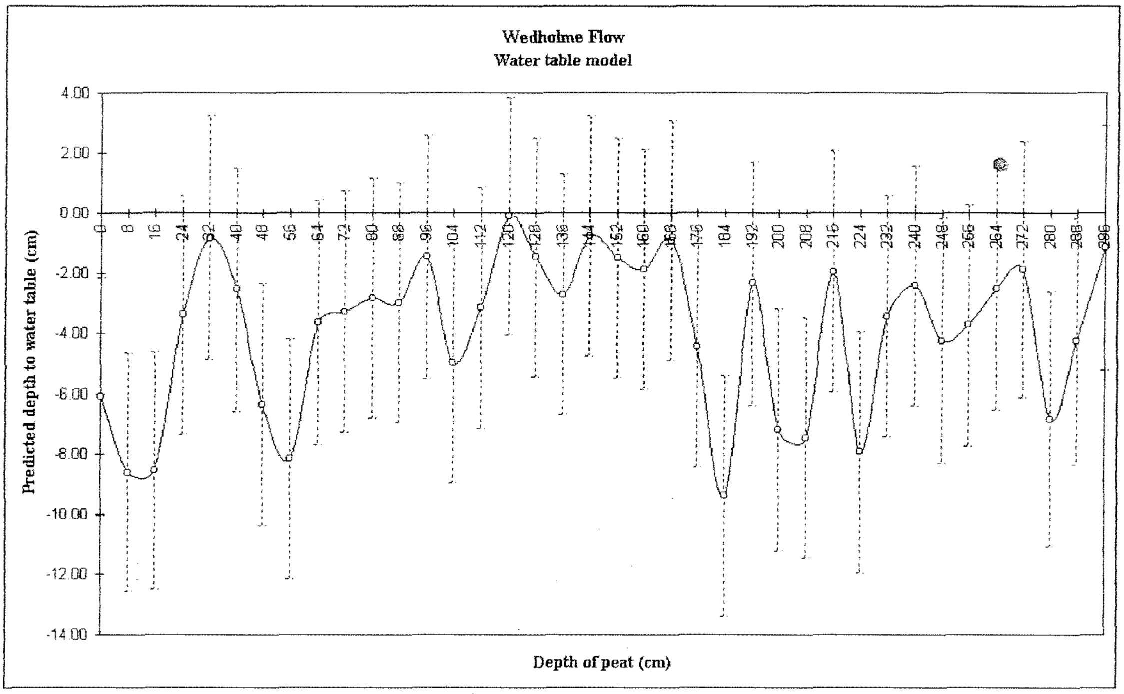

Figure 4.4.16 Water table - depth model for Wedholme Flow.

An almost perfect match is found between the testate amoebae derived water table model and the plot of DCA axis 1 with depth (Figure 4.2.17). The amplitude of the DCA axis 1 plot is rather more subdued except where *S.* sect. *Cuspidata* are present and most especially, the recent phase in which *S. tenellum* and *M. caerulea* were dominant. This due to their statistical rarity which results in the very low DCA axis 1 scores at this depth. Earlier in the stratigraphy, between 196 cm and 240 cm, the increases in moisture recorded by the vegetation derived DCA axis 1 .v. depth plot are of a smaller amplitude in comparison to those at the surface. Here, *S. tenellum* is again present, but now with *S. cuspidatum* and *S. imbricatum*. The latter species is probably reverting to its lax growth form here, gaining competitive advantage over *S. cuspidatum* and ultimately, masking the concomitant change in the water table as indicated more strongly by the testate amoebae.

Greater variation in the water table state is apparent between 48 cm and 172 cm in the vegetation based, DCA axis 1 water table model than in that derived from the testate amoebae data, when *S. auriculatum*, *S. cuspidatum*, *S. imbricatum* and *S. magellanicum* are variably present within the vegetation. To some extent, this may be due to the difference in sampling interval but it is also apparent that the *Sphagnum* community here comprises four species whose relative abundances change markedly at each sampling interval. It is assumed that the diversity and extremity of the species' shifts here give the DCA axis 1 .v. depth plot its amplitude and spikiness.

4.4.10 Wreaks Moss

The microfossil diagram constructed for Wreaks Moss (Figure 4.4.17) is immediately divisible into two hydrological zones; a dry lower phase dominated by *H. subflava* with *D. pulex* and an upper, wetter phase indicated by the presence of *Amphitrema* spp.. *A. muscorum* remains equably present throughout and *D. pulex* only dies out when the water table is indicated as almost surficial.

From 300 cm onwards, the abundant and at times, almost complete dominance of *H. subflava* indicates a low water table predicted to lie at *c.* -15.0 cm (Figure 4.4.18). This state persists until 224 cm when *H. subflava* initially falls to low figures before becoming extinct at 186 cm. Concurrently, *A. wrightianum* becomes present in the stratigraphy and by 192 cm water table model values are within -5.0 cm of the surface. Through the continued rise of *A. wrightianum* and the coincident low of *D. pulex* the water table model rises to just superficial levels at 72 cm stratigraphic depth. After this depth, *A. muscorum* and *D. pulex* become more abundant and the abundance of *A.*

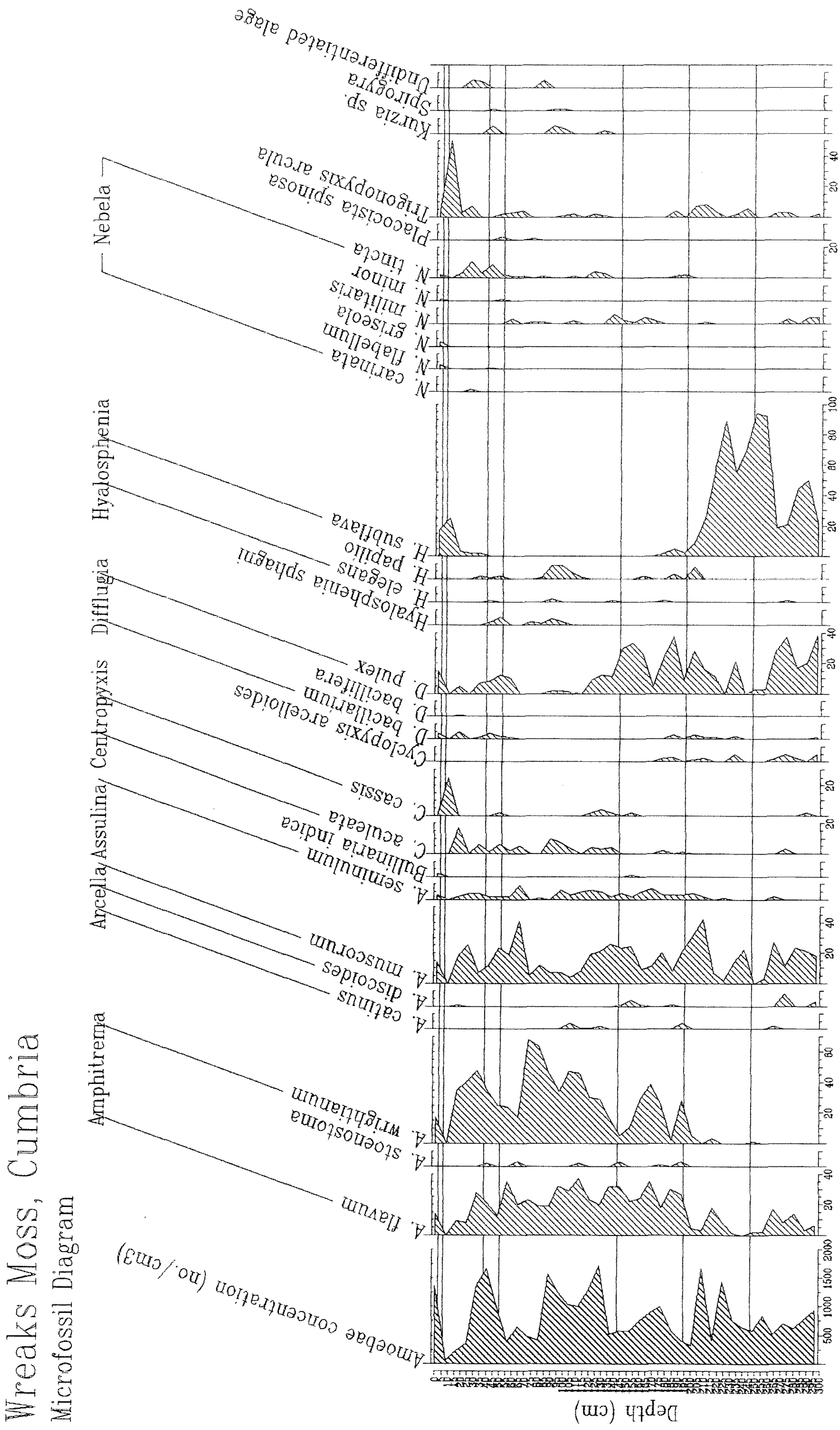

Figure 4.4.17 Wreaks Moss microfossil diagram.

wrightianum falls. This is reflected in the vegetation through replacement of *S. cuspidatum* by *S. auriculatum* this latter species probably indicating that the water table was in a state of bipolar flux.

Throughout the phase of UOM spanning from 8 cm to 40 cm stratigraphic depth the testate amoebae concentration falls dramatically but there is no apparent change in the water table. This suggests that this layer of UOM has been formed by degeneration of the upper peat layers post-formation rather than as a feature of slow peat accumulation under relatively oxic conditions. The sharp decrease in this peak of UOM and upturn in the depth of water table in contemporary layers indicates no small degree of hydrological recovery for Wreaks Moss. The extant testate amoebae assemblage is primarily composed of those species that have predominated throughout the stratigraphy, namely; *Amphitrema* spp., *A. muscorum*, *A. seminulum*, *D. pulex* and *H. subflava*.

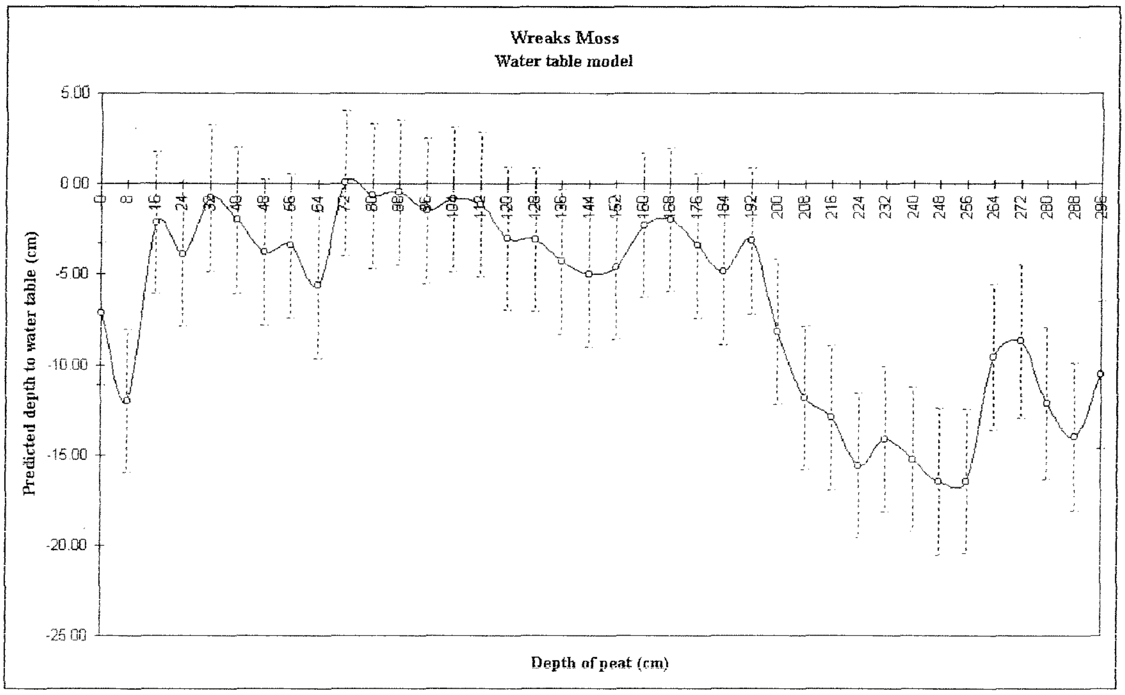

Figure 4.4.18 Water table - depth model for Wreaks Moss.

The history of peat cutting and scrub invasion on this moss has resulted in divergence of the DCA axis 1 plot with depth (Figure 4.2.21) from the testate amoebae derived water table model. A high amount of Unidentified Organic Matter in the stratigraphy between 6 cm and 42 cm has resulted in large scores for this on DCA axis 1. By comparison, the testate amoebae indicate that this is a wet phase so it is assumed that an original peat layer has undergone considerable secondary mineralisation within the observed limits.

In the macrofossil diagram (Figure 4.1.9), *S. cuspidatum* becomes consistently present between 56 cm and 142 cm. The testate amoebae derived water table model records a rise of the water table to surficial levels during this phase but this is not indicated in the vegetation-based DCA axis 1 .v. depth plot which indicates no hydric difference between this phase and the preceding one, wholly dominated by *S. imbricatum*. Only towards the end of the phase are there two "wet" peaks, corresponding to those of *S. cuspidatum*, indicated at 68 cm and 80 cm.

A dry peak in the DCA axis 1 .v. depth plot, determined by the presence of *E. vaginatum*, is also recorded synchronously in the testate amoebae derived water table model. Further synchronicity is seen in the abrupt onset of wet conditions that give rise to the *Sphagnum* based vegetation in this stratigraphy at 242 cm.

4.5 DATING

4.5.1 Radiocarbon dates

The radiocarbon dates presented below from Arnaby Moss, Cranley Moss and Mullenakill Bog were determined to permit calculation of the rates of peat accumulation and transition between one community's phase and the next. These calibrated dates and the uncalibrated radiocarbon ages are presented below in Table 4.5.1.

Depth (cm)	Radiocarbon Reference	Radiocarbon Age (BP)	Calibrated Error -	Calibrated Mid-point (BP)	Calibrated Error +
Arnaby Moss					
36	SSR-6160	675 ± 40	115	665	25
44	SSR-6161	795 ± 40	30	700	90
148	SSR-6162	1680 ± 45	90	1600	110
168	SSR-6163	1900 ± 45	120	1850	90
204	SSR-6164	2265 ± 45	100	2250	100
212	SSR-6165	2520 ± 40	150	2620	140
272	SSR-6166	2775 ± 40	90	2870	110
Cranley Moss					
24	SSR-6154	Modern carbon			
80	SSR-6155	1525 ± 40	70	1410	110
88	SSR-6156	1875 ± 45	120	1830	100
208	SSR-6157	3260 ± 45	90	3480	180
216	SSR-6158	3005 ± 45	270	3320	40
280	SSR-6159	3840 ± 45	140	4270	130
Mullenakill Bog					
20	SSR-6167	Modern carbon			
52	SSR-6168	1790 ± 40	90	1650	130
60	SSR-6169	1620 ± 45	100	1530	140
124	SSR-6170	2780 ± 45	120	2870	90
140	SSR-6171	3085 ± 45	120	3280	110
192	SSR-6172	3535 ± 45	150	3780	90
200	SSR-6173	3470 ± 45	160	3700	70
228	SSR-6174	3745 ± 45	130	4140	160

Table 4.5.1 Summary table of the raw radiocarbon data and derived range of calibrated, calendar dates expressed as years BP (Before Present). Upper and lower probability limits expressed at 95.4% (2 δ). Results produced by the OxCal program (Bronk Ramsey, 1994).

4.5.2 Rates of peat accumulation and phase transition

The radiocarbon dates obtained for the three stratigraphic sections provide temporal data for six of the communities recognised in section 4.4, namely; the Callunetum, Degradation Phase, Heterogeneous *Sphagnum* Lawn, Homogeneous *Sphagnum* Lawn, *S. auriculatum* - *Polytrichum* Lawn and the *S. capillifolium* Lawn and Hummock. The rates of peat accumulation for each phase and type of transition derived from the age-depth models (figures 4.4.1 to 4.4.3) are presented below in Table 4.4.2 for each raised bog.

Community	Peat Accumulation Rate (cm.decade^{-1})	Transition
Arnaby Moss		
S. cuspidatum/auriculatum Lawn and Pool	na	
		C
Homogenous *Sphagnum* lawn	0.48	
		C
Expansion of Homogenous *Sphagnum* lawn	0.39	
		C
Callunetum	1.04	
		C
S. auriculatum - *Polytrichum* Lawn	0.64	
Cranley Moss		
S. cuspidatum/auriculatum Lawn and Pool	na	
		H?
Homo-/Heterogeneous *Sphagnum* Lawn	0.73	
		C
S. cuspidatum/auriculatum Lawn and Pool	0.67	
Mullenakill Bog		
S. cuspidatum/auriculatum Lawn and Pool	na	
		C
Heterogeneous *Sphagnum* Lawn	1.1'	
		C
Degradation Phase	0.80	
		C
Homogenous *Sphagnum* Lawn	0.90	
		H?
Heterogeneous *Sphagnum* Lawn	2.40	

Table 4.5.2 Rates of peat accumulation under some of the communities described within this study.

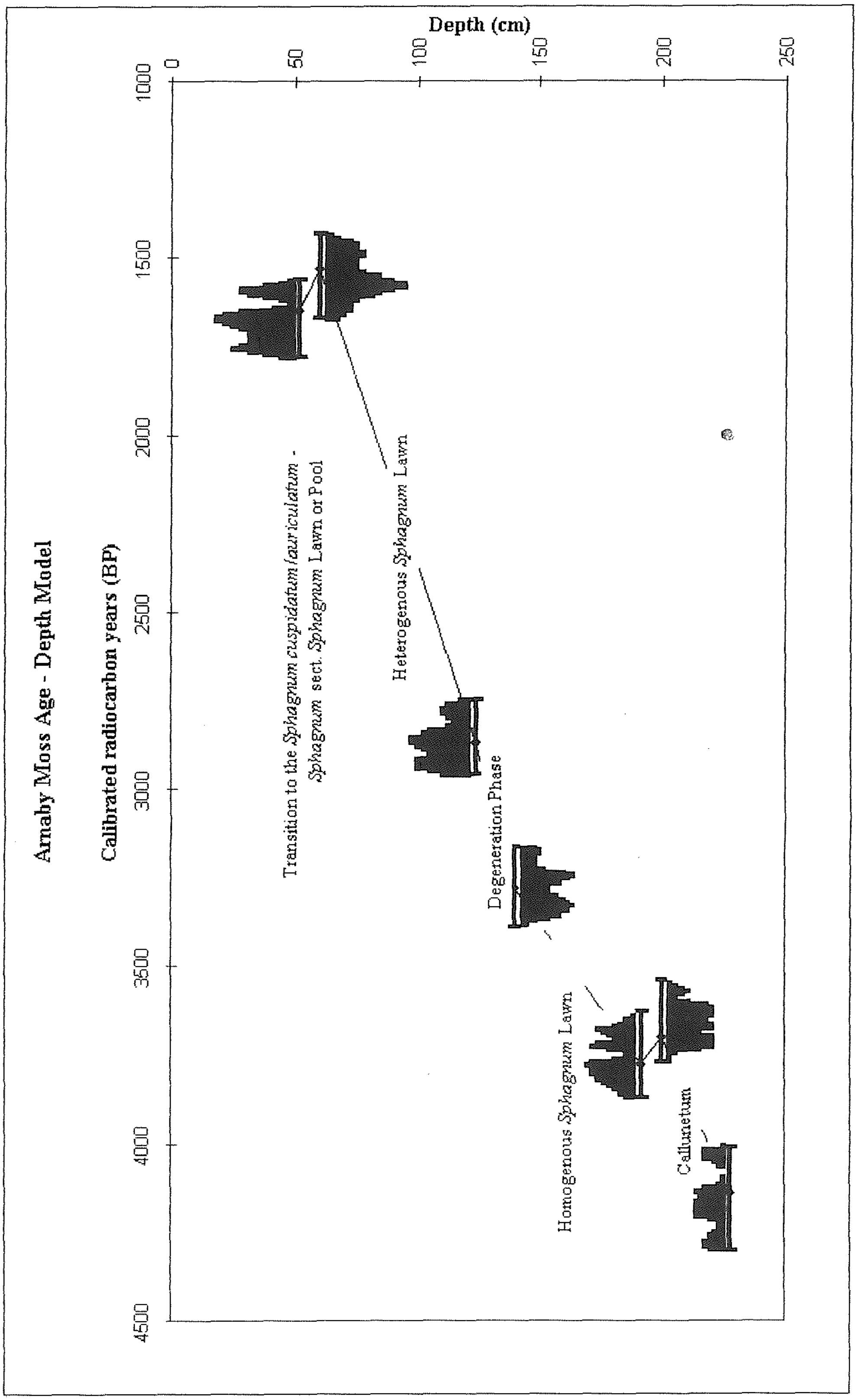

Figure 4.5.1 Age-depth model for Arnaby Moss. Probability distribution curves derived from OxCal appended to the error bars and the accepted date indicated by the position of each plotted point within these limits.

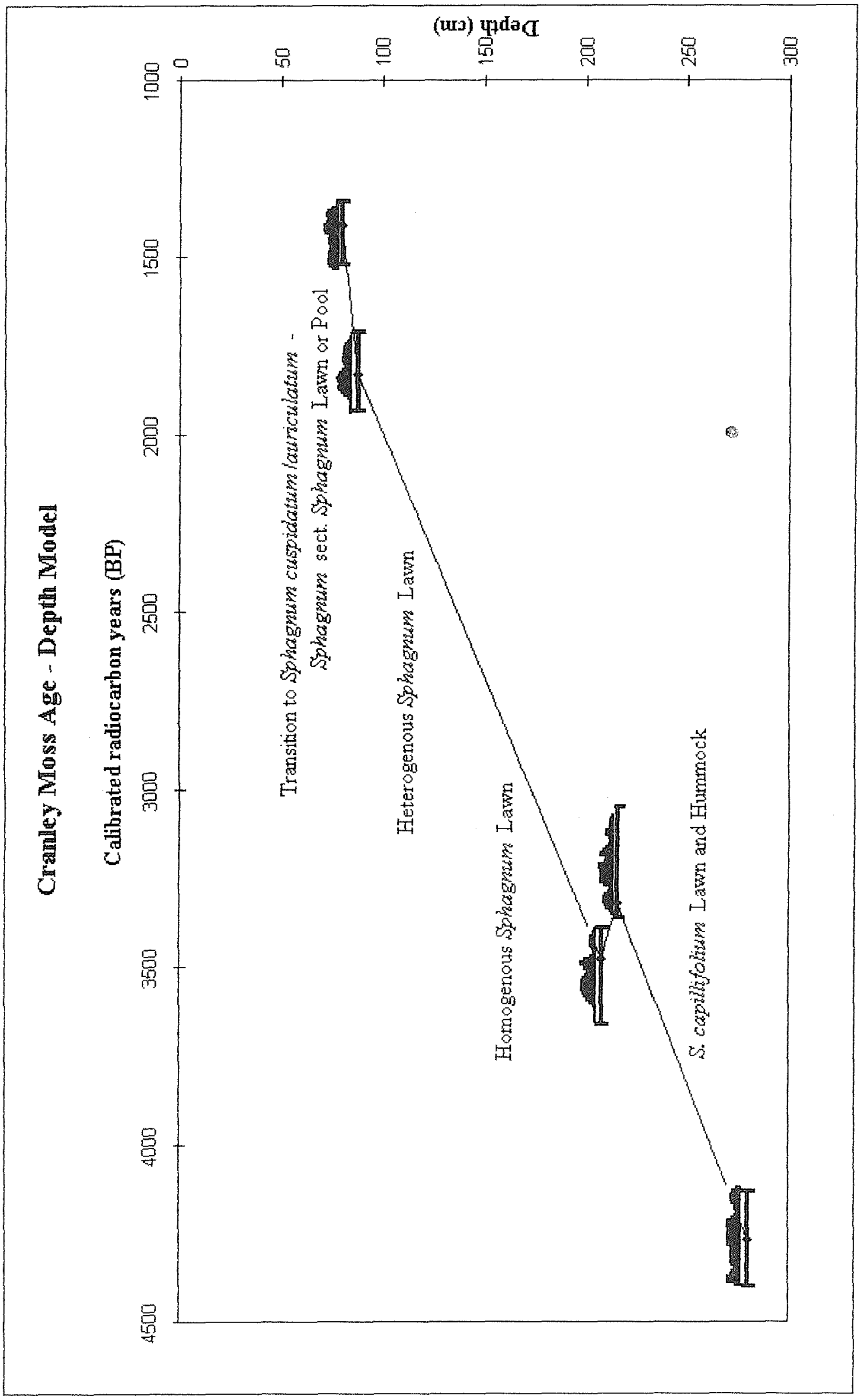

Figure 4.5.2 Age-depth model for Cranley Moss. Probability distribution curves derived from OxCal appended to the error bars and the accepted date indicated by the position of each plotted point within these limits.

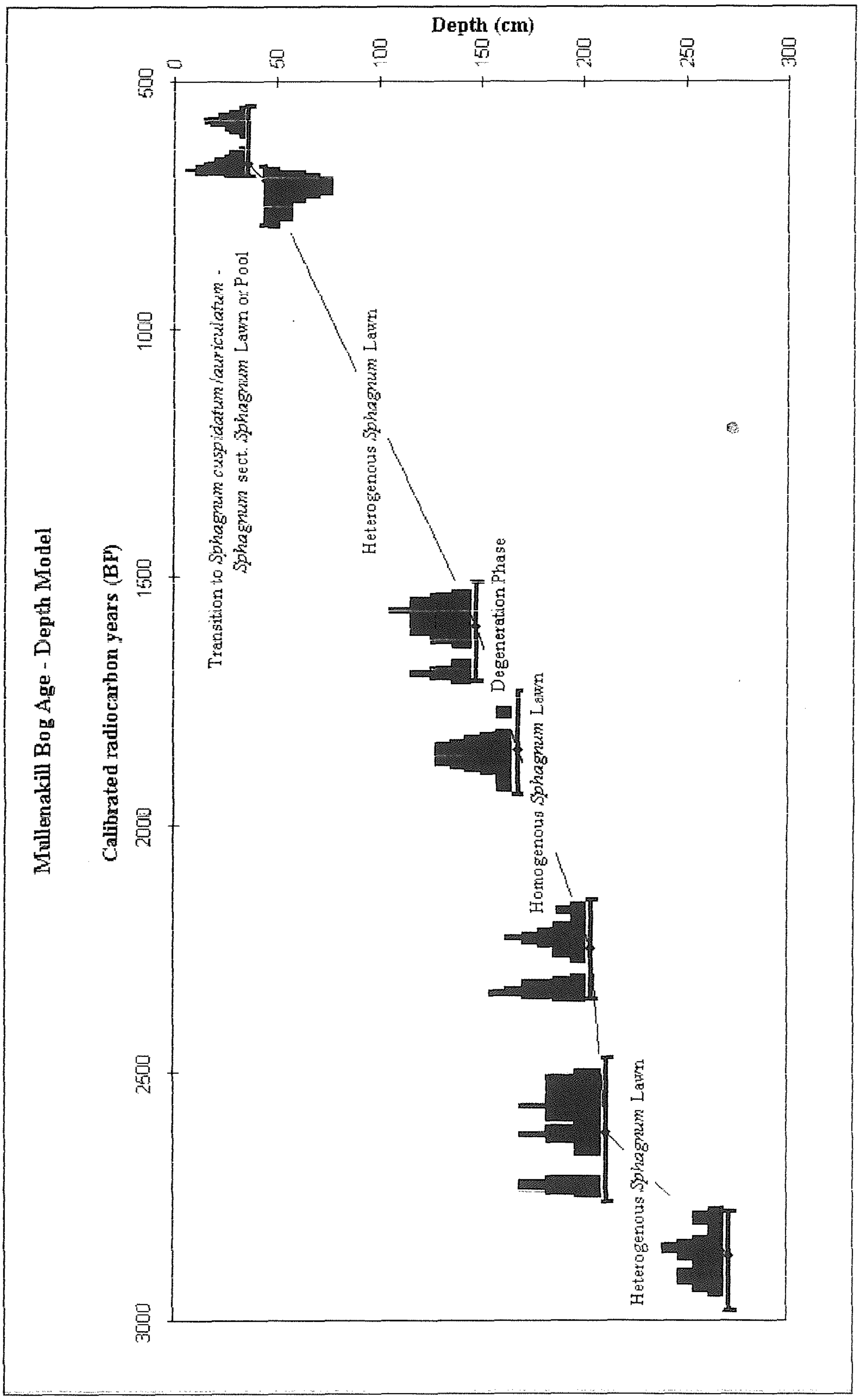

Figure 4.5.3 Age-depth model for Mullenakill Bog. Probability distribution curves derived from OxCal appended to the error bars and the accepted date indicated by the position of each plotted point within these limits.

The lowest rate of peat accumulation is found during the period of *S. imbricatum* expansion which succeeds a hypnaceous moss flora as the phase of Callunetum at Arnaby Moss ends. A cessation of bog growth might be expected to occur if the extinction of hypnaceous species exceeds the expansion of Sphagna and the overall abundance of peat forming taxa is accordingly reduced. Such a scenario might be considered under a rapidly rising water table which drowns out the hypnaceous species faster than *S. imbricatum* can expand and this is suggested by the testate amoebae derived water table model which rises rapidly from -14 .8 cm to -6.0 cm. This curve lags behind that of *S. imbricatum* and this is possibly due to the scarcity of *Sphagnum* and its favourable microenvironment for hydrophilous testate amoebae to inhabit during this heath-like phase for which the model was not developed.

The most rapid rate of peat accumulation is encountered during phases of the Heterogeneous *Sphagnum* Lawn from which values of 1.11 cm.dec^{-1} and 2.4 cm dec^{-1} are recorded from Mullenakill Bog. The latter figure appears erroneously high and a revised, minimum accumulation rate, calculated using the calibrated date limits, still gives a relatively rapid rate of 0.98 cm.dec^{-1}. An additional rate of peat accumulation for this community is derived from its conjoined dating with the Homogeneous *Sphagnum* Lawn at Cranley Moss where a figure, apparently intermediate between these communities, of 0.73 cm.dec^{-1} is indicated.

As indicated above, the Homogenous *Sphagnum* Lawn accumulates peat at a lower rate than the Heterogeneous *Sphagnum* Lawn with two values indicating the range 0.48 cm.dec^{-1} to 0.90 cm dec^{-1}. A third date for this community is that from its conjoined phase with the heterogeneous *Sphagnum* lawn and this gives a rate of 0.73 dec.cm^{-1}. The remaining Sphagnetum communities both have peat accumulation rates within the range shown by the Homogenous *Sphagnum* Lawn. The *S. auriculatum - Polytrichum* Lawn has an accumulation rate of 0.64 cm.dec^{-1} and the *S. capillifolium* Lawn and Hummock an accumulation rate of 0.67 cm.dec^{-1}.

Surprisingly the Callunetum and Degeneration Phase both indicate rates of peat accumulation equable to and exceeding that of some of the *Sphagnum* based communities. The Callunetum from Arnaby Moss, rich in hypnaceous moss species, is indicated to have accumulated peat at the rate of 1.04 cm.dec^{-1} and the single Degeneration Phase dated from Mullenakill Bog accumulates peat at the slightly lower rate of 0.8 cm.dec^{-1}. Interpretation of the latter's rate of peat accumulation is complicated by the indeterminable amount of oxidative mineralisation that may have penetrated into the preceding, less humified community. In this instance, the figure of 0.8 cm.dec^{-1} determined for the Degeneration Phase should be considered as a maximum rate of peat accumulation.

The appearance of a hiatus at 206 cm in Mullenakill Bog between the Heterogeneous *Sphagnum* Lawn and the Homogeneous *Sphagnum* Lawn is rather inexplicable and it may be the consequence of an indeterminable error since such a phenomenon is absent elsewhere. It would appear most reasonable to assume that the lower, transition date is too old and such an assumption would also reduce the very high rate of peat accrual under the Heterogeneous *Sphagnum* Lawn in this instance. A further, less marked hiatus occurs in transition to the *S. cuspidatum/auriculatum* Lawn and Pool from the preceding Heterogeneous *Sphagnum* Lawn, at Cranley Moss. This hiatus will be due, at least in part, to the apparent slowing down of peat growth as a consequence of the procumbent habit of *S. auriculatum.*

4.5.3 Palynological dating of Deer Dyke Moss

The first date of 1540 AD is inferred from the closure of Furness Abbey which saw an end to pastoral usage of the surrounding land and an increase in mixed farming concomitant with respective rises in the spores and pollen of *Pteridium aquilinum* and weed species (Oldfield, 1963). This date is indicated here at 34 cm depth, 4 cm lower in the profile than Oldfield's (1969) position. Unfortunately, the large amounts of Unidentified Organic Matter present in the macrofossil diagram throughout this stratigraphy means that it is unclear whether these different depths are due to differing rates of production and/or decomposition.

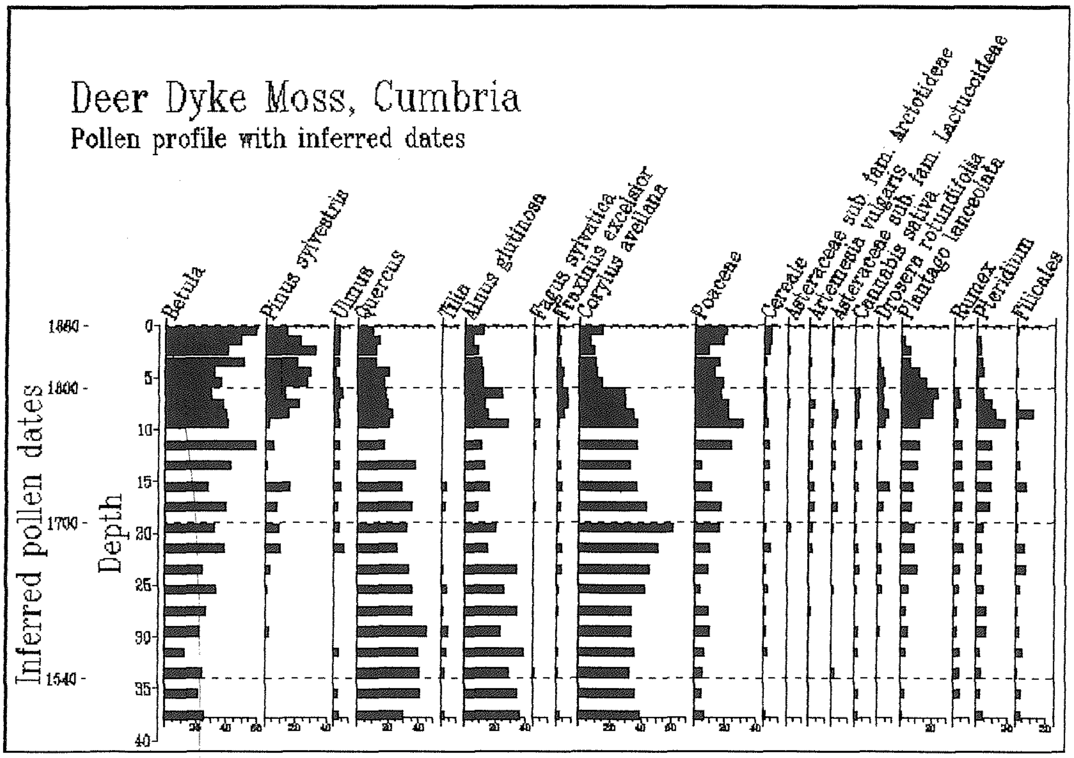

Figure 4.5.4 Pollen diagram produced to date the upper section of stratigraphy at Deer Dyke Moss with inferred dates as derived from the work of Oldfield (1969). Pollen counts presented as percentages of total, non mire taxa.

The stratigraphic position of 1700 AD is, in Oldfield's (1969) words, tentative and inferred from a decrease in woodland and wasteground taxa concomitant with a rise in agricultural indicators. I have placed this date at 19 cm based on the decrease of *Corylus avellana*, *Alnus glutinosa* and

Pinus sylvestris and corresponding increase in the ruderal Asteraceae species, *Plantago* spp. and *Rumex* spp.. Oldfield (1969) places this date a little higher in the stratigraphy at *c.* 17 cm but given the ambiguity of this determination it may be suggested that these depths are roughly comparable or subject to the same peat processes indicated above.

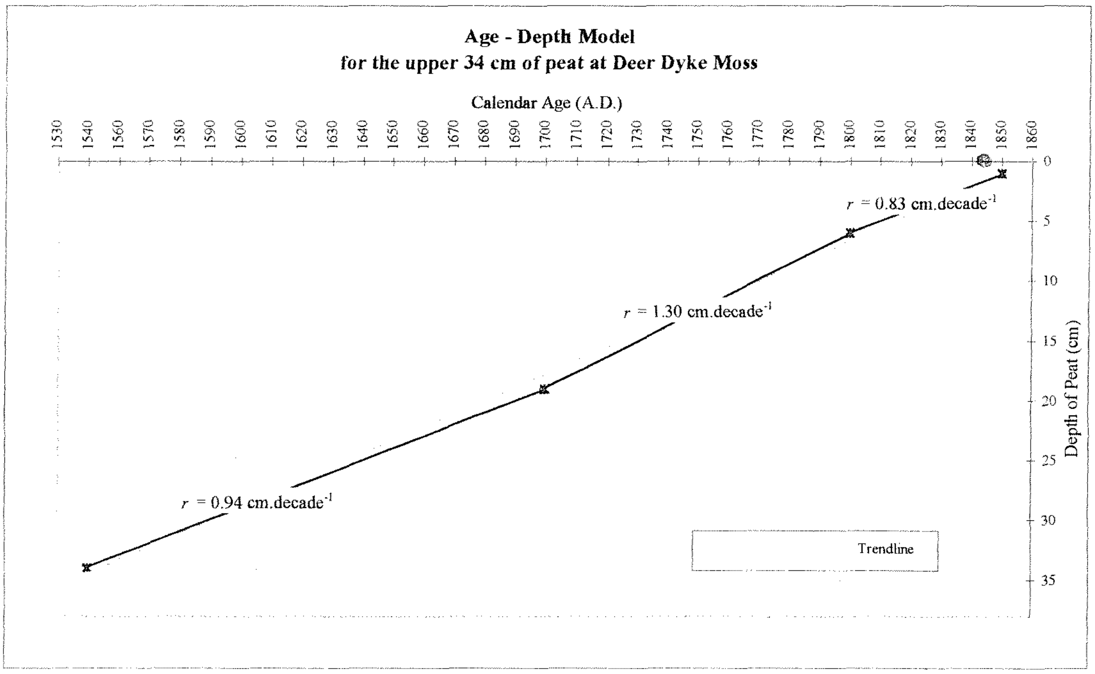

Figure 4.5.5 Age-depth model constructed for the upper 34 cm of stratigraphy at Deer Dyke Moss. 0 cm indicates the top of the catotelm peat and not the new growth accompanying restorative work to the water table.

The date of 1800 AD, placed here at 6 cm is the time of the "New Husbandry" (Oldfield, 1963), the onset of intensive, cereal based agriculture. In this instance it is indicated by a decrease in the pollen of *Cannabis sativa* (*cf.* Houseman, 1800 cited in Oldfield, 1969) and *Artemesia vulgaris* (Oldfield, 1969). The depth of this date here is directly comparable to that of Oldfield (1969).

The final date of 1860 AD is estimated by Oldfield (1969) by extrapolation of the peat accumulation rate and the absence of any post-1870 changes in the palynology. An extrapolation of the line of best fit for the preceding dates here also gives a figure for the upper surface in the 1860's. It is unclear how much Oldfield's (1969) placement of the date 1860 was influenced by historical considerations against those of his extrapolation but the indication is that no further peat wastage has taken place in the three decades intervening our studies. This suggests that the post-drainage slumping and wastage of the peat massif had reached an equilibrium with the water table, prior to Oldfield's (1969) study, that persisted despite the continued presence of trees until the mid 1980's.

The rates of peat accumulation calculated between each date are indicated on the age-depth model (figure 4.4.5). These rates are broadly comparable to those calculated by Oldfield (1969, $r_{\text{peat growth}}$ = 1 cm per 11 to 12 years) and in general, those obtained within this study by radiocarbon dating. However, with the amount of Unidentified Organic Matter reaching 85 % in the macrofossil diagram it is surprising that these figures are not lower since a lot of wastage of the peat is seen to have taken place. This suggests that although there has been a great loss of structure the volume of the peat has not decreased to a considerable degree throughout the 35 cm of peat stratigraphy. This implies that slumping, as opposed to wastage, is the primary mechanism in groundwater mound - vegetation surface homeostasis.

4.6 CONTEMPORARY VEGETATION

4.6.1 Introduction

In this section, the contemporary quadrat data collected for each site is tabulated in a way that allows hydrological trends in the vegetation, from hummock to hollow, to be inferred. Such a tabulation was arrived at by means of Detrended Correspondance Analysis from which the arrangement of species and quadrats in each table was derived, according to their position on Axis 1, which usually reflected a hydrological gradient. Those sites which have a clear distinction between lawn, hummock and hollow yield a clear oblique (e.g. Arnaby Moss Regeneration Peat) whereas those of lesser topographic variation present a more diffuse arrangement of numbers apparent as a block (e.g. Deer Dyke Moss). In addition, small scale patterning on the mire will result in a blocky structure to the table, by inclusion of two or more microtopes within one sample.

The vegetation of each mire is also related to the National Vegetation Classification (NVC). In many cases, despite a physiognomic fit to this classification, none of the floristic elements were present particularly; *A. polifolia*, *E. nigrum*, *Pleurozium schreberi* and especially where fire has been prevalent, squamulose *Cladonia* spp.. The former, vascular species are typically replaced by *C. vulgaris* and the latter, cryptogamous species, by *Campylopus introflexus* and *H. cupressiforme*. This is, in some cases, a consequence of the disturbance that all of these raised bogs have seen but even in their natural state there is no reason to suppose the existence of Rodwell's (1991) titular species, such is the variability of vegetation. This occurrence has been foreseen by Rodwell (1991) who indicates that it is acceptable to name the relevant sub-/communities in the absence of their titular species.

4.6.2 Arnaby Moss Regeneration Peat

	Quadrat																			
	6	*1*	*14*	*15*	*19*	*4*	*18*	*2*	*8*	*20*	*3*	*16*	*12*	*13*	*17*	*7*	*10*	*5*	*11*	*9*
Empetrum nigrum	2	1																		
Erica tetralix	2	1	2																	
Calluna vulgaris	2	1	1	4																
Aulacomnium palustre	1				2								1							
Eriophorum vaginatum	2	1	1	1	1	3	1	1	1	1	2	2	1	3	3	3	1			
Sphagnum recurvum	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Vaccinium oxycoccus	2	2	2	2	2	2	2	3	3	3	2	2	3	3	3	4	2	3	3	3
Polytrichum commune											1	2			1	2		2		
Eriophorum angustifolium													2	2	2		2		2	4

Table 4.6.1 5-point scale quadrat data collected for the contemporary vegetation of Arnaby Moss Regeneration Peat. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The vascular flora of Arnaby Moss Regeneration Peat is set against a continuous lawn of *Sphagnum recurvum* varieties (*sensu* Hill, 1978) which occur centrally in Table 4.6.1. *E. vaginatum* is also common as isolated shoots which have not matured to form hummocks and is only absent from the wettest quadrats where P. commune and *E. angustifolium* are dominant. An extensive network of procumbent shoots is formed over the whole mire surface by *V. oxycoccus* which appears commonest in the wettest quadrats, being generally outcompeted by the taller growth of the sub-shrubs which are indicated towards the top left corner of Table 4.6.1.

In terms of the NVC, the community described for Arnaby Moss Regeneration Peat slots readily into the *S. recurvum* sub-community of the *S. cuspidatum/recurvum* bog pool community, **M2a** (*cf.* Rodwell, 1991).

4.6.3 Arnaby Moss

	Quadrat																								
	3	*16*	*24*	*1*	*6*	*14*	*17*	*18*	*25*	*8*	*4*	*10*	*11*	*15*	*21*	*9*	*12*	*13*	*2*	*22*	*19*	*23*	*7*	*20*	*5*
Sphagnum magellanicum	4																				2				
Dicranum scoparium	2																								
Erica tetralix	2	2	1	2	2	2	2	2	1					2		1					1	1			
Rhyncospora alba					2																				1
Eriophorum vaginatum	2	1		1	1	2	1	2	1	2	2	2	2	1	3	2	1	2	1	2	2	2	2	3	1
Calluna vulgaris	3	5	5	4	5	3	4	3	5	5	5	4	5	5	3	3	5	5	4	3	4	4	5	3	
Sphagnum capillifolium					5			3				2	3							2		1		2	
Narthecium ossifragum						3	2	2								1				1	2	1			
Eriophorum angustifolium			1	1			1		1	1			1	2						1	1		1		1
Leucobryum glaucum										2															
Hypnum cupressiforme				5	2	5	5	1	5		2	2		4	3	4	3	5	5	4	1	4		5	2
Molinia caerulea																3							2		
Sphagnum palustre																					2				
Sphagnum cuspidatum																						2			
Betula sp.																					1	1			
Sphagnum recurvum								2						3							4			1	5
Sphagnum papillosum																						2	5	5	

Table 4.6.2 5-point scale quadrat data collected for the contemporary vegetation of Arnaby Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

In Table 4.6.2 no clear trend avails itself upon the DCA axis 1. This is considered to be a reflection of the data gathering method, most notably the quadrat size. Overall, the first visual impression of this raised bog is the dominance of tall, dry hummocks vegetated by *C. vulgaris*, *E. vaginatum* and the pleurocarpous *H. cupressiforme*. Between these structures are small hollows which may be the only actively growing components of the mire and these areas contain a diverse range of assemblages encompassing pool, lawn and wet hummock species. The random placement of quadrats over this mosaic may include one or all of these microtopes and give rise to an apparently complex pattern of associations. In this instance, a series of subjectively placed quadrats, by necessity of differing size and shape, confined to a single microtope would have yielded more meaningful data.

Placement of this community within the NVC is complicated by extensive modification to the vegetation through intensive, marginal peat cutting, drainage, the development of scrub and its removal. To some extent too, it may be argued that there are two, distinct communities present within the mosaic of hummock and hollow; *C. vulgaris* and *H. cupressiforme* dominating the former and *Sphagnum* based associations present within the wet, regenerating hollows. Accordingly, two sub-communities are recognised from this Moss, both derived from the *E. tetralix* - *S. papillosum* raised and blanket mire or M18 node. Keying through the NVC communities and reference to their descriptions suggests floristic affinities also with the *C. vulgaris* - *E. vaginatum* blanket mire or M19 but this community is typically developed at altitude and does not posses the well developed topography seen here (Rodwell, 1991). Accordingly, it is suggested that the vegetation of the hummocks at Arnaby Moss is referable to a species poor *E. tetralix* - *S. papillosum* raised and blanket mire, *E. nigrum* - *Cladonia* spp. sub-community or M18b. The aberrant scarcity of lichens is ascribed to the shade previously cast by scrub and currently, by leggy *C. vulgaris*. Competition by this species may also explain the exclusion of other ericoid sub-shrubs, with exception to *E. tetralix* which occurs in open, waterlogged situations around the margins of hummocks and on stable mats of *Sphagnum*.

The regenerative, hollow vegetation of this Moss is attributable to the *S. magellanicum* - *A. polifolia* sub-community of the *E. tetralix* - *S. papillosum* raised and blanket mire community, *i.e.* M18a. Vascular species, occurring here within a lawn of *Sphagnum*, are apparently derived from those upon the stagnant hummocks so that the titular *A. polifolia* and sub-shrubs other than *E. tetralix* are absent. However, the *Sphagnum* complement here is in very close agreement with that described by Rodwell (1991) for the M18a sub-community. In addition to this *S. magellanicum* - *A. polifolia* sub-community, very wet areas of the hollows support the *S. cuspidatum/recurvum* bog pool community, *S. recurvum* sub-community or **M2a**, as exemplified by Quadrat 15.

4.6.4 Ballynahone Bog

	Quadrat																							
	1	*2*	*22*	*18*	*23*	*25*	*24*	*20*	*9*	*21*	*4*	*5*	*3*	*19*	*10*	*14*	*8*	*11*	*7*	*13*	*16*	*6*	*17*	*12*	*15*
Sphagnum cuspidatum	1																								
Tricophorum caespitosum	2	1	1																						
Odontoschisma sphagni	2	1							1							1									
Sphagnum tenellum	2	5	3	4	3	4	2	3		3				1											
Narthecium ossifragum	3	4			2	2	1		2	2	2	2	2		2		2	2	1						
Rhyncospora alba	1							1		1				1					1						
Erica tetralix	2	2	2	4	5	4	2	4	2	3	2	2	3	4	3	2	3	3	1	3	2		2	2	2
Campylopus atrovirens											1														
Eriophorum angustifolium		1	2	2	2	1	1	1	1		2	1	2	1	1	2	1	1	1	2	1		1	1	1
Sphagnum capillifolium													3												
Calluna vulgaris		2	2	2	2	3	4	3	3	3	3	5	2	2	3	3	3	3	2	2	3	5	4	3	3
Sphagnum magellanicum									2									2						1	
Sphagnum papillosum									1	2			2	2				1					3	2	
Hypnum cupressiforme								2		3		2		2		3					3		2		4
Sphagnum subnitens				1		2																2	2	2	2
Cladonia					1					1	1		1	1		2	2		2	2	1	2	2	2	
Bare ground															3		2	3	3	3	2		2	3	
Eriophorum vaginatum																									2

Table 4.6.3 5-point scale quadrat data collected for the contemporary vegetation of Ballynahone Bog. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

Ballynahone Bog exhibits a blocky structure similar to that found above for Arnaby Moss and for similar reasons. However, in this case, the topography of the vegetation is subdued and a hydrological arrangement of species and quadrats along DCA axis 1 is apparent.

The pool and hollow, species and quadrats are indicated towards the top, left hand side of Table 4.6.3. The abundance of *S. tenellum* is a striking feature of this group and is probably related to site management raising water tables, thereby allowing this colonial species to spread over the denuded peat which is colonised by *Cladonia* spp. in drier situations. A large amount of bare peat still remains and this must owe its origins to the combined effects of burning (Cruickshank and Tomlinson, 1988) and drainage.

The *Sphagnum* cover is still extensive and more diverse than the quadrat data would suggest but it is displaced by *Cladonia* spp. and *H. cupressiforme* on the low hummocks and drier areas of denuded peat. The vascular flora is dominated by *E. tetralix* with *C. vulgaris*, *E. angustifolium* and *N. ossifragum* common. All of these species occur consistently through the tabulated quadrats and consequently appear centrally in the DCA axis 1 derived list of species to which they show no marked relationship. *E. vaginatum* and *T. caespitosum* are relatively rare components of the vegetation which in part, explains their distal placements.

In terms of the NVC, both sub-communities of the *E. tetralix* - *S. papillosum* raised and blanket mire are indicated. As noted by Rodwell (1991) they are distributed topographically with the *S. magellanicum* - *A. polifolia* sub-community (M18a) occupying lawns and pools and the *E. nigrum* - *Cladonia* spp. sub-community (M18b), the hummocks and denuded areas of lawn. *A. polifolia*, not indicated by the quadrat data, is found on Ballynahone Bog but no records appear for *E. nigrum* whose place appears to have been wholly taken by *C. vulgaris*.

4.6.5 Coalburn Moss

The intact vegetation of Coalburn Moss has an extensive cover of *Sphagnum* in which the prominent species are *S. capillifolium*, *S. magellanicum* and *S. tenellum*. The notable *S. imbricatum* was recorded within one of the quadrats and it appears in the wet, upper left corner of Table 4.6.4 with *S. auriculatum*, *S. compactum* and *S. cuspidatum*. This association explains its apparently erroneous position since it is now considered to be restricted to dry hummock tops but, as suggested here, only on wet mires (Hill, 1981; Daniels & Eddy, 1990). *S. papillosum* is an infrequent component of this vegetation and was recorded in only two of the quadrats and like *S. magellanicum*, it is found towards the drier end of the DCA axis. Other bryophytes include, *M. anomala*, *C. paradoxus* and especially on the hummocks, *O. sphagni*, *H. cupressiforme* and *P. juniperinum*.

	Quadrat																								
	6	*11*	*21*	*10*	*7*	*24*	*2*	*5*	*4*	*13*	*22*	*9*	*1*	*8*	*14*	*25*	*15*	*12*	*3*	*18*	*16*	*17*	*19*	*23*	*20*
Sphagnum cuspidatum	5	2																							
Sphagnum compactum		2	1																						
Sphagnum imbricatum					1																				
Sphagnum auriculatum						1	3																		
Andromeda polifolia	1	3	3	3	4	1	1	3	2	5	4	4	1	2	4	4	3	4	1						
Calluna vulgaris	3	2	3	2	2	3	2	2	3		2	4	4	3	2	2	2	2	4	3	3	3	3	3	3
Eriophorum vaginatum	3	2	1	4	2	2	4	3	3	2	2	3	3	4	3	3	4	3	3	1	3	2			
Mylia anomala										1	1														
Campylopus paradoxus										1															
Hypnum cupressiforme				4	4	1	3	3	5	4	2	3	4	3	3	1	2	2	4						
Sphagnum papillosum													1				1								
Sphagnum tenellum		3			2	1	3		1				2		3		3	3		2	2				
Sphagnum capillifolium				2	3			3	1	1		3		2	1	1				2		1	2		
Erica tetralix		2	1						1						2	1	2	2		2	2	2	2	3	2
Sphagnum magellanicum							1			3		2	1	2	2	1	2	3	3	4	4	4	4	2	5
Polytrichum juniperinum																					1	1			
Vaccinium oxycoccus																					2			1	
Odontoschisma sphagni																							2		2

Table 4.6.4 5-point scale quadrat data collected for the intact, contemporary vegetation of Coalburn Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

Vascular species are represented most consistently by; *C. vulgaris*, *A. polifolia* and *E. vaginatum* with the former occurring most commonly as sub-shrubs of small stature. *E. tetralix* is also very common and again it appears towards the drier end of DCA axis 1 where *V. oxycoccus* is also present, in just two quadrats.

In relation to the NVC, contemporary vegetation data from Coalburn Moss fits readily into the more hydrophilous *S. magellanicum* - *A. polifolia* sub-community (M18a) of the *E. tetralix* - *S. papillosum* raised and blanket mire community. Both of these titular species are common and consistently present within the diverse vegetation. This vegetation is of subdued topography and it lacks the degree of anthropogenic drainage or development of hummocks that would support the *E. nigrum* - *Cladonia* spp. sub-community (M18b).

4.6.5a Muir grip vegetation

	Quadrat														
	4	*2*	*11*	*15*	*1*	*13*	*3*	*10*	*9*	*12*	*7*	*14*	*5*	*6*	*8*
Small hepatic mats	3														
Eriophorum angustifolium	2	3	1		2	1	2	1	2		1				
Calluna vulgaris	5	4	4	4	3	3	4	3	4	4	4	4	3	4	3
Odontoschisma sphagni	1		3	3		3		3		2		1			
Eriophorum vaginatum	1	2	2	3	2	3	2	3	2	3	3	3	3	3	3
Hypnum cupressiforme		5	2	3		2	4		2			3	5		
Aulacomnium palustre							1								
Sphagnum tenellum				2					2		1				
Sphagnum capillifolium					3		3	2	3	3	1		2	2	2
Sphagnum magellanicum			3		2	3		3	3	3	4	4		5	5
Erica tetralix						1	2	1	1			1	2		2
Sphagnum papillosum											2	1			

Table 4.6.5 5-point scale quadrat data collected for the contemporary muir grip vegetation of Coalburn Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The muir grip vegetation is derived directly from that of the relatively intact mire surface and is still referable to the *S. magellanicum* - *A. polifolia* sub-community or M18a. The *Sphagnum* lawn is still well developed but its more xeric character is revealed in a greater preponderance of *S. capillifolium* against a concomitant decrease in the presence of *S. tenellum*. The relative abundance of *H. cupressiforme* appears unaffected and with changes in the bryophyte layer primarily limited to species shifts amongst the *Sphagnum* it may be suggested that the water table still resides within close proximity to the surface. The expanse of *O. sphagni* is unexpected and this species may be responding to reduced upward growth of the Sphagna, increased nutrition through desiccation or the moist, *C. vulgaris* generated microclimate.

C. vulgaris is very prominent amongst the vascular associates of this area in which *A. polifolia* appears to have become almost extinct. Such an apparent sensitivity to disturbance is of concern for a plant that is in decline in the British Isles (Stewart *et al.*, 1994) but as its recent history at Mullenakill Bog indicates, the ecology of this plant is not straightforward. The abundance of hydrophilous *E. tetralix* is also diminished in this area of muir-grip but *E. angustifolium* is now distinct within the vegetation despite its rarity over the more intact area of mire. The occurrence of *E. vaginatum* tussocks appears to be unaffected.

4.6.5b Burnt vegetation

	Quadrat						
	1	*6*	*5*	*4*	*3*	*7*	*2*
Sphagnum magellanicum	5	1	2				
Eriophorum angustifolium	1	1	1				
Sphagnum tenellum			1				
Erica tetralix	2	2	2	2	2	3	2
Calluna vulgaris	3	2	2	3	2	2	2
Sphagnum capillifolium			2	2	1		
Small hepatic mats		1					
Hypnum cupressiforme		4		5	4	3	5
Eriophorum vaginatum	1	3	4	3	3	4	4

Table 4.6.6 5-point scale quadrat data collected for the burnt, contemporary vegetation of Coalburn Moss. Species and quadrats ordered according to the results from a detrended Correspondance Analysis.. (Scale; 1 = 5%, 2 = 6% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

Burning of the vegetation appears to suppress the sub-shrubs *C. vulgaris* and particularly, *A. polifolia* which becomes extinct within this area of vegetation. *S. capillifolium* and *E. tetralix* appear to be unaffected. Of the remaining Sphagna, both *S. magellanicum* and *S. tenellum* are at reduced levels of cover by comparison to the intact vegetation and the latter is also much less frequent, all to the benefit of *H. cupressiforme*. Patches of bare peat opened up by burning are now colonised by small hepatics, mostly *Gymnocolea inflata* in whose mats threads of *Cephalozia* spp. and *Cephaloziella* spp. find habitat. Cyperaceae are well represented with *E. vaginatum* being particularly abundant, sometimes as small tussocks and *E. angustifolium* occurs sporadically here as isolated individuals.

4.6.6 Cranley Moss

	Quadrat																								
	2	*1*	*24*	*4*	*23*	*21*	*7*	*17*	*3*	*25*	*12*	*6*	*19*	*11*	*18*	*20*	*10*	*22*	*8*	*13*	*16*	*5*	*14*	*15*	*9*
Sphagnum auriculatum	4																								
Sphagnum tenellum	3	3		2	2	2	2																		
Odontoschisma sphagni	1		2					2		1															
Dicranum scoparium			4																						
P. juniperinum						1																			
Eriophorum vaginatum	3	4		3	1	3	2	3	2		4	3	4	2	3	3	2		2	3	2	3	1	2	2
Calluna vulgaris	3	3	3	3	3	3	3	2	5	3	3	2	2	5	2	3	2	4	2	2	3	2	4	3	4
Small hepatic mats							1																		
Hypnum cupressiforme		3		2			3					3		2		2		1		1					
Sphagnum magellanicum		2	4	3	4	4	3	2	4	5		4	2		4			3	3		4	5		4	
Erica tetralix		2	2	2	3	2	4	3	1	2	1	2	3		3	2		2	4	2	3	3	2	3	
Sphagnum capillifolium		2	2	2	2		2	4	2		5	2		4	1	3	2	3	2	5	2	2	3		3
Vaccinium oxycoccus						2	1	1			2	2			2			2		2		2		2	
Sphagnum subnitens								2													3				
Empetrum nigrum							3										4								2
Pleurozium schreberi						1				2			3		1	3							3	2	3
Leucobryum glaucum				3														1							2
Polytrichum commune								2			2				1		2				2		2	2	2
Eriophorum angustifolium																								2	

Table 4.6.7 5-point scale quadrat data collected for the contemporary vegetation of Cranley Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The vegetation of Cranley Moss is more or less comparable to that of Coalburn Moss in terms of structure but floristically there are some marked and surprising differences. Most especially, *A. polifolia* is totally absent here yet on Coalburn Moss and others in the area (McTeague & Watson, 1981) it is a not an uncommon plant. Fire and competition from *C. vulgaris* can be excluded as historical factors for this since both elements are absent from the stratigraphy of Cranley Moss but frequent in the upper stratigraphy of Coalburn Moss. Altitude, climate and pedology of the sites are similar and within the ecological limits described for this fecund plant by Jacquemart (1998). However, the stratigraphy of Cranley Moss reveals a more subdued surface topography than that at Coalburn Moss and possibly this restricted the presence of *A. polifolia*. Unless there is a wind-borne polluting influence from Lanark no further explanation can be found for this phenomenon since no geographical barrier that might have historically restricted the spread of this plant appears to be present.

E. nigrum is sporadically present here as well developed sub-shrubs on hummocks in association with *C. vulgaris* and the bryopsid bryophytes; *H. cupressiforme*, *P. schreberi*, *P. commune* and *P. juniperinum* which occur otherwise within this microtope. *L. glaucum* and *S. subnitens* also form low hummocks and *V. oxycoccus* occurs in this niche too, spreading out onto the lawns of *Sphagnum* as suggested by its position on DCA axis 1 (Table 4.6.7). This lawn of *Sphagnum* is extensive with the red hued *S. capillifolium* and *S. magellanicum* most prominent but including also *S. auriculatum* and *S. tenellum* in the wetter quadrats, often in association with Hepaticae.

The vegetation of this mire is readily attributable to both sub-communities of the *E. tetralix* - *S. papillosum* raised and blanket mire community (**M18**). More precisely, the lawn and hollow component is attributable to the *S. magellanicum* - *A. polifolia* sub-community (M18a) and the drier hummock vegetation to the *E. nigrum* - *Cladonia* spp. sub-community (M18b).

4.6.7 Deer Dyke Moss

No trends are apparent in the DCA axis 1 arrangement of species and quadrats for Deer Dyke Moss and it is considered that this is a consequence of the spatial structure of the vegetation, with a range of hydrological conditions and species contained within the boundaries of a single quadrat leading to the complex arrangement of associations seen in the blocky structure of Table 4.6.8. In part, this effect may also be due to the recent recolonistion and expansion of species on a mire surface degraded by scrub encroachment and its removal. This appears to have resulted in a mosaic of species according to the stochastic arrival of diaspores, as opposed to a climactic arrangement of species dictated by interspecific competition.

The *Sphagnum* cover is surprisingly extensive with a frequency of 76% and it is dominated by *S. capillifolium* and *S. magellanicum* with *S. cuspidatum, S. subnitens* and *S. tenellum* occasional, although the latter was recorded only within field-notes. On the mounds and drier areas of the peat surface, which still shows signs of desiccation, *S. capillifolium* is replaced by *H. cupressiforme* and dendroid *Cladonia* spp., the former possibly as a ruderal replacement for *P. schreberi* within what would be referable the *E. nigrum* - *Cladonia* spp. sub - community, M18b. The typical sub-shrubs, *A. polifolia, C. vulgaris* and *E. tetralix* are common and managed by mowing to reduce the abundance of *C. vulgaris*, in particular to allow greater amounts of light through to the Sphagna. *V. myrtillus* is also present here and has probably been favoured on the moss by scrub encroachment reducing the light intensity at ground level and accordingly, the competitive advantage of *C. vulgaris* (Hester *et al.*, 1991). The continuance of mowing upon the Moss might be expected to increase further the frequency and cover of *V. myrtillus* unless it is overcome by vigorous *Sphagnum* growth or shallower water table levels (*cf.* Welch, 1998).

	Quadrat																								
	19	*24*	*18*	*3*	*13*	*25*	*4*	*14*	*23*	*8*	*11*	*9*	*2*	*7*	*16*	*17*	*6*	*12*	*1*	*5*	*10*	*22*	*20*	*21*	*15*
Sphagnum subnitens	4																								
Andromeda polifolia		2	2			1				1		1		1				1			1				
Sphagnum magellanicum	2	2	4	2	5			1	2				2				1								
Betula sp.	1		2	1		1	2	2	1	2							1		1						
Vaccinium myrtillus				2			2						2												2
Eriophorum angustifolium	1	1	2	1		1	2	1	1	2	1		2	1	1	2	1			1		2			1
Dicranum scoparium								1			1														
Eriophorum vaginatum	2	4	2	5	5	4	2	2	3	2	4	3	3	3	2	2	4	3	2	4	4	3	2	3	2
Erica tetralix	1					1		2	1	3		3		3	2	2	2	2			2				
Sphagnum cuspidatum											2														
Molinia caerulea							2					2							2						
Calluna vulgaris			3		1		3	4	4	1	2	2	3		3	2	1	2	3	3	1	2	2		4
Sphagnum capillifolium						3				5	3	3	3	2		4	2		3		5			3	3
Hypnum cupressiforme								3	4		2	2	1	3	2		3					4	5	3	1
Odontoschisma sphagni		1																				1		2	
Bare ground									1				1			1		2	2			2	3		1
Rhyncospora alba																					2	2		2	
Cladonia																	2								4

Table 4.6.8 5-point scale quadrat data collected for the contemporary vegetation of Deer Dyke Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The mowing of the vegetation on Deer Dyke Moss has also encouraged the preponderance of *E. vaginatum* which, under extremes of this regime, comes to dominate within the NVC community, *E. vaginatum* blanket and raised mire or M20. Other Monocotyledonae on Deer Dyke Moss include, *E. angustifolium*, *M. caerulea* and *R. alba* although only the former is a frequent component of the vegetation. *Betula* seedlings are unfortunately frequent here (*c.* 40%) but it may be hoped that a continuation in mowing and the spread of *Sphagnum* through further increases in the height of the water table may overcome these generally unwelcome invaders.

The vegetation of Deer Dyke Moss must be considered atypical with its history of woodland development and current mowing regime but despite this it retains an obvious ombrogenous character. Both sub-communities of the *E. tetralix* - *S. papillosum* raised and blanket mire community, M18, appear to be present although the titular, *E. nigrum* is absent and neither component is fully developed along the criteria described by Rodwell (1991). Accordingly, while the vegetation is derived from and expected to return to this community, some affinities with the floristics and management of M20, the *E. vaginatum* raised and blanket mire, are apparent.

4.6.8 Mullenakill Bog

The arrangement of species in Table 4.6.9 corresponds to an apparent, hydrological gradient, running from a *Sphagnum* lawn to the flora of hummocks and desiccated areas of bare peat towards the bottom right. The wetter vegetation, attributable to hollows and lawns is *Sphagnum* dominated with *S. papillosum* most frequent (32%) and accompanied by *S. auriculatum*, *S. cuspidatum* and *S. magellanicum*. Other bryophytes associated with this group of species are *C. introflexus*, *L. glaucum*, *H. cupressiforme* and *O. sphagni*, of which, only the latter pair occur as consistent components of the vegetation.

	Quadrat																								
	2	*23*	*25*	*16*	*11*	*17*	*9*	*12*	*21*	*19*	*15*	*18*	*4*	*20*	*13*	*7*	*14*	*8*	*6*	*10*	*22*	*24*	*5*	*3*	*1*
Sphagnum magellanicum	3			2						1															
Sphagnum papillosum	3	3	1	2	3	2		2	1																
Sphagnum cuspidatum		2	2						2																
Hypnum cupressiforme			2		2	2	5	2																	
Campylopus introflexus							1																		
Leucobryum glaucum							1																		
Odontoschisma sphagni			2		2			2		2		1										1			1
Eriophorum angustifolium	1	1	1				1		1		1	1		1		1	2	1							
Sphagnum auriculatum											3														
Rhyncospora alba		1	1	1		2			1	1	1	1	2	1		2	1	1	2						
Eriophorum vaginatum	1			2	2	1		3	2	1			2		1		2		2		2	2	1		
Erica tetralix	2	2	4	2	2	2	2	3	2	2	2	2	2	2	2	2	2	2	1	2	3	1	1	1	2
Calluna vulgaris	2	4	2	4	3	3	4	3	4	3	3	3	2	5	4	3	3	2	4	3	3	5	5	3	3
Sphagnum tenellum			1		2	1	2					2	4			2				2	2				2
Cladonia			1	1			1	2	2	2	2	3		2		1	2	3		2		1		2	
Tricophorum caespitosum							2	2	1								2					2		2	2
Narthecium ossifragum																		1							
Bare ground																	2	3	2			2			
Sphagnum capillifolium																2	2		2	3	4	2	5	3	4
Nardia scalaris																						2		1	
Dicranum scoparium																									2

Table 4.6.9 5-point scale quadrat data collected for the contemporary vegetation of Mullenakill Bog. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The Cyperaceae, *E. angustifolium*, *R. alba* and possibly *E. vaginatum* are centrally placed on DCA axis 1 as a consequence of their frequent occurrence across the bog where they are absent only from the drier quadrats. This makes them statistically insensitive to DCA axis 1. *E. tetralix* may also occur within this group but like *C. vulgaris* it occurs across the table with 100% frequency and correspondingly, neither species is strongly correlated with DCA axis 1.

The drier group of species, presented below *C. vulgaris*, in Table 4.6.9, contain the wet lawn species *S. tenellum*. It is suggested that the sporadic but consistent occurrence of *S. tenellum* throughout the table is responsible for the otherwise erroneous placement of this species. Amongst the remainder of this group dendroid *Cladonia* spp. are the most frequent and these testify to the absence of burning on the site. *T. caespitosum* is relatively frequent (28%) and *N. ossifragum* is recorded within the quadrats as one individual plant. Some patches of bare peat are still evident and these are locally colonised by the bryophytes, *N. scalaris* and *C. introflexus*, although the latter occurs at the opposite end of the table on account of its rarity.

The red-hued *S. capillifolium* shows a range of associates as a hummock forming species. At the wetter end of the scale, *R. alba* and *O. sphagni* are associated with *S. capillifolium* where it borders onto the lawn or hollow microtopes. On the drier lawns and hummocks of *S. capillifolium*, other cryptogams become more prominent in the vegetation including, *Cladonia* spp. and *D. scoparium* whereas the cover of sub-shrubs, particularly *E. tetralix*, falls. The abundance of *Cladonia* spp. would suggest that the fire damage noted by Shaw (1993) was not so severe as to have reduced dramatically the abundance of this sensitive taxon, at least locally. *A. polifolia* is also a component of the vegetation here, recolonising from nearby railway embankments but given its current scarcity it was not recorded from within any of the random quadrats.

This abundance of *Cladonia* spp. and the relative paucity of *S. magellanicum* indicates that within the M18, *E. tetralix* - *S. papillosum* raised and blanket mire community the drier *E. nigrum* - *Cladonia* spp. sub-community is best represented (M18b).

4.6.8a Areas of seasonally inundated, cut-over peat at Peatlands Park

	Quadrat																								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*
Bare ground	1		5				3	3		1		5		2	2	2									
Erica tetralix		1									1			2											
Myrica gale	2					2			2	1			3												
Eriophorum angustifolium		1	2	1	2				1	1		1	5			2				1					
Calluna vulgaris		1				1	1	2	3	2				1									1		
Eriophorum vaginatum	4	5	1	3	3	3	4	3	3	4	5	2		4	5	4	1	4	5	2	4	2	2	5	3
Sphagnum papillosum																			2					1	
Sphagnum magellanicum																			1		1			1	
Sphagnum cuspidatum				3	4	3					2						4	3	2	4	3	5	5		4

Table 4.6.10 5-point scale quadrat data collected for the areas of seasonally inundated, cut-over peat at Peatlands Park. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The vegetation described in Table 4.6.10 is that developing in the area of former, commercial peat cutting and Derryadd Lake where water levels are maintained close to or above the peat surface. *E. vaginatum* is the most frequent and covering plant and this species is apparently secondary to the currently sporadic *E. angustifolium*, in the succession from bare peat (K. Stanfield, pers. comm.). Bare peat is still prevalent here although the cover of *Sphagnum* is reducing the extent of this. Rafts of *S. cuspidatum* have developed and the remaining *Sphagnum* species; *S. magellanicum* and *S. papillosum* are restricted to only a few quadrats where these rafts of *S. cuspidatum* are particularly well developed. *E. tetralix* is sporadic despite the apparently suitable water table found here which perhaps favours *M. gale* in the release of nutrients from previously mineralised peat.

In terms of the NVC it is probably inappropriate to assign such an atypical community to any classification found there. However, it might be suggested that the vegetation corresponds to an immature form of the **M2**, *S. cuspidatum/recurvum* bog pool community although assignation to either of its sub-communities is precluded by the origins of the species poor vegetation here. However *R. alba*, the titular indicator of **M2a**, is present but not at a sufficient frequency to have been included within any of the quadrats. Additionally, components of a species poor M18 are present and it may be suggested on contemporary data alone that this is the direction of succession here, undoubtedly to be aided by the proximity of propagoules from Mullenakill Bog..

4.6.8b Areas of dry cut-over peat at Peatlands Park

	Quadrat																								
	3	*2*	*12*	*6*	*7*	*13*	*19*	*5*	*8*	*20*	*10*	*24*	*1*	*9*	*18*	*22*	*17*	*23*	*25*	*21*	*11*	*14*	*4*	*16*	*15*
Erica tetralix	3	2	2	1	1	1	2																		
Eriophorum angustifolium	1	1	1	3	2	2	1	2	2		1	1	1	1				1							
Calluna vulgaris	3	3	3	2	4	3	3	3	2	3	4	3	3	4	2	2	4	3	4	5	2	2	2	2	3
Bare ground		3	3	3	2	3	3	3	4		3	3	4	5	2	2	2	4	3	3	5	5	5	5	4
Campylopus introflexus	1																1	2	1	2		2	1	1	
Molinia caerulea																									1

Table 4.6.11 5-point scale quadrat data collected for the areas of dry cut-over peat at Peatlands Park. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

This Callunetum is developing on bare peat, above the water table, in those areas of peatland previously occupied by the commercial peat workings and to a lesser extent, Derryadd Lake (Table 4.6.11), It is floristically less diverse and much more xeric than that described above. This is revealed most cogently by the complete absence of *Sphagnum* here and its replacement in the bryophyte layer by *C. introflexus* whose hyaline hair points assist its maintenance in such habitats (*cf.* Proctor, 1981). This small, acrocarpous species is of comparatively low cover and that attributable to bare peat is accordingly both high and frequent. *E. angustifolium* is still common here, by comparison to Table 4.6.10 and this may suggest, by reference to the observations of K. Stanfield (pers. comm.), that the succession here is hydrologically retarded since *E. vaginatum* is only present as a few isolated individuals which were not included within any of the random quadrats. This is in comparison to its dominance in the wetter areas of revegetation described above. Instead, leggy *C. vulgaris* dominates here and *E. tetralix* curiously appears with a slightly greater frequency here than on the wetter peat. *M. caerulea*, very sporadic in both areas of revegetating peat, is indicated within just one quadrat and may be restricted by the lack of water.

In terms of the NVC, this community is without parallel and no attempt to fit it even loosely to a community will be attempted.

4.6.9 Wedholme Flow

A clear hydrological arrangement of species is indicated in Table 4.6.12 which exhibits a blocky structure according to the homogeneity of the vegetation here, with exception to the cluster of pool/hollow species in the top, left hand corner. This group includes; *S. cuspidatum*, *E. angustifolium* and *R. alba* and it is presumably derivative of the **M2**, *S. cuspidatum/recurvum* bog pool community which, under continued perturbation to the hydrology of Wedholme Flow, may be expected to diminish greatly in its extent. The *Sphagnum* lawn is otherwise dominated by *S.*

magellanicum at high values of cover and frequency (*f* = 92%). *S. capillifolium* is less frequent (*f* = 68%) but still a common component within this lawn where it forms both hummocks and lawns. The only other *Sphagnum* species occurring here and recorded within the quadrats is *S. tenellum* but *S. papillosum* was noted in the field to occur as occasional, low hummocks in which sub-shrubs were commonly rooted. Other bryophytes are common within the *Sphagnum* lawn and they include, in their order of their appearance on DCA axis 1, from wet to dry; *P. alpestre*, *M. anomala*, *O. sphagni*, small hepatic mats and *H. cupressiforme*.

The vascular flora of Wedholme Flow's Southern Lobe is diverse although *A. polifolia* was not recorded during field work there. The sub-shrubs *C. vulgaris* and *E. tetralix* are usually of low stature, typically in the region of 1 - 2 dm in height and both occur frequently across the table, although the invariable cover of *E. tetralix* is relatively low by comparison to that of *C. vulgaris* which increases towards the drier, right hand side of the table.

	Quadrat																								
	15	*14*	*19*	*21*	*18*	*22*	*20*	*13*	*12*	*16*	*17*	*24*	*25*	*8*	*11*	*7*	*9*	*10*	*3*	*2*	*6*	*4*	*23*	*5*	*1*
Rhyncospora alba	4	5		2	4																				
Sphagnum cuspidatum			4	3		2																			
Eriophorum angustifolium			2	1			1																		
Polytrichum alpestre							1																		
Sphagnum magellanicum	4	4	3	4	4	4	4	4	4	4	5	3	4	3	4	1	3	4	3	1	2		2	2	
Myrica gale	2	2	2	2	2			2	2	2	2	2		2				1	2	2		1	1	1	1
Eriophorum vaginatum	2	4	2	3	4	2	3	3	3	2	2	3	3	2	3	3	3	3	2	2	2	2	3	2	2
Sphagnum tenellum										2	1													1	
Erica tetralix	1	2	2	2		2	2			1	2	1		2	3	1	2	2		1	1	3	2	1	1
Vaccinium oxycoccus			2	2			2				2			1	1	1			2	1	2	1	2	1	1
Calluna vulgaris	2	2	4	2	2	2	3		3	2	4	2	1	4	2	4	4	4	3	4	4	3	2	4	5
Mylia anomala				2		2		2											2			3	2	3	
Sphagnum capillifolium				2	3						1	4	4	3	2	4	3	3	2	2	1	3	4	1	2
Odontoschisma sphagni					2									2	3		2	2	4	4	4	3	5	3	4
Small hepatic mats																									2
Hypnum cupressiforme																		2						3	

Table 4.6.12 5-point scale quadrat data collected for the contemporary vegetation of Wedholme Flow. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

Spindly *M. gale* is a noticeable component of the vegetation standing clear of the other sub-shrubs. The cover attributable to this species is low, indicating its growth form here, despite its great frequency (*f* = 72%). Creeping over the surface of the mosses is *V. oxycoccus* which occurs with greater frequency towards the drier end of DCA axis 1 although it is sporadically present throughout the table. It may thus be seen that the sub-shrub community of Wedholme Flow forms a complex cover of several layers and admixtures which results in quadrat cover sums of up to 23 (≈ 400%) in some cases. Finally, *E. vaginatum* is common and consistent throughout the table and it may be suggested that as the water table continues to fall and become more variable, this species will increase greatly in extent.

Despite the hydrological perturbation to this mire the vegetation remains attributable to the hydrophilous *A. polifolia* - *S. magellanicum* sub-community (M18a) of the *E. tetralix* - *S. papillosum* raised and blanket mire community. This is ascertained on the abundance of *S. magellanicum* and presence of *M. gale* which is occasionally found within this community (Rodwell, 1991). Under continued, marginal extraction the low hummocks will presumably show a shift to the *E. nigrum* - *Cladonia* spp. sub-community.

4.6.10 Wreaks Moss

The heterogeneity of Wreaks Moss is revealed most cogently by the oblique arrangement of species and quadrats in Table 4.6.13. Centrally placed, *C. vulgaris*, *E. tetralix* and *E. vaginatum* occur throughout the table and are accordingly unrelated to DCA axis 1. Those species and quadrats appearing in the top, left hand corner of the table correspond to lawn and pool vegetation in which the Sphagna play a prominent role. *S. papillosum* erroneously appears as the wettest species and this must be a consequence of its rarity within the vegetation. *S. recurvum* and *S. tenellum* form wet lawns and pools in which *M. caerulea* and the bryophytes, *M. anomala*, *O. sphagni* and *P.*

commune are present. This would indicate that this component of the vegetation (Quadrats 1, 2, 17 and 18) is referable to the M2, *S. cuspidatum/recurvum* bog pool community and particularly to the *S. recurvum* sub-community (M2b). *Betula* spp. seedlings are also found here and it is suggested that this shade intolerant species is establishing in the absence of competition from *C. vulgaris*.

	Quadrat																								
	19	*20*	*4*	*17*	*2*	*1*	*18*	*21*	*3*	*24*	*22*	*16*	*23*	*25*	*5*	*10*	*15*	*11*	*8*	*9*	*7*	*14*	*6*	*12*	*13*
Sphagnum papillosum	5	3																							
Betula sp.		2	1		1																				
Sphagnum tenellum			3																						
Mylia anomala			2																						
Odontoschisma sphagni			2																						
Sphagnum recurvum			3	5	2	5	2																		
Aulacomnium palustre					1																				
Molinia caerulea			1		1	1			1																
Sphagnum magellanicum		2			1			2	2		2														
Sphagnum capillifolium			3						5	1	4	2		5			3								
Sphagnum fuscum									1																
Polytrichum commune			1		4	2	2												3			2			
Eriophorum vaginatum	3		3	2	2	5	3	2	3	2	2	4	2	3	3		3	3	2	3	2	3	3	3	
Calluna vulgaris	2	2	2		4	1		4	3	3	5	2	2	2	4	3	2	2	2	2	2	2	2	2	2
Erica tetralix		2		2		2			2	2	2	2	2		1	3	1	3	2		2	1		2	1
Pleurozium schreberi									1										2			4	2		
Vaccinium myrtillus			1														2			2	2		2	2	3
P. juniperinum																			2			3			
Dicranum scoparium																					2				
Cladonia																		2	2	3	2		3	2	4
Hypnum cupressiforme																						3		5	

Table 4.6.13 5-point scale quadrat data collected for the contemporary vegetation of Wreaks Moss. Species and quadrats ordered according to Detrended Correspondance Analysis axis 1 results. (Scale; 1 = 5%, 2 = 5% - 25%, 3 = 26% - 50%, 4 = 51% - 75%, 5 = 76% - 100%).

The species comprising the remainder of the lawn and hummock component include the Sphagna; *S. capillifolium*, *S. fuscum*, *S. magellanicum* and *S. papillosum* with an overall frequency of 36 % (excluding those quadrats in which *S. recurvum* [*f* = 20 %] is present). These Sphagna become increasingly rare on the hummocks where the bryopsid mosses *D. scoparium*, *H. cupressiforme*, *P. schreberi* and *P. juniperinum* are prevalent although the latter extends downwards into the lawns. *V. myrtillus* is common here too and the associated abundance of *Cladonia* spp. would indicate that the surface of Wreaks Moss has been relatively free from fire and that the development of scrub did not become too closed and shade out these species.

In addition to the M2b, *S. recurvum* sub-community, M18b, the *E. nigrum* - *Cladonia* spp. sub-community is widely present (*f* = 80%). The occurrence of this sub-community here is indicated by the prevalence of leggy *C. vulgaris*, the relative abundance of bryopsid mosses and *S. capillifolium*, compared to that of *S. magellanicum* and additionally, the high cover of *Cladonia* spp.

5. DISCUSSION

5.1 THE REPLACEMENT OF *S. IMBRICATUM* BY *S. MAGELLANICUM* AND *S. PAPILLOSUM*

The dominant, raised bog species, over much of the late Holocene, was *S. imbricatum,* a taxon which, after an abrupt decline between *c.* 1000 AD and 1500 AD (Mauquoy & Barber 1999), is now reduced to the tops of hummocks in the north and west of Britain where it occurs only locally on very wet mires (Green, 1968; Hill, 1978; Daniels & Eddy, 1990). The cause of this retraction is inconclusively discussed by Stoneman, Barber and Maddy (1993) and Mauquoy and Barber (1999). In this section, consideration is given only to its apparent replacement by *S. magellanicum* and *S. papillosum* since their replacement of this species poses some difficulty in application of the palaeovegetation communities. In fact, the appearance of these species is as curious as the disappearance of *S. imbricatum* since both are uncommon components of the macrofossil diagrams presented here and in other studies (e.g. Barber, 1981; Barber *et al.*, 1994; Mauquoy and Barber, 1999),

During this study *S. imbricatum* was encountered only once in a contemporary setting, on top of a hummock in a very wet area of Cranley Moss. A comparison with its position in the DCA plots presented in this study (Figures 4.2.1 to 4.2.21) indicates that it was present on hummock tops in the past but that another ecad (environmentally induced form) was also present in the wetter microforms of lawn and overgrown pool, as considered initially by Tallis (1962). Green (1968) experimentally confirmed the existence of these two ecads by the use of branch characters and his findings were supported by Flatberg (1986) who studied the biometry of the branch leaves. This latter approach lends itself to the study of palaeoecological material where branches may become dismembered. Such a biometric study could help to elucidate the manner of *S. imbricatum*'s virtual extinction by providing information on the ecads present throughout time but such a study would prove very time consuming.

The position of the three ombrotrophic *Sphagnum* sect. *Sphagnum* species on the DCA axes presented in Figures 4.3.1 to 4.3.21 are summarised in Table 5.8.1. In this table *S. magellanicum* consistently appears towards the wettest end of the axis except at Wedholme Flow and Wreaks Moss. At Wedholme Flow its intermediate position is due in part to its rarity and hence, outlying placement on the axis and also, the presence of *S. papillosum* with *S. imbricatum* during wetter phases of bog growth. At Wreaks Moss, the dry placement of *S. magellanicum* is due to its presence within a Degradation Phase and it cannot be ascertained whether it grew during this phase or, formed a peat layer that was subjected to secondary mineralisation during a period of water table draw down.

Stratigraphy	**Wet** (Lawn)	——→	**Dry** (Hummock)
Arnaby Moss	*S. papillosum*		*S. imbricatum*
Ballynahone Bog	*S. magellanicum*	*S. papillosum*	*S. imbricatum*
Coalburn Moss	*S. magellanicum*	*S. imbricatum*	*S. papillosum*
Cranley Moss	*S. magellanicum*	*S. imbricatum*	*S. papillosum*
Deer Dyke Moss	*S. magellanicum*	*S. papillosum*	*S. imbricatum*
Mullenakill Bog	*S. magellanicum*	*S. imbricatum*	*S. papillosum*
Wedholme Flow	*S. papillosum*	*S. magellanicum*	*S. imbricatum*
Wreaks Moss	*S. papillosum*/ *S. imbricatum*		*S. magellanicum*$^{?}$

Table 5.1.1 The arrangement of ombrogenous *Sphagnum* sect. *Sphagnum* species along the hydrological gradient of the DCA analyses (Figures 4.3.1 to 4.3.21). The $^{?}$ symbol denotes a dubious placement along this gradient (see text).

S. papillosum and *S. imbricatum* are, with exception to the atypical DCA plots of Wedholme Flow and Wreaks Moss, found towards the dry end of the axes. The extreme "wet" placement of *S. papillosum* at these sites may be explained in part by its comparative rarity compared to the lengths of stratigraphy in which *S. imbricatum* is encountered. However, *S. papillosum* is now consistently found on the tops of hummocks although it may also occur during the early stages of pool infilling, as seen at Cranley Moss (30 cm to 46 cm depth) (Mauquoy & Barber 1999).

The fact that *S. imbricatum* does not appear intermediately, but towards the drier end of the axes, despite its consistent appearance throughout phases where the water table lies close to the surface, suggests that in the past it tended towards its hummock forming ecad. This is usually indicated by the concomitant appearance of *C. vulgaris* in the macrofossil diagrams (Figures 4.1.1 to 4.1.9). Green (1968) experimentally induced both ecads from the same genetic material which suggests that the wetter form may naturally tend towards hummock formation after consolidation of the surface in which it established. Currently, with a few exceptions, the sequence is from *S. magellanicum* to *S. papillosum* and this can also be seen in contemporary settings such as the infilling of flooded, stagnant ditches where the latter establishes in lawns of the former, over rafts of *S. cuspidatum*.

According to the above it is apparent that *S. magellanicum* has replaced the lawn ecad of *S. imbricatum* (Stoneman, Barber & Maddy, 1993) although the origin of this former species is indeterminable on account of its almost complete absence from previous sections of stratigraphy (Mauqoy & Barber, 1999). *S. papillosum*, according to its succession on lawns of *S. magellanicum* and position in the DCA plots (Table 5.8.1) is considered to have now replaced the hummock forming, *S. imbricatum* ecad. Unfortunately it is not always possible to determine palaeoecologically which of the two *S. imbricatum* ecads were present so the *S.* sect. *Sphagnum* sum is given in the community descriptions in section 4.6 because, in the absence of a clear autecological distinction in the data presented here and elsewhere, this is probably the best way to compare the past abundance of these taxa within the contemporary situation.

5.2 THE HYDROLOGICAL SEQUENCE OF UNPERTURBED COMMUNITIES

In absence of more dominant external factors the hydrologically determined sequence of communities recognised within this study accords closely to that recognised for the titular taxa by other authors (Figure 1.1). This core sequence of communities is indicated below, in Figure 5.1.1, by order of increasing hydrophily.

This central core of communities is largely encompassed within the limits of the *E. tetralix* - *S. papillosum* raised and blanket mire community (M18) described by Rodwell (1991), and in addition, his two pool communities (M1 & M2) which may be present within the former on raised bogs that have a marked topography. Accordingly, it is therefore confirmed by palaeoecological means that M18 is, with the two pool communities already mentioned, the natural plant community of this habitat, as surmised by many ecologists studying the contemporary vegetation of raised bogs (e.g. Rodwell, 1991; Wheeler & Shaw, 1995) although only aspects of it may be prevalent at a particular point in time. In addition, the surface topography that this community is noted for is not necessarily well developed, as indicated by the longish sections of apparently stable Homogeneous *Sphagnum* Lawn which is itself, a component of the Heterogeneous *Sphagnum* Lawn (Table 4.3.7).

The prevalence of any M18 component is related to the prevailing hydrology and topography of the site, because as the water table recedes, the hummock communities can be seen in the macrofossil diagrams (Figures 4.1.1 to 4.1.9) to spread down into the lawns and hollows. The converse is also apparent during wetter phases when semi-/aquatic Sphagna come to dominate the raised bog surface and only isolated hummocks may persist at such times, as indicated by only the presence of only readily dispersed, *C. vulgaris* seeds in the relevant, stratigraphic sections. These oscillations of the vegetation occur within a water table range that apparently fluctuates between a modelled 2 cm above the vegetation surface for the pool communities, down to a depth of *c.* -15 cm for the Hypnaceous Callunetum but the accuracy of this latter, maximum water depth is discussed in the next section (5.2).

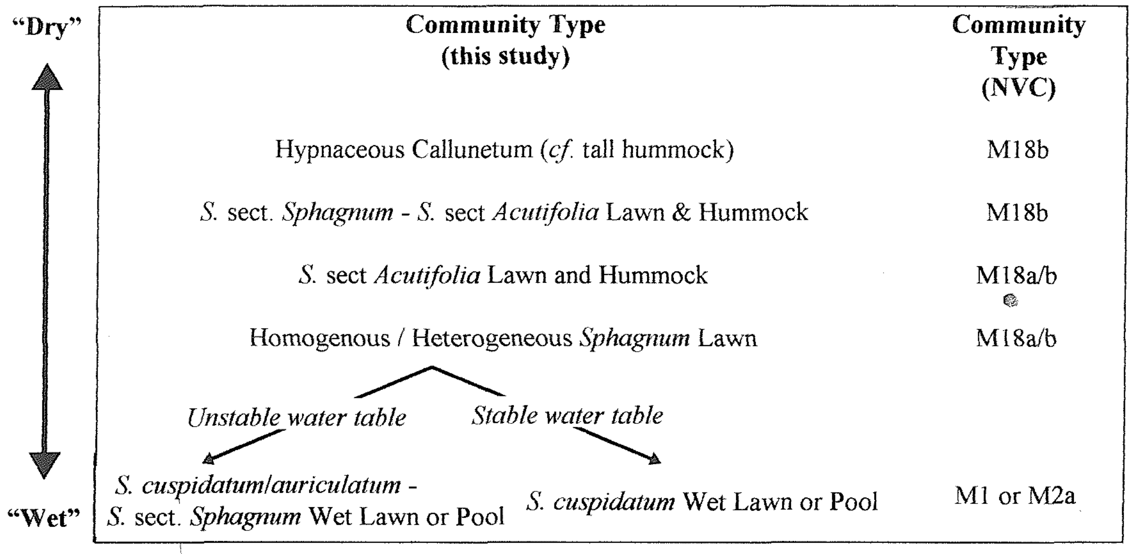

Figure 5.2.1 The proposed core pathway of vegetation change in raised bogs according to the prevailing water table state.

The model of hydrologically determined vegetation succession proposed (Figure 5.2.1) is initially linear with the following sequence of *Sphagnum* sections present from the hummock tops to the lawns; *S.* sect. *Sphagnum*, *S.* sect *Acutifolia*, *S.* sect. *Sphagnum*. Within the hollows and/or pools two pathways are indicated in Figure 5.2.1 and it is considered that two environmental factors select for either the dominating presence of *S. auriculatum* or *S. cuspidatum* since it is not unusual for the to occur together. These considered factors are the temporal, hydrological balance and the availability of nutrients.

Nutrient enrichment of raised bog water is prominent in coastal sites where there is an influx of marine solutes (Proctor, 1992). Some small degree of enrichment may also occur through the oxidation of hollow or pool peats during times of drought and/or the inwash of nutritive exudates from hummock species such as *C. vulgaris* (*cf.* Hulme, 1978). The effect of marine derived inputs may be seen in the high presence of *S. auriculatum* during phases of stratigraphy at the coastal, Cumbrian sites; Arnaby Moss, Wedholme Flow and Wreaks Moss. By comparison, *S. auriculatum* is a rare species at the inland Irish sites, Ballynahone Bog and Mullenakill Bog where it is only present when respectively, the development of *C. vulgaris* bearing hummocks is indicated (Figure 4.1.3; 36 cm) or oxidation of the peat, as revealed by a peak of Unidentified Organic Matter and *Kurzia* spp. in the absence of algae (Figure 4.1.7; 280 cm).

In the Upper Clyde Valley, *S. auriculatum* was recorded only from the stratigraphy of Cranley Moss but its presence at Coalburn Moss cannot be excluded on account of its possible, spatial orientation to the borehole. Here it is considered that poikylohydry (drought-resistance) was a more important ecological strategy for *S. auriculatum* than its response to nutritious inputs in replacing *S. cuspidatum*. This is revealed most cogently by reference to the stratigraphy of Cranley Moss (section 4.1.5) where the onset of a known, wet climatic phase sees an increase in both *S. auriculatum* and *S. cuspidatum* until the onset of a drier shift (Aaby, 1976; Blackford and Chambers, 1991 and Stoneman, 1993) at which time the latter becomes absent. *S. cuspidatum* returns to the vegetation once more at a time of more consistent, effective precipitation (Aaby, 1976; Barber, 1981 and Stoneman, 1993). All of these changes occur chronologically within the limits of the age - depth model (Figure 4.5.2).

This minerotrophic and poikylohydric nature of *S. auriculatum* has also been noted by Daniels and Eddy (1990) who state further that it is capable of withstanding levels of eutrophication deleterious to other Sphagna. It is therefore curious that this species has not been more prevalent in the rafts of *Sphagnum* that currently colonise following the rewetting of cut-over bogs in Britain, the Netherlands and Germany (*cf.* Smart, Wheeler & Willis, 1986a, 1986b; Joosten, 1992, 1995a; pers. obs.). Both species produce capsules (Hill, 1978; Daniels & Eddy, 1990), although *S. cuspidatum* does so more frequently and possibly, this factor coupled with the apparent scarcity of *S. auriculatum* in the contemporary vegetation of raised bogs (see section 4.6, for example) precludes its dispersion and subsequent expansion. Climatically, there is no apparent difference between these two species and both the varieties of *S. auriculatum* since their western European distributions are equable and Hill and Preston (1998) classify them all within the same zonobiome, *i.e.* European Boreo-temperate.

5.3 EFFICACY OF THE TESTATE AMOEBAE DERIVED WATER TABLE MODELS

Site by site calibration of the testate amoebae derived water table models against a modern data set was hampered because only one study site, Wedholme Flow, has been monitored for its hydrology. This monitoring was undertaken by the site staff and Bragg (1992) has used the data for predicting hydrological change at this site, in terms of Ingram's (1982) groundwater mound model (see section 3.8). The relevant transect of dip-wells cuts through the eastern end of the Southern Lobe in order to assess the impact of cutting and drainage there and to avoid this disturbance the core studied here was taken 700m to the west. The spatial and temporal diversity of water table depth is cogent within this data which indicates that on the scale of tens of metres, very different results can be expected with, in this case, a definite fall in the observed depth to the water table as the boundary drain and disturbed areas of the Southern Lobe are approached. Despite this, it is not considered imprudent to compare my modelled water table depths with those recorded by the site staff since potentially accurate means taken from this data are reported in Jackson (1996) for the period, 1990 to 1995.

The means reported in Jackson (1996) show the actual water table to lie between -5.0 cm to - 13.0 cm, in the dipwells closest to the coring site (dipwells S7 to S13). The water table model derived from the testate amoebae counts (Figure 4.4.16) indicates that at the most recent sample depth (c. 2 cm) the predicted water table lies 6.1 cm below the vegetation surface. This indicates the upper limit of the observed water tables. With the testate amoebae sample taken 700 m away from the disturbed, dipwell area, a shallower, predicted water table depth is expected. This one sample, insufficient as it is, does however indicate the potential accuracy of the testate amoebae derived water table models.

Agreement between the modelled and actual water tables for the vegetation of drier phases dominated by hypnaceous mosses, Cyperaceae and/or Ericaceae cannot be relied upon because the modern data set used to calibrate the testate amoebae derived models was collated from *Sphagnum*-rich vegetation (Warner & Charman, 1994). The lowest modelled depths to the water table in this study are at a maximum of *c*. -15 cm during the Heterogeneous *Sphagnum* Lawn, *S.* sect. *Sphagnum* - *S.* sect *Acutifolia* Lawn and Hummock community and the two Calluneta. A number of dips to this depth are sporadic throughout the models constructed for other of the communities but these are apparently due to the presence of *E. vaginatum* tussocks providing an alternative microenvironment for the testate amoebae.

The modelled depths to the water table in each of the Sphagneta are generally accepted, on the basis of the modern, *Sphagnum* derived data set used to calibrate the model and the apparently sensible figures obtained. However, the modelled water table depths during phases of heathy vegetation where *Sphagnum* is absent are rejected because the model was not derived form this vegetation type and additionally, the water table depths appear too shallow, matching those of the most xeric Sphagneta. Accordingly it is suggested that -15 cm is the minimum water table depth of the *Sphagnum* communities recognised here. As such, it is considered that this figure probably represents the upper limit of the water table determining the presence of a heath phase whose true depth cannot be modelled in the absence of an appropriate modern data set for calibration of the derived water table models is the consistency of the predicted values between similar communities from different bogs. This indicates that the modelled magnitude of the water table depth is accurate in relative terms at least, but the absolute precision of the values obtained obviously cannot be attested to. However, as already stated, the models are considered as inaccurate only during phases of Callunetum.

The testate amobae derived water table models appear to offer greater sensitivity by comparison to those determined from the plant macrofossils. This is because the long sections of stratigraphy dominated by *S. imbricatum* are apparently insensitive to changes in the water table below the threshold of the contemporary community. It is suspected that the dimorphic nature of *S. imbricatum* may mask this change if only the *presence* of its leaves is used as part of a measure to determine past moisture levels. Biometry of these leaves, relating to the work of Flatberg (1986) may offer greater resolution in plant macrofossil work but would prove to be a very time consuming method. In addition, The vegetation response is occasionally seen to lag behind that of the testate amoebae to predicted water table change. This is attributed to sub-threshold changes in the predicted water table, to which the plant communities fail to respond until the appropriate limit is surpassed.

Some error is inherent in the testate amoebae derived water table models where the contamination of lawn and pool microhabitats by hummock taxa is seen to occur. This is apparent in the most recent section of stratigraphy from Arnaby Moss where high, *C. vulgaris* dominated hummocks are suspected to have contaminated the wet hollows where active regeneration is taking place and this results in an over-estimation of the depth to the water table. More commonly, the passage of an *E. vaginatum* tussock through the borehole is seen to correspond to a sharp dip in the testate amoebae derived water table model. It is apparent then that tussocks of this plant support xeric, testate amoebae communities that differ to those found more widely in the *Sphagnum* lawn and it is therefore prudent to recognise and dismiss such sections of stratigraphy in the final stages of analysis.

It is assumed that the testate amoebae from hummocks are washed down and into lower lying microfroms by rainfall but t is not apparent to what extent this may occur here or over the whole mire surface, as water is shed down the gradient of the rand. This would result in mixing of the tests and prediction of a more average value for the water table but reduce the efficacy of relating the vegetation of a sample to the corresponding water table.

5.4 RECOLONISATION OF *SPHAGNUM* ON DEVEGETATED PEATLAND SURFACES

In this section the establishment of *Sphagnum* communities on devegetated, peatland surfaces is considered by reference to the pathways elucidated palaeoecologically within this study and to a lesser extent, the literature pertaining to restoration attempts. Figure 5.4.1 below summarises the communities that may establish on these devegetated surfaces in relation to both the quality of water supply and its position relative to the potential vegetation surface.

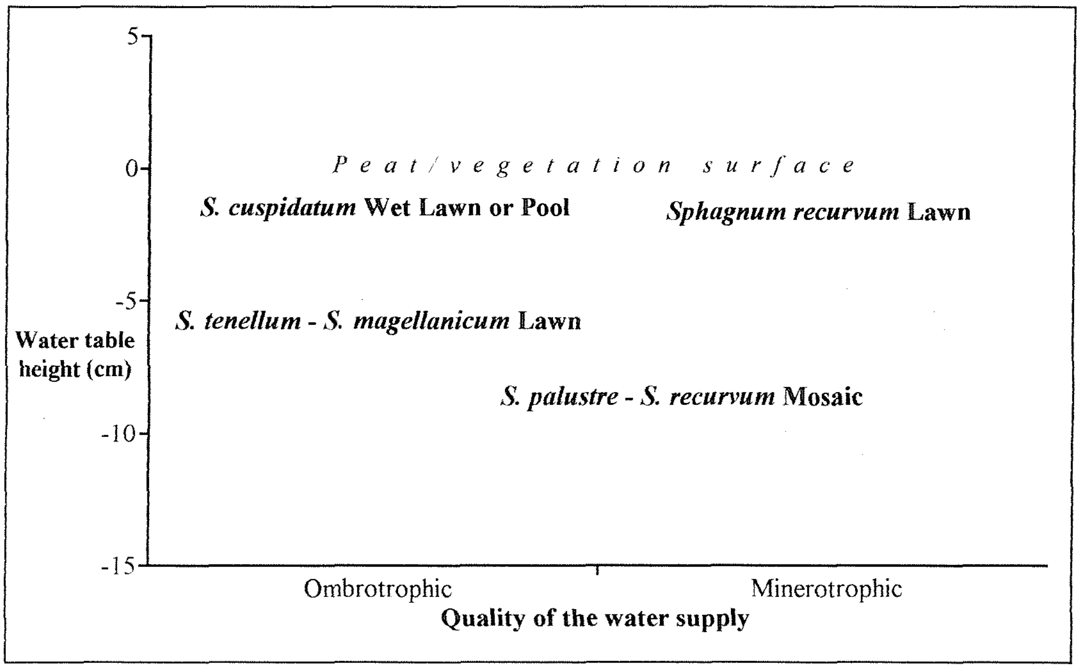

Figure 5.4.1 The communities that may establish on degraded peatland surfaces where Calluneta have not established.

Determination of the most appropriate water table in advance of the restoration attempt is usually considered imprudent on account of the unpredictability of this factor and the possibility of an increased hydraulic head resulting in a "bog burst" as at Mullenakill Bog (see section 3.6). In consideration of the four communities below (indicated in Table 5.4.1), that generally established on denuded peatland surfaces, the *S. recurvum* Lawn (section 5.4.3) and *S. palustre - S. recurvum* Mosaic (5.4.3) may be considered unnatural. This is because no analogue for them is found in the palaeoecological archive in the absence of anthropogenic influence and to some extent, development upon fen peat surfaces. The *S. palustre - S. recurvum* Mosaic may be considered more desirable on account of the more ombrogenous microhabitat afforded by hummocks of *S. palustre*, a plant invariably present at the fen - bog transition (Hughes, 1997). Accordingly, in restoring raised bog vegetation upon fen peat it is desirable to maintain the water table below the peatland surface in order to prevent swamping of the establishing vegetation by mineral rich groundwater which would promote the dominance of *S. recurvum* varieties and place the system at a possibly earlier successional stage. To assist in this maintenance of more ombrogenous areas reconformation of the peat into hummocks and pools, as occurred incidentally at Arnaby Moss Regeneration Peat.

The *S. cuspidatum* pool is a natural component of healthy raised bog vegetation but in restoring expanses of cut-over peat this taxon may become dominant as at Mullenakill Bog or more widely in the Netherlands. It is apparent from the peatland stratigraphies presented here that this taxon has seen similar expansions, naturally, in the past, typically in response to climate or sea-level change raising the predicted water table to superficial levels and then maintaining itself within 2 cm from the vegetation surface. However *S. cuspidatum* is typically replaced by *S. sect. Sphagnum* species as the loose surface it forms consolidates. These taxa may be accompanied by *S. tenellum*, indicating the *S. tenellum - S. magellanicum* Lawn which establishes on ombrogenous peatland surfaces instead of the *S. cuspidatum* Lawn when the predicted water table lies below the potential vegetation surface. However this community appears, by reference to its recovery at Deer Dyke Moss, to be limited by an absence of the microenvironment created by surrounding vegetation, especially vascular species. Accordingly, in these circumstances, it is desirable to attain a superficial water table in order to establish the *S. cuspidatum* Lawn. Otherwise, establishment of this community may place the succession at an earlier stage than that of the succeeding *S. tenellum - S. magellanicum* Lawn or prove impossible in the absence of a suitable water source.

5.4.1 *S. cuspidatum* Wet Lawn or Pool

Two oligotrophic, ombrogenous communities are considered in Figure 5.4.1, the *S. cuspidatum* Wet Lawn or Pool and the *S. tenellum - S. magellanicum* Lawn. The former's establishment following a Degradation Phase was not observed within this study but its prevalence on the flooded workings of the Bargerveen in the Netherlands has been much commented on (Joosten, 1992) and currently, at Peatlands Park, Northern Ireland it is recolonising flooded, derelict cuttings (Shaw, 1993 and see section 4.6 in this study). The presence of this community appears to be reliant on a water table that is consistently at or above the potential vegetation surface (Shaw, 1993) to a maximum depth determined by the decreasing supply of carbon dioxide (Baker & Boatman, 1985, 1990). At depths where this factor becomes limiting for *S. cuspidatum* it is not clear which species may colonise, if any, but the presence of *S. subsecundum* in Scottish lochs at depths of up to 5m (Richardson, 1981) suggests that it may be a prudent introduction but in light of the critical nature of this section it is not necessarily clear which taxon or taxa may be most favourable (*cf.* Rahman, 1972; Hill, 1975 & Eddy, 1977).

Within these hydrological limits the facultatively procumbent growth form of *S. cuspidatum* lends it self to the rapid coverage of degraded peat surfaces and this habit is also shared by *S. tenellum* and to a lesser extent, *S. recurvum* var. *mucronatum*. This habit also allows for the presentation of a greater surface area for photosynthesis and hence, increased productivity (Grosvernier, Matthey & Buttler, 1997). In deep water, growth is initially vertical as the plants are rooted and buoyed up by bubbles of oxygen. Expansion becomes procumbent only when the water surface is reached, either by biomass accumulation or water table draw down (Tomlinson, 1970; Boatman & Tomlinson, 1977; Boatman, 1983). The raft so formed resists desiccation and flooding by following the water table in its fluctuations and as it stabilises, colonisation by *S. magellanicum* or *S. papillosum* occurs, leading to development of the Homogenous *Sphagnum* sect. *Sphagnum* Lawn as seen at Arnaby Moss, Ballynahone Bog, Coalburn Moss and Cranley Moss. At Deer Dyke

Moss and Mullenakill Bog however, the phase *S. cuspidatum* Wet Lawn or Pool is terminated by a peak of Unidentified Organic Matter and this presumably corresponds to the drainage that was implemented on these mires around the turn of the century thus interrupting this particular phase. The stratigraphic profiles from Ballynahone Bog, Coalburn Moss and Cranley Moss indicate that a more diverse, Heterogeneous *Sphagnum* Lawn may subsequently develop upon that of a more homogenous nature and this may apparently occur within a few decades.

5.4.2 *S. tenellum - S. magellanicum* Lawn

A water supply that is both oligotrophic and below the potential vegetation surface will give rise to the *S. tenellum - S. magellanicum* Lawn. The water table for this community is indicated by the testate amoebae derived water table models to be in the range -3.8 cm to -8.8 cm but perhaps the most important factor, emerging from field observations in mid to late summer and the consistent presence of protist, *Arcella discoides*, is that the peatland surface must remain moist during the growing season. However, as indicated by the xeric nature of many mire plants the surrounding atmosphere can be desiccating and some authors therefore advocate the creation of a humid microenvironment, such as by the companion planting of vascular species (e.g. Campeau & Rochefort, 1985). In the recent establishment of this community on Ballynahone Bog, Mullenakill Bog, Wedholme Flow and Wreaks Moss, the expansion of *S. tenellum* is no doubt favoured by the presence of vascular vegetation cover capable of providing this humid microenvironment. By comparison, expansion of this community at Deer Dyke Moss appears very sluggish and this is probably a consequence of the mowing regime there suppressing the growth of *C. vulgaris* and other sub-shrubs with their coincident microenvironment. Some sublime regeneration of *S.* sect *Acutifolia* and *S.* sect. *Sphagnum* species is in evidence here all the same, suggesting that to some extent, *S. tenellum* is an opportunist species exploiting a window of opportunity from which it is eventually outcompeted by other taxa. An alternative view would be that *S. tenellum* rapidly restores a functional acrotelm to the devegetated surface, thereby hastening the return of other *Sphagnum* species but this does not appear to be in evidence here.

S. tenellum behaves as an *r*-strategist within raised mire vegetation, a tactic shared by *S. molle* (Heikkila & Lindholm, 1988) with which it may associate, as seen at Cranley Moss in the wake of a severe fire event. In accordance with this strategy, *S. tenellum* appears sporadically and at low values throughout the palaeoecological profiles usually being confined to isolated pockets over the mire surface (Lindsay & Ross, 1994). Even when this species is not in evidence at the surface careful searching amongst contemporary lawns of *S.* sect. *Sphagnum* often reveals the presence of etiolated *S. tenellum* just shoots below the surface. These shoots do not appear to preserve well, or when they do, it is most probable they are passed over in the leaf counts on account of their atypical form and small size.

In his study of a fire event on Glasson Moss, Lindsay (reported in Lindsay & Ross, 1994) considers the role of sexual reproduction in the colonisation and spread of this species. In half of the recent phases of the *S. tenellum - S. magellanicum* Lawn and also, the phase of *S.* sect *Acutifolia* Lawn and Hummock at Cranley Moss that is perturbed by a large fire event, capsules apparently referable to *S. tenellum* are present. It is presumed that the presence of these capsules indicates that some degree of sexual reproduction is present during the expansion of *S. tenellum*, concomitant with its vegetative spread, but this cannot be conclusively demonstrated by palaeoecological data.

Currently, growth of the *S. tenellum - S. magellanicum* Lawn is succeeded by *S. papillosum* and eventually, the vascular species, *C. vulgaris*, *E. tetralix* and *Eriophorum* spp. which ultimately become components of either the Homogeneous or Heterogeneous *Sphagnum* Lawn. The presence of *C. vulgaris* in particular appears to promote the development of a more topographically diverse surface through the possibly hastening effect of stem flow on *Sphagnum* growth and this phenomenon is discussed more fully in section 5.4.

5.4.3 *S. recurvum* Lawn

The *S. recurvum* aggregate is well known as the most frequent and abundant taxon of ombrogenous bogs that have been at least partially flooded with a minerotrophic water supply or cut to below the groundwater table and consequently, into underlying fen peats (Lee, Baxter & Eames 1990; Koerselman & Verhoeven, 1992; Joosten, 1992; Rochefort, Gauthier & Laquere, 1995; Grosvernier, Matthey, & Buttler, 1997).

The only ombrogenous occurrence of the aggregate in this study is at Cranley Moss where it is scarcely and fleetingly present within a pool otherwise dominated by *S. cuspidatum.* The relatively recent occurrence of this event, interpolated to be post-1800, by reference to the age - depth model from Coalburn Moss (Figure 4.5.2), may correspond to the well known, national increase of atmospheric borne nutrients at this time (Baddeley, Thompson, & Lee, 1994; Woolgrove & Woodin, 1996). This observation is further supported by the downwind situation of Cranley Moss from Lanark whereas *S. recurvum* is absent from the stratigraphy of Coalburn Moss situated upwind of this then industrial town. The contemporary presence of *S. recurvum* on ombrogenous mires in Britain may therefore be considered as anthropogenic on account of its absence in earlier and potentially unpolluted sections of stratigraphy.

At Arnaby Moss Regeneration Peat the *S. recurvum* aggregate is almost exclusively present within a community that has arisen upon fen peats and it becomes particularly dominant after an increase in the groundwater table to superficial levels. From the stratigraphy of this Moss the stem leaves of three *S. recurvum* varieties were recovered and these are appended here with the epithets commonly encountered in extra-British literature; *amblyphyllum* (*S. flexuosum* Doz. & Molk.), *mucronatum*, (*S. fallax* (Kinggr.) Klinngr.) and *tenue* (*S. angustifolium* (Russ.) C. Jens). Of these three varieties only *S.r.* var. *mucronatum* and *S.r.* var. *tenue* were consistently present and the latter in particular, is indicative of the mesotrophic conditions that prevailed throughout the phase of this community (Daniels & Eddy, 1990). The recent decline of *S.r.* var. *tenue* coupled with a decrease in the modelled water table depth may suggest that ombrogenous waters are beginning to exert an influence as was seen in the early development of this community amongst hummocks of *S. palustre* (see section 4.1). At this time, as now, only stem leaves of *S.r.* var. *mucronatum* were present in what was a more oligotrophic, minero-ombrogenous community.

A striking feature of the *S. recurvum* aggregate is its very rapid growth rate which has been calculated to be *c.* 2.4 cm.annum^{-1} in this instance (section 4.1.1). In experimental conditions, Grosvernier, Matthey & Buttler (1997) recorded an increase in length of 8.1 cm over a fifteen week period which corresponds to a potential 21 cm throughout the growing season (February to November, *cf.* Boatman, 1983). Such high rates of growth rapidly scavenge nutrients from the water which are then removed from the ecosystem and stored in this growth, as has been considered for the greenhouse gas, carbon dioxide (e.g. Klinger, Taylor & Franzen, 1996). The wider implications of this for the environment are obvious and equally, for the raised bog habitat, the removal of excess nutrients and enhanced growth towards the water table surface will promote the colonisation of ombrogenous species. This makes the *S. recurvum* Lawn community an important one in terms of large and small scale ecosystem restoration. In this instance, the additional benefit arising from the interception and stripping of nutrients from an agriculturally, eutrophied groundwater table can only be of benefit considering the downstream impacts upon an estuarine ecosystem (Rose, 1990).

In terms of biodiversity this community can have all the allure of a garden lawn but its covering at Arnaby Moss of *V. oxycoccus* in particular, led Lindsay (1978) to rate it most highly amongst the Duddon Mosses when using the Shannon Index of diversity. It may be argued that this measure is somewhat artificial but it does illustrate how an objectively viewed, secondary mire can have as much conservation value as those of a primary nature.

5.4.4 *S. palustre - S. recurvum* Mosaic

This community arose on fen peats exposed by the cutting of Arnaby Moss under the influence of a water table indicated by the testate amoebae derived model (Figure 4.3.2) to lie within the range, -4.0 cm to -11.2 cm. A similar community described by Koerselman & Verhoeven (1992, as "Type-4") from the Netherlands, is considered by them to be present on thin peats affected by a eutrophied groundwater table and both properties are similarly in evidence here. Some degree of ombrogenous influence may also be apparent, according to the presence of *S. palustre* and a predicted water table, modelled from the testate amoebae data, to lie as deep as -12 cm. This may be an over exaggeration, according to the presence of semi-aquatic *S. recurvum*. Error may be introduced to the testate amoebae derived water table model as a consequence of the trophic status being greater than that for which it was developed or the inclusion of tests from a *S. palustre* dominated hummock. However, the presence of a mineral rich substratum and groundwater are held to be the dominant environmental factors in the establishment of this community, with a locally deep water table and partially ombrogenous water supply distinguishing it from the conditions required for establishment of the *S. recurvum* Lawn alone.

-	**Height above the water table**	+
Pools & hollows	**Lawns**	**Hummocks**
S. cuspidatum	*Polytrichum commune*	*S. palustre*
S. recurvum varieties	*P. juniperinum* type	*Hylocomium splendens*
Drepanocladus fluitans	*Phragmites communis*	*Pleurozium schreberi*
		Pohlia sp.
		Rhytidiadelphus squarrosus
		C. vulgaris

Table 5.4.1 Position of species present within the *S. palustre - S. recurvum* Mosaic, relative to the water table position.

It is assumed that the hummocks of *S. palustre* are able to persist above the deep water table by intercepting and storing their own meteroic water like a mini-raised bog suggesting that the underlying substrate is relatively impervious. This may be due to compaction of the peat or proximity of the groundwater table to the base of these hummocks. In contrast to this it is suggested that *S. recurvum* occupies hollows between these hummocks and according to the ecology of this species, these lower lying areas are at or around the water table.

A high degree of spatial heterogeneity is indicated within this community by the juxtaposition of *S. palustre* hummocks and a *S. recurvum* lawn, the latter referable to the community so titled within this study (section 4.3.13). This topography was probably instigated during harvesting operations when some incidental reconformation of the fen peat surface into hummocks and hollows probably occurred, as is currently practised in the deliberate restoration of raised bogs (Wheeler & Shaw, 1995). These microforms were probably colonised according to Table 5.4.1 by a diverse assemblage which attests to the efficacy of peatland reconformation in restoring a diverse flora. This diversity is lost from Arnaby Moss Regeneration Peat when the water table rises markedly and *S. recurvum* becomes almost exclusively dominant.

When the currently falling water table fails to support further growth of *S. recurvum* colonisation by *S. palustre* may ensue (Hughes, 1997; Glen Moss, Strathclyde, pers. obs.). This is a step towards the reinstatement of oligotrophic, ombrogenous conditions and the *S. palustre* - *S. recurvum* community may then become succeeded by the Heterogenous *Sphagnum* sect. *Sphagnum* Lawn on account of the antecedent topography or its homogenous equivalent. However, this cannot be stated with any certainty since no palaeoecological analogue exists for succession from the *S. recurvum* lawn.

5.4.5 *Racomitrium canescens* and the colonisation of small scale, bare-peat patches

Small scale, bare patches, on the scale of cm^2 to dm^2 are frequent in the vegetation of raised bogs especially where afforestation has occurred (pers. obs.). Other sources of these patches include;

trampling, herbicide treatment, drought stress and the stagnation of moribund *E. vaginatum* tussocks is also indicated in the palaeoecological profiles from Mullenakill Bog and Wreaks Moss. In the former instance it appears that growth of an *E. vaginatum* tussock was interrupted and that *R. canescens* colonised the moribund mound (Figure 4.1.7). At Wreaks Moss, *R. canescens* was present within what was an apparently open, cyperaceous community with a high breakdown of matter induced under a low water table leading to the creation of bare patches. These features are respectively evident in the accompanying peaks of monocotyledonous roots and scarcity of aerial remains with a vicarious amount of Unidentified Organic Matter (Figure 4.1.9).

The occurrence of *R. canescens* is unusual in these situations by reference to its contemporary niche (Dickson, 1973; Smith, 1978) and the usual place of *R. lanuginosum* on dry peat substrates (Tallis, 1958, 1995; Ratcliffe, 1968; Dickson, 1973). It is apparent that an ecological shift has taken place and comparatively recently too, according to its position in the profile from Wreaks Moss. The palaeoecological data presented and contemporary floras indicate a wide geographical range for this species and thus, an ecological tolerance that would presumably have buffered it against environmental change, such as the increase and in some cases, partial decrease of atmospheric pollutants over recent decades (*cf.* Oldfield *et al.*, 1978 & 1979; Clymo *et al.*, 1990; Koerselman & Verhoeven, 1992). It is possible that *Campylopus introflexus*, a recent arrival from the southern hemisphere which is now very common on areas of bare peat (Richards, 1963; Richards & Smith, 1975), may have ousted *R. canescens* from this niche. However, it is unusual that no records for *R. canescens* are present in the literature from this habitat, which suggests that this shift may have been autogenic and in advance of both the botanical exploration that accompanied the Victorian era in this country and the arrival of *C. introflexus* a century later.

Apart from *R. canescens*, the only other common taxon of bare peat patches, present in the palaeoecological record, is *Kurzia* spp.. Despite the common presence of filiforme liverworts and their larger counterparts such as *Odontoschisma sphagni* in mire vegetation, no investigation has been made into their possible ecological roles. This has also been commented on by van der Molen, Schalkoort & Smit (1993) who found *O. sphagni* to be an abundant component of the vegetation at Clara Bog, Offaly (Ireland) and this is cogent too in the contemporary data collected for this study but without any apparent pattern according to disturbance, geography and hydrology.

It has been considered that *Kurzia* spp. and other, habitually similar species of the genera *Cephalozia*, *Cephaloziella* and *Gymnocolea*, may resist erosion of the peat surface. This is a likely proposition but possibly limited in its efficacy by the effect of summer drought on these plants (A.C. Crundwell, pers. comm.) unless there is a closed microenvironment. It is also common to see these plants growing amongst wet *Sphagnum* carpets and while this is often considered an ecological requirement of these taxa, their tolerance of drier regimes could actually suggest that such lawns become wetter due to their filamentous growth increasing resistivity of the *Sphagnum* layer to lateral water flow. In a similar manner, the closely approximate or imbricating leaves of *Mylia* spp. and *O. sphagni* may create small islands of resistance that impede lateral water flow in a manner similar to a pin-board restricting the fall of a ball along a gradient.

At Wreaks Moss, where Roundup™ treatment of *Rhododendron* had left large, bare patches of vegetation, a number of small acrocarps forming an extensive lawn were present (section 3.9), probably favoured over the more delicate hepatics by both the exposed microenvironment and possibly still mildly toxic regime. In this instance, consolidation of the upper 1-2 cm of peat by rhizoids was evident but even so, drought induced cracking of the peat surface had occurred and some of the mats so defined were seen to have become dislodged. It is therefore considered unlikely that the Hepaticae and Bryopsida have a role in the colonisation of extensive, bare peat surfaces but when present as smaller patches within areas of degeneration they can enhance the site's biodiversity and proffer some degree of protection to small areas of exposed peat.

5.4.6 The regeneration of *Sphagnum* within Calluneta

Under conditions of water table draw down, through natural or anthropogenic influence, the vegetation of a raised bog shifts towards a state where there is a loss of *Sphagnum* vicarious with an increase in the Cyperaceae, Ericaceae and in the absence of fire, hypnaceous mosses (Rodwell, 1991; Bragg, 1995; Wheeler & Shaw, 1995); These communities may take decades to become closed (Campeau & Rochefort, 1996) and accordingly, open areas persist within the vegetation, through a number of unexplored processes including, natural degeneration (e.g. of *E. vaginatum* tussocks), fire, trampling, and/or localised waterlogging. Within these patches, *Sphagnum* may persist for up to a millennium, as seen at Arnaby Moss and then rapidly regain dominance under a return to more favourable hydrological conditions.

The natural regeneration of *Sphagnum* within the closed vegetation of a Callunetum is seen at Arnaby Moss and Wreaks Moss, both of which form a part of the Duddon Mosses. At Arnaby Moss, water table draw down during a phase of Sphagnetum was related to marine transgression (section 4.1.2) but unfortunately, in the absence of radiocarbon dates this origin cannot be demonstrated for the Callunetum at Wreaks Moss. However, a synchronous and similar mechanism as that at Arnaby Moss seems a reasonable supposition.

5.4.7 Regeneration of *Sphagnum* within a Hypnaceous Callunetum

At Arnaby Moss, the expansion of *Sphagnum* took place within a moss layer dominated by hypnaceous moss species in a two stage return of the water table towards the vegetation surface. The initial, unstable rise in the water table to *c.* -10 cm led to a slight, but sustained increase in *Sphagnum* sect. *Sphagnum* abundance. At this depth of the modelled water table the hypnaceous mosses become extinct but only when the water table rose to a depth of *c.* -5 cm did *S. imbricatum* expand to dominance. The actual depth of the water table at the time of this event is not easy to discern because it falls mid way between two very different values of the water table model. However, a water table depth of less than -2 cm is the usual figure at which *C. vulgaris* disappears from the stratigraphy and this accords well with what is known of the hydrological tolerance of this plant (e.g. Gimingham, 1960; Bannister, 1964; Wallen, 1987). A small peak of *S. cuspidatum* is seen to accompany this expansion of *S. imbricatum* this and indicates that pooling of meteoric water occurred on the surface, presumably as a consequence of oxidation driven compaction of the peat.

The final rise in the water table led to the almost complete extinction of both Cyperaceae and Ericaceae and these are succeeded by a Homogeneous *Sphagnum* Lawn dominated by *S. imbricatum*. The diversity of this lawn is low and suggests that water table restoration should be a controlled event that does not drown out the vascular species which may otherwise assist in the creation of a more diverse habitat for fauna and flora. Unfortunately, even with the best of plans and intentions, such hydrological control is very difficult to achieve (Heathwaite, 1994 & 1995).

How vascular species may assist in the creation of a more topographically diverse community is unclear and probably in need of experimental investigation. In his doctoral study, Hulme (1978) noted how the wooden posts he used promoted the growth of *Sphagnum* into low hummocks whereas plastic piping similarly driven into the mire surface elicited no response. This led him to suggest that it was the nutrient enriched stem flow from the wooden posts that stimulated the growth of *Sphagnum* and not just the physical support which would have similarly stimulated the development of hummocks around the plastic piping. The shade cast by sub-shrubs and to a lesser extent, the Cyperaceae may also result in the creation of a more homogenous surface by the patchiness of light and humidity so created at the mire surface. However, the flooded *C. vulgaris* plants at Arnaby Moss would have persisted in a moribund state throughout the onset of the phase when no heterogeneity is seen in the vegetation. As such, it may be that only living plants can stimulate the growth of *Sphagnum* into hummocks attesting perhaps to the importance of nutrient enriched stem flow from rooting taxa which can tap into the nutrients of deeper layers than the ombrogenous, rootless Sphagna.

5.4.8 Regeneration of *Sphagnum* within a pyrogenic *Callunetum*

In this instance, recovery of the water table actually appeared to occur *throughout* the phase of Heterogeneous *Sphagnum* Lawn that replaced the Callunetum at Wreaks Moss and at the time of this succession, the modelled water table is indicated to still lie at over -15 cm depth. A small peak of *S. cuspidatum* is present at the onset of *Sphagnum* regeneration indicating, as at Arnaby Moss, that there was pooling of meteoric water on the peatland surface. This feature was probably due to the wastage driven compaction of the upper layers of peat that occurred throughout the phase of Callunetum as evidenced in the marked peaks of Unidentified Organic Matter.

This series of observations suggest that it was probably an increase in meteoric water which led to the regeneration of *Sphagnum* at Wreaks Moss. The proposed mechanism is that ponding of water on the surface a relatively impermeable, mineralised peat substrate led to the expansion of *S. imbricatum* as hummocks which could persist due to their own interception and storage of precipitation which would otherwise have gone to replenish the groundwater mound or been lost through lateral flow. This suggests that compaction in the upper layers of a *Sphagnum* poor peatland may enhance regeneration if there is a suitable climatic regime or more specifically, a positive precipitation/evaporation ratio. Site management may achieve the necessary compaction most rapidly by burning off the moribund vegetation to rapidly seal the upper peat layers. It is not possible to categorically state what the climatic regime should be but an annual rainfall of *c.* 1300cm is generally considered as the minimum required to promote the paludification process that leads to formation of a blanket bog (e.g. Pearsall, 1950).

Some degree of sea level recovery (Yong, 1998) may have assisted in the regeneration seen here but the relatively deep, modelled water table that is present as the *Sphagnum* reattains dominance suggests that its effect is not marked and that a pseudo- water table developed above that indicated by the testate amoebae to initially the regeneration of Sphagna.

5.5 PATHWAYS OF VEGETATION CHANGE FOLLOWING RESTORATION

In the previous section, the regeneration of *Sphagnum* based communities was discussed in relation to a number of starting points, according to the depth of the water table, its quality and the presence of existing vegetation. In this section, the most desirable outcomes of restoration and the pathways by which they may be achieved, are discussed in relation to management of the water table.

Following restoration it is probably most desirable to reinstate the Heterogeneous *Sphagnum* Lawn or, in terms of the National Vegetation Classification, the M18, *S. papillosum* - *E. tetralix* mire community. This community, particularly in the accompaniment of associated pool communities, is widely regarded as the most natural state to be found upon our raised mires. This is confirmed by palaeoecological means within this study where, at its fullest expression, incorporating both hummock and pool microforms, it is seen to contain elements of the full range of communities to be found on raised bogs; from hypnaceous Calluneta on the hummocks to pools dominated by aquatic Sphagna. This range of diversity is possibly to be favoured over more monotonous communities, such as the Homogenous *Sphagnum* Lawn which may arise following restoration. However, the persistence of this community and others defined in this study, over long sections of stratigraphy, indicates that they may arise quite naturally in response to a particular set of environmental circumstances and should not therefore be dismissed as an unnatural or unsuccessful outcome. Such scenarios are possibly most likely to arise on raised bogs where a large amount of diversity has been lost through deleterious management and this may indicate the prudence of transplantation. The reinstatement of such biodiversity may assist maintenance of the mire in the long term by enhancing its ability to cope with future changes.

Diversity may be maintained in relatively discrete units across a mire surface, for instance; hummock communities on baulks or water shedding areas of peat and those of the pools in intervening ditches and areas prone to flooding (as at Peatlands Park, for example - Section 3.6). Such an approach lends itself to the restoration and conservation of heavily disturbed and dissected areas of mire, such as Wedholme Flow. Otherwise, a juxtaposition of microforms, across the mire surface, may be seen as the most desirable and natural outcome.

One avenues by which this may be achieved is illustrated in the establishment of *Sphagnum* within Calluneta at the neighbouring Arnaby and Wreaks Mosses, in response to an increase in sea-level. At Arnaby Moss the onset of a higher water table appears to have killed off *C. vulgaris* and a Homogenous *Sphagnum* Lawn developed. At the more inland Wreaks Moss, where *C. vulgaris* persists in the stratigraphy following a possibly slower rise in the water table, a Homogenous *Sphagnum* Lawn develops. It is presumed that this heterogeneity arise in response to nutrient stimulation from *C. vulgaris* (see Section 5.4.7). If this is the case, it suggests that the rising water should be managed in such a way as to ensure that *C. vulgaris* is not eliminated from the vegetation. This is generally seen to occur when it rises above -2 cm in the predicted water table models, which accords closely to the minimum rooting of this plant (Gimingham, 1960). In the stratigraphic sections presented here, the Heterogeneous *Sphagnum* Lawn is also seen to naturally succeed the *S. tenellum - S. magellanicum* Lawn and the *S. cuspidatum* Lawn, especially when *C. vulgaris* is present.

A depth of -2 cm is also the apparent, lower limit for *S. cuspidatum* which usually becomes established following a rise of the predicted water table to superficial levels. Accordingly, spring flooding of the mire surface may stimulate the expansion of pool communities, but this should be timed to take into consideration the growing season for *C. vulgaris*. Greater success in the adoption of this method would probably ensue from reconformation of the mire surface into hummocks and hollows thus ensuring establishment of a topographically heterogeneous community from the outset.

The establishment of communities other than the Heterogeneous *Sphagnum* Lawn is, as already stated, not to be seen as an unnatural or unsuccessful outcome. The restoration of ombrogenous pool communities, as seen widely in the Bargerveen, allows for a succession to lawn and hummock microforms as the rafting, aquatic *Sphagna* consolidate and buffer the vegetation surface, eventually permitting the entry of vascular taxa. In minerotrophic situations, the aquatic Sphagna sequester nutrients and build the vegetation surface to above the groundwater table and ombrogeny. At this stage, hummocks of *S. palustre* usually develop and these may initiate a heterogeneous surface open to appropriate colonisation by ombrogenous taxa.

If the restored (or extant) vegetation moves towards dominance by *S.* sect. *Acutifolia* some indication of a low or falling water table is apparent. This is a likely scenario at Wedholme Flow, for example, where continued peat extraction is expected to further increase water loss from some of the peripheral areas currently managed for nature conservation. The subsequent appearance of *S.* sect *Sphagnum* (currently *S. papillosum*) on top of the hummocks formed by *S.* sect. *Acutifolia* will indicate a *Sphagnum* based community on the verge of becoming too dry to maintain itself and consequently, a subsequent shift to dominance by hypnaceous taxa in the moss layer, Ericaceae and Cyperaceae. In this study, the lowest predicted water table depth at which *Sphagnum* based vegetation persists is -15 cm. This figure is a little high compared to the work of van der Molen and colleagues (1993) who record summer depths of up to -30 cm to -40 cm, presumably from hummocks. Accordingly, the predicted depth of -15 cm may be seen as an average depth to the water table and a safer, minimum target.

5.6 PYROGENIC IMPACTS

The effects of fire upon lowland raised bog vegetation are not well studied because from a long term perspective the perturbation it imposes is generally considered inferior to that induced by drainage, (Kuhry, 1994). By comparison, Pearsall (1950) considered the reverse to be true for blanket bogs in upland Britain where the effects of fire have been studied intensively due to the importance of its use as a management tool in maintaining young, *C. vulgaris* growth for grazing animals (Hobbs & Gimingham, 1984a). These studies offer some insight into fire driven impacts on the closely related vegetation of lowland raised bogs although such investigations are largely restricted to the palatable phanerogams.

Insight to the effects of fire upon raised bogs can also be gained from the extensive literature pertaining to the implications of drainage. Fires entail the same oxidative processes as drainage induced drying of the peat although these complex interactions are very much accelerated in the former and in the absence of drainage, slumping of the peat massif does not necessarily accompany this pyrogenic wastage (slumping & wastage; *sensu* Heathwaite *et al.*, 1993).

In his investigation into the effect of fire upon *Sphagnum* dominated peatlands in western, boreal Canada, Kuhry (1994) considered a cyclic pattern in the occurrence of charcoal layers. Within the stratigraphic profiles presented here such a cyclic pattern is not apparent and no evidence of fires was found in the stratigraphy of Mullenakill Bog, which spans some 3 000 years, or in that of Wedholme Flow which was undated but presumably spans a similar duration. In the stratigraphy of the remaining sites, layers of charcoal are most commonly sporadic in occurrence but they may recur repeatedly throughout a section of stratigraphy, such as during the phase of Heterogeneous *Sphagnum* Lawn at Coalburn Moss (Figure 4.1.4; 58 cm to 134 cm) or the Callunetum at Wreaks Moss (Figure 4.4.9; 246 cm to 300 cm). Unfortunately, in the absence of palynological data, it is not possible to determine whether these fires were natural or anthropogenic (Middleton *et al.*, 1995).

However, the recurrence of fires throughout these phases noted above, strongly suggests an anthropogenic origin in these instances at least.

The most apparently severe fire event in this study is that centred on 264 cm depth in Cranley Moss which, at least locally, caused a major shift in the vegetation away from dominance by *S. capillifolium* to its replacement by the more hydrophilous *S. auriculatum* and less significantly, *S. tenellum*. In his study of vegetation recovery following a fire at Glasson Moss in 1979, Lindsay (in a JNCC report largely reiterated in Lindsay and Ross, 1994) found that *S. tenellum* became dominant whereas at Cranley Moss, *S. auriculatum* was the prevalent species. This suggests that the deeply lying groundwater mound of the interrupted, *S.* sect *Acutifolia* Lawn and Hummock community was possibly replaced by an overlying, ponding of meteoric water that was not consistent over the growing season. However, as has been considered above, *S. auriculatum* may also respond to the presence of low levels of nutrients that may have been released here as a consequence of the fire.

The *S.* sect *Acutifolia* Lawn and Hummock community at Cranley Moss shows resilience by re-establishing itself after the fire event. No radiocarbon dates are available but assuming a growth rate of *c.* 0.65 cm.decade-1 for both the *S. capillifolium* and *S. auriculatum* communities (section 4.5.2) it is indicated that the latter community persisted for about 50 years. In the existence of a mire this is a short time span but from a human perspective, great concern would have been expressed at the slow speed of recovery apparently seen here. The rapid rate of change seen here after an apparently stable phase is a frequent feature of raised bog vegetation in stratigraphic sections which accords to the threshold concept of von Post (Conway, 1948).

At Glasson Moss, Lindsay (Lindsay and Ross, 1994) observed that it took over a decade for significant recovery of *S. capillifolium* to occur but this regeneration was retarded by leachate from the boardwalk ironically used to reduce disturbance to his transects. The presence of severe charring to the apical capitula resulted in the regeneration of *S. capillifolium* at Glasson Moss from axillary shoots (Lindsay and Ross, 1994) which accords with the findings of Poschold (1995) who observed vegetative regeneration in this species from brown stems up to 15 cm below the surface. At Cranley Moss, it is not possible to directly determine how regeneration took place but given the inferred time lag it is not implausible that the blanketing growth of *S. auriculatum* probably suppressed any vegetative regeneration from *in situ* material. Campeau and Rochefort (1996) point out that *Sphagnum* regeneration from below 10 cm depth is not a practical consideration despite laboratory based observations of its occurrence at depths of up to 30 cm (Clymo & Duckett, 1986). It is therefore suggested that sexual means of reproduction were necessary for recovery of the *S.* sect *Acutifolia* Lawn and Hummock community in this case, through an influx of spores from elsewhere on Cranley Moss or neighbouring bogs where, by reference to the stratigraphy of Coalburn Moss, *S. capillifolium* was a common species.

Kyall (1966) considers microrelief, wind speed and direction, type and distribution of litter and moisture content to be the variables controlling fire behaviour as it passes through a heathland. Most frequently fires appear to pass rapidly over the wet surface of a raised bog with only minor effects upon the vegetation seen in the stratigraphy. This is probably attributable to the moisture content of *Sphagnum* based vegetation which may exceed the flammable limit of 300% of Hobbs and Gimingham (1984a) by up to a factor of 10 (*cf.* Daniels 1989).

The swift passage of most raised bog fires is undoubtedly also a consequence of the upward growth of a healthy *Sphagnum* lawn which will absorb and dilute the accumulation of highly flammable, cyperaceous and ericaceous litter. Once incorporated into the *Sphagnum* lawn, litter will then be protected from ignition. Whittaker (1961), for example, found that the peat surface temperature could be as much as 440°C when at 1 cm depth temperature was raised by only 28°C.

The importance of growth forms was also highlighted by Whittaker's (1961) study with the hummocks of *Leucobryum glaucum*, her closest analogue to a *Sphagnum* hummock, a better protector of the peat than the rough mat of *Pleurozium schreberi* which was in turn, superior to the smooth mat of *Hypnum jutlandicum*. This latter species is generally replaced by *H. cupressiforme*, a weedy moss of the same growth form, on disturbed raised bogs. Continued disturbance, which promotes the expansion of *H. cupressiforme* at the expense of *Sphagnum*, will therefore reduce the ability of a raised bog to resist fire in an undesirable, positive feedback loop. Ultimately, under continued burning, the hypnaceous layer is lost and the species poor Callunetum described from Wreaks Moss succeeds. However, *Sphagnum* regeneration is still possible in such circumstances, as described in section 5.7.8, and it may even be promoted by the mineralisation forced, compaction of the peat.

5.7 THE CURRENT AND FUTURE CONDITION OF THE STUDY SITES

In this section, the current status of each site is assessed and predictions, based on the contemporary and palaeoecological data, are made on the future development of the study sites. The current state of the raised bogs studied here is very encouraging, both in terms of the apparently limited extent of damage imposed by drainage (Ballynahone Bog, Coalburn Moss and Cranley Moss) and the regeneration that has arisen through either semi-natural (Arnaby Moss Regeneration Peat) or anthropogenic means (Arnaby Moss, Ballynahone Bog, Deer Dyke Moss, Mullenakill Bog, Wedholme Flow and Wreaks Moss). This indicates that bog vegetation is both stable and resilient (*sensu* Pimm, 1984; 1991), the latter term implying a rapid return to the "normal" state. This is± exemplified here by the catastrophic fire event at Cranley Moss during a phase of *S.* sect *Acutifolia* Lawn and Hummock, or less strictly, the speed of acrotelm recovery attained by *S. cuspidatum*, *S. recurvum* and/or *S. tenellum* following major perturbations that do not result in a permanent lowering of the water table (*cf.* Lindsay & Ross, 1994). Pimm (1984; 1991) also considers persistence and resistance as characteristics of a particular vegetation type. Extending these two measures to this study it is readily apparent that raised bog vegetation shows *persistence*, since a given community may exist for many centuries and this implies some *resistance* to change, against perturbations such as fire and relatively minor changes in the water table, unless the threshold of that community is surpassed and then succession to another predictable type ensues (Conway, 1948).

5.7.1 Arnaby Moss Regeneration Peat

Unfortunately, no palaeoecological analogue was found for succession from the *S. recurvum* Lawn which dominates this area of mire within the stratigraphic sections. However, the work of Hughes (1997) on the fen-bog transition and my own observations at Glen Moss SSSI, Strathclyde (McMullen, unpublished data) suggest that this community will become replaced by the *S. palustre* - *S. recurvum* Mosaic. Development from this point onwards may lead to the establishment of a Heterogeneous or Homogeneous *Sphagnum* Lawn depending upon the surface topography.

The abundance of *P. sylvestris* and *M. caerulea* encroaching onto the margins of this mire expanse suggests that unless these species are kept in check an acid, species poor fen carr community will probably develop. Any hummocks of *S. palustre* or *S. recurvum* developing on the surface of the lawn dominated by the latter species will probably assist this process by providing a suitable nidus for the germination of tree seedlings (Ohlson & Zackrison, 1991). If, as is indicated in the testate amoebae derived water table model (Figure 4.4.2) there is a continued down turn in the depth to the water table which favours tree growth then this situation may be further exacerbated by preventing the development of raised bog vegetation through shading, in the short term at least.

5.7.2 Arnaby Moss

This small remnant, recently cleared of trees, has a pronounced topography with hollows of active *Sphagnum* growth and xeric hummocks vegetated by *C. vulgaris* and *H. cupressiforme*. The current vegetation can thus be described as a mosaic of Heterogeneous *Sphagnum* Lawn and species poor Hypnaceous Callunetum. Continued growth of the former is likely, in the short term, since this community shows persistence. However, the upstanding topography of this remnant may not possess a suitable morphology for the maintenance of an appropriate groundwater mound above a certain height of the vegetation surface. In this event, failure of the groundwater mound to follow the increase in height of the vegetation surface will probably lead to the establishment of a phanerogam and hypnaceous moss dominated community at the expense of *Sphagnum*.

Should the groundwater mound support it, continued upward growth of the *Sphagnum* community in the hollows will raise the water table towards the top of the hummocks and in so doing, regenerate *Sphagnum* growth there, unless restricted in this by the unsuitable height:width ratio. However, the growth rates established for this community indicate that it will take between 16.6 and 83.3' decades for this upward growth to occur, assuming a rise of *c.* 40 cm for the water table to lie within 10 cm from the modal hummock tops. The habitat that the Hypnaceous Callunetum creates for fauna should not be dismissed but it does present a relatively homogenous scene. If not restricted by the surrounding woodland, burning of the flammable hummock vegetation may expedite this process by reducing the topography (*cf.* Barkman, 1992) and by sealing the surface with ash in order to hold water on the flatter areas of species poor Hypnaceous Callunetum.

5.7.3 Ballynahone Bog

Damage done to this bog by the burning and drainage that took place in the latter half of the 1980's appears to have been but a minor blip in the history of this extensive, largely intact, raised bog. Recent but short lived peaks of Unidentified Organic Matter and charcoal undoubtedly correspond to the fire event that Cruickshank and Tomlinson (1989) saw the aftermath of during their survey in 1988. It is therefore unnecessary to attribute the small peak of Unidentified Organic Matter to drainage induced, oxidation of the peat so the five years of water loss that the bog endured may be considered as having only a secondary impact on the vegetation, by comparison to the fire. Drainage, especially on the southern half of the mire, possibly exacerbated the temperature of this fire but bogs have the potential to rapidly slump and maintain a shallow water table depth in the early stages of drainage (Bragg, 1995).

If the water table had fallen markedly it would not have supported expansion of the *S. tenellum - S. magellanicum* Lawn which still persists, as evidenced in the continuing abundance of *S. tenellum*. This further suggests, in addition to the ongoing persistence of bare ground, that vegetation on the site is still returning to an equilibrium state almost a decade after the fire event and it was possibly hampered in this recovery by the drainage.

A change in floristics is currently evident, by comparison with the stratigraphic record. At the time of survey a striking feature of the vegetation were the red-hued leaves of *E. angustifolium* which has increased greatly in frequency since the fire, but it still maintains low cover. This species is known to be a frequent colonist of bare peat (Phillips, 1954) such as at Arnaby Moss Regeneration Peat or currently at Peatlands Park, as is the weedy *H. cupressiforme* which has also increased its frequency both here and on the other raised bogs studied. This is undoubtedly a consequence of the disturbance that these raised bogs have undergone.

5.7.4 Coalburn Moss

Despite the perturbations which have occurred on this site; marginal cutting, drainage, burning and dissection by two railway lines, the vegetation is not seen to have suffered any noticeable, adverse effects. This is revealed most cogently in the absence of a sub-surface peak of Unidentified Organic Matter arising due to oxidation of the surface peat during extended periods of water table draw down. Accordingly, it is suggested that the groundwater mound of this extensive site is surprisingly undisturbed.

The localised burning events at Coalburn Moss, in the vicinity of a walkway, are not considered to be of long term effect. Their vegetation, as discussed in section 4.6.5b, is floristically the same as that present on unburnt areas but the *Sphagnum* cover decreases to a vicarious increase in *H. cupressiforme*, phanerogams and bare ground. The areas of muir grip show a similar response but species replacement is not so in evidence within the vegetation which maintains a community similar to that on unburnt areas but with a greater preponderance of *S. capillifolium*.

5.7.5 Cranley Moss

Recently, damming of the drains at Cranley Moss has been undertaken by Scottish Natural Heritage (L. Buckle, pers. comm.) and this might be expected to push the vegetation towards a greater dominance of the *S. cuspidatum* Wet Lawn and Pool community whilst retaining its character as a Heterogeneous *Sphagnum* Lawn. However, unless the rate of hummock growth is also accelerated, the vegetation surface may tend towards a more subdued topography in the short term at least, and into the longer term if vascular components are drowned out. However, this has been the state of Cranley Moss throughout most of the late Holocene, as is indicated by the almost complete absence of *C. vulgaris* remains since 3 400 BP (Figure 4.1.5), except for the readily dispersed seeds of this plant indicating the sporadic presence of hummocks. Accordingly, we may see this moss return to a state which closely resembles its intrinsic condition.

5.7.6 Deer Dyke Moss

The most striking features of the stratigraphy at Deer Dyke Moss are the relatively complacent plant and testate amoebae communities (Figures 4.1.6 & 4.4.12). The position of Deer Dyke Moss, hemmed in on three sides by bog and upland, has resulted in a hydrological buffering effect that has been overridden by the installation of an efficient drainage network and subsequent afforestation. This resulted in draw down of the otherwise stable water table which, according to the testate amoebae derived water table model (Figure 4.4.12), has now apparently recovered to original levels after tree removal and damming of the drains.

The vegetation response to hydrological restoration at Deer Dyke Moss has been slow, as evidenced by the scarcity of colonist species, most particularly, *S. tenellum* and the continued presence of bare ground (Table 4.6.7). It is considered that this poor response is due to two factors. Primarily, it is very probable that the annual mowing regime is removing the sheltering effect of phanerogam growth (*cf.* Campeau & Rochefort, 1996) and secondarily, the afforestation of Deer Dyke Moss was probably responsible for the shading out of ombrogenous *Sphagnum* species. This environmental factor may have led to the local extinction of shade-intolerant *S. tenellum* since it was not recorded during the time of contemporary vegetation survey. Unless the peat surface is flooded and *S. cuspidatum* expands from the ditches, the recovery of a complete acrotelm on Deer Dyke Moss may be limited because although other species of *Sphagnum* are not incapable of restoring the acrotelm, they do so at a much slower rate than the colonists already noted (Rochefort, Gauthier, & Laquere, 1995; Campeau & Rochefort, 1996). Amongst the stratigraphic profiles presented here, the expansion of *Sphagnum* is seen to occur within *C. vulgaris* and *E. vaginatum* dominated communities following restoration of the water table (sections 5.4.1 and 5.4.2), attesting to the possibly superfluous role of mowing. In both instances of this there is seen to be a small, initial peak of *S. cuspidatum* which implies the localised presence of surficial water. In both occurrences of this regeneration, at Arnaby Moss and Wreaks Moss, *S. tenellum* played only a minor role.

5.7.7 Mullenakill Bog

Reversal of drainage imposed on the expanse of raised bog at Peatlands Park has been successful, as evidenced in the regeneration of a *S. tenellum* - *S. magellanicum* Lawn at Mullenakill Bog and the *S. cuspidatum* Wet Lawn and Pool community arising on neighbouring areas of cut-over peat. In addition, the provincially rare *A. polifolia* (Hackney, 1992) has also been recolonising the former from its refugium on an adjacent railway embankment (Shaw, 1993). This illustrates most cogently the unusual ecology of this plant which also shows a curious distribution between Coalburn and Cranley Mosses.

The current abundance of *C. vulgaris* at Mullenakill Bog, in particular, is a continuing consequence of the hydrological damage imposed. Comparison to the palaeoecological profile shows that this plant was not common on site, particularly over the past 2500 years. Should the water table rise sufficiently to drown out this plant it might be argued that the character of Mullenakill Bog will be more fully restored but the regional drainage of the Lough Neagh area may inhibit such a return to the intrinsic state (*cf.* Peatlands Park Management Plan).

The expansion of *S. cuspidatum* on areas of cut-over peat at Peatlands Park is limited because the coincident, altitudinal and hydrological gradients of the main expanse prevent its complete rewetting (Shaw, 1993). In the absence of a continuous litter layer on the upstanding, dry areas burning cannot be recommended as a technique to lower this upstanding peat and seal its surface. This could hasten the process of paludification from currently regenerating areas. Consequently, the restoration of these upstanding areas must be looked to in the long term as slumping of the peat occurs through noncombustive oxidation and paludification proceeds from the build up of peat in lower lying, inundated areas. The expansion of *S. cuspidatum* will presumably be succeeded by *S. magellanicum* in the formation of a Homogeneous *Sphagnum* Lawn as is current in the now flooded ditches. Following the establishment of further species resident in the many peatland habitats contained within Peatlands Park, a much more topographically and biologically diverse community may be expected to ensue.

5.7.8 Wedholme Flow

Currently the vegetation of the Southern Lobe of Wedholme Flow is in a healthy condition with an extensive, continuous cover of *Sphagnum*. This *Sphagnum* rich vegetation has regenerated since 1991 when the drains imposed during the middle of the last century were dammed (F. Mawby, pers. comm.) and recovery took place via a short phase of *S. tenellum* - *S. magellanicum* Lawn which succeeded to the Heterogenous *Sphagnum* Lawn that is currently extant. That the vegetation is now at or near equilibrium is revealed in the retreat of *S. tenellum* to a low presence according to its r-selected strategy (Lindsay & Ross, 1994; see Table 4.6.12).

Unfortunately, despite this success and currently healthy appearance, the ongoing extraction of peat from within the confines of the Southern Lobe basin means that water losses will ensue (Bragg, 1991). Bragg considers that unless the rate of peat slumping matches the fall of the water table there will be a catastrophic failure of the whole. In the absence of a good predictive model for this change it can only be suggested that the vegetation will tend along the core communities outlined in Figure 5.1.1, towards the Hypnaceous Callunetum via an increase in *S. capillifolium* and the loss of semi-/aquatic species such as *S. cuspidatum* and *S. tenellum*. However, if the water table does suddenly fail, the sublime appearance of a Hypnaceous Callunetum is to be expected. Given the relative isolation of this moss burning of such a community is not expected to occur.

By reference to the species currently present on Wedholme Flow, in comparison to those described from the Hypnaceous Callunetum at Arnaby Moss, the future diversity of the bryophyte layer is likely to be low. *H. cupressiforme* is expected to dominate almost wholly, possibly with some *Polytrichum alpestre* and the colonist, *Campylopus introflexus* abundant on bare patches of peat. The current lack of fecundity exhibited by many of the moss species present in the Hypnaceous Callunetum (Smith, 1978; Longton, 1992) will preclude their appearance at this relatively isolated site bordered by agricultural fields. In terms of the phanerogams, the increased levels of mineralisation may well allow *M. gale* to persist but the dominant vascular species will probably be the usual association of *C. vulgaris* and *E. vaginatum.* Any burning during the establishment of this community will lessen the biodiversity further and result in the development of a species poor Callunetum (section 4.6.12).

5.7.9 Wreaks Moss

The vegetation of Wreaks Moss is returning to the *Sphagnum* rich communities that have dominated its surface over much of the Late Holocene except for the initial phase in the macrofossil diagram (Figure 4.1.9) where sea level regression is considered to have lowered the groundwater table and promoted the development of a heath like vegetation.

Antecedent to the regeneration current at Wreaks Moss is another dry (Degeneration) phase which, for reasons discussed in section 4.3.14), it is not possible to determine the origins of, it either being a phase of requital breakdown or a period when highly humified was peat accumulating. The former scenario seems most plausible since no *Pinus* needles were encountered during this phase and the penetration of tree roots into peat is known to result in the degradation of original peat layers (Ohlson & Zackrison, 1991, Wheeler & Shaw, 1995).

The *Sphagnum* vegetation that is currently present on Wreaks Moss appears to have rapidly reached an equilibrium within the lawn and hollow microforms via a short lived peak of *S. tenellum*. The hummocks are still dominated by *Cladonia* spp., pleurocarpous mosses and *V. myrtillus* and of these, the former two taxa may continue to persist under renewed bog growth. It is expected that the shade tolerant, *V. myrtillus*, will eventually succumb to the greater competitive advantage of *C. vulgaris* under the full light conditions that were reinstated with the removal of scrub (*cf.* Hester, Miles & Gimingham, 1991). *C. vulgaris* is currently frequent across the moss but at low cover values but how the magnitude of this may change is unclear and dependant upon the restored water table.

5.8 THE RESPONSE OF RAISED BOGS TO CLIMATE CHANGE

The effects of global climate change on British weather are uncertain but the generally accepted view is that the vegetation of raised bogs will become more xeric as the water table recedes from the surface (Freeman *et al.*, 1996; Hughes, Reynolds & Hudson, 1996; Chambers, 1997; Hughes *et al.*, 1999; Dowrick *et al.*, 1999). This scenario is analogous to that considered for Wedholme Flow where, under anthropogenic water table draw down, the vegetation is expected to tend towards dominance of the *S.* sect *Acutifolia* communities before passing on to a state where the Sphagnum are lost from the vegetation and a Callunetum develops. The *S.* sect *Acutifolia* communities are amongst the most diverse of those described here, both in terms of topography and flora but the multifarious, microscopic fauna prevalent in the bog pools will become restricted. However, as evidenced by the small sporadic peaks of *S. auriculatum*, *S. cuspidatum* and *S. tenellum* that appear throughout *S.* sect *Acutifolia* phases, *r*-selected semi-/aquatic species are able to persist and expand when conditions are appropriate. The greater frequency of fire that accompanies water table draw down may further enhance this biodiversity by the creation of novel microhabitats (McFerran *et al.*, 1995) but at its recurrent extreme, will result in a highly modified, homogenous environment through the imposition of a single, dominant environmental factor and wastage of the peat.

The past effects of sea level change on the coastal Cumbrian site Arnaby Moss and possibly also its neighbour, the undated Wreaks Moss, have been shown to be of sufficient magnitude to exceed the hydrological threshold of the then dominant communities. The future rises in sea level that are expected to accompany melting of the polar ice caps may therefore be expected to stimulate the expansion of *Sphagnum* communities on the coastal Arnaby Moss Regeneration Peat, Arnaby Moss, Deer Dyke Moss, Wedholme Flow, and Wreaks Moss. This is however, a long term scenario but it offers hope for the future of the potentially moribund Southern Lobe at Wedholme Flow and other of the raised bog remnants along the British coat.

The capacity of *Sphagnum* bogs to act as a sink for carbon dioxide and other nutrients makes them pivotal in the biogeochemical cycles of the wider environment. Such an ability is especially evident in the *S. recurvum* aggregate where very high rates of growth and hence, biomass accumulation are possible. The ecosystem effects of this have already been considered for Arnaby Moss Regeneration Peat, situated upstream of an estuary. In a similar manner, the regeneration of the many moribund peat masses in the north and west of Britain may have a significant contribution to biogeochemical cycling especially if growth of *S. recurvum* can be stimulated. Depending upon the ratio of carbon loss .v. carbon gain, it may be suggested that in the short term, the promotion of this species may be achieved through reconformation of moribund peatland areas to below the groundwater table or, flooding them with nutrient rich, agricultural water. Such restoration work may even be subsidised in part by the peat extracted.

Within a thirty mile stretch of the Dee Valley, extending west from Aberdeen, is to be found a great diversity of secondary, raised bog vegetation ranging from dry, open heath to permanently flooded areas colonised by *Alnus-Betula-Salix* woodland. Despite their anthropogenic origins these sites contain a wide diversity of taxa with inherent protection extending from the frequent difficulty of passage across them. Managed with a little imagination they might retain this diversity and offer some degree of biogeochemical, bioremediation within this intensively agricultural area. A glance to the rainforest gardens of Java shows that it is possible for humanity to manage its environment in a way that enhances its own life as well as ensuring a diversity of habitat and biota.

6. CONCLUSIONS

(i) Some evidence is presented to suggest that *S. imbricatum* has now become replaced by *S. magellanicum* in the lawn and low hummock microforms and that *S. papillosum* now replaces it in hummock top situations.

(ii) It is conformed by palaeoecological means that the *E. tetralix* - *S. papillosum* mire (M18), recognised in the National Vegetation Classification (Rodwell, 1991), is the core plant community of raised bogs. Individual components of this community, recognised in some cases, as distinct communities here, are present or absent according to the prevailing hydrology and topography. Long phases of low topography, *Sphagnum* lawn are apparent in the stratigraphic sections suggesting that the much commented on, hummock-hollow topography of this habitat is not always well developed.

(iii) Communities of *S. cuspidatum, S. recurvum* or *S. tenellum* are capable of colonising bare peat surfaces, each according to the prevailing water table position and quality. The presence of *S. recurvum* and also, *H. cupressiforme*, in the contemporary vegetation of raised bogs is considered to be a consequence of anthropogenic disturbance since they are absent from ancient sections.

(iv) *Sphagnum* regeneration within *C. vulgaris* dominated communities can be rapid and is probably assisted in this case by the presence of a sheltered microenvironment. The flooding out of vascular species by a recovering water table can lead to the loss of vascular species and subsequently, topographic diversity.

(v) Mineralisation of degraded peatland surfaces may promote the expansion of *Sphagnum* by retaining meteoric water on the impervious substrate so formed but this is dependant upon a suitable, climatic regime.

(vi) Vegetation communities may persist almost indefinitely, for over a millennium in some instances, with only minor changes in floristic composition apparent and the sassemblage remaining generally constant. Following a change in the water table that surpasses the threshold tolerance of the prevailing community a rapid change is seen in the vegetation with the appearance of a new assemblage of species.

(vii) The effects of fire on the vegetation of raised bogs are usually short lived and rare events in the absence of anthropogenic influence. Recovery is usually by a phase of *S. tenellum* expansion if the microenvironment is humid enough. If a complete change in community is apparent following a severe fire, the original may be restored abruptly, after a period of persistence by its successor.

(viii) Water table draw down under climate change will lead to a greater preponderance of *C. vulgaris* dominated, heath-like communities on our raised bogs via a greater abundance of *S.* sect *Acutifolia* species before *Sphagnum* is lost from the vegetation to be replaced by Bryopsida. Such communities are more susceptible to fire and in such circumstances, become dominated by *C. vulgaris* and *E. vaginatum* with a loss of floral biodiversity. The sea-level rise accompanying climate change may ameliorate this condition in the coastal raised bog sites because this phenomenon will raise regional water tables.

(ix) All of the sites studied here are showing good signs of recovery following hydrological management and the stratigraphic profiles indicate that in many instances, the recent damage that they have suffered is only a small blip in the history of some of these systems. Sections of wastage and shifts to heath communities are apparent in the stratigraphic sections studied and their previous recovery from these states bodes well for their future.

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